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# Fish Passage Restoration for the Paskamanset River

Aaron B. Sabbs  
*Worcester Polytechnic Institute*

Nathaniel Allan Eames  
*Worcester Polytechnic Institute*

Richard Raymond Breault  
*Worcester Polytechnic Institute*

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## Fish Passage Restoration for the Paskamanset River

A Major Qualifying Project Report:

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

*Richard R. Breault Jr.*

Richard Breault

*Nathaniel Eames*

Nathaniel Eames

*Aaron Sabbs*

Aaron Sabbs

Date: April 25, 2013

Approved:

\_\_\_\_\_  
Leonard D. Albano

\_\_\_\_\_  
Paul P. Mathisen

## **Abstract**

River obstructions are contributors to the decline in the population of river herring in Massachusetts. Creating bypasses will benefit the herring by allowing them to migrate upstream to suitable spawning grounds. Two obstructions, Russells Mills Dam and Smith Mills Dam, were assessed to determine the possibility of fish passage restoration. To determine the feasibility of passage restoration, hydraulic and structural analyses were performed. Designs for new construction were prepared. Lastly, environmental assessments of the sites were completed.

## **Authorship and Acknowledgements**

The project was completed by two civil engineering majors and one environmental studies major, Nathaniel Eames, Aaron Sabbs, and Richard Breault, respectively. It was completed during A, B and C terms of the 2012-2013 academic year. Research and writing involving dams, fish ladders, and environmental constraints were done by Richard Breault. Site conditions, hydraulics, and structural aspects were researched by Nathaniel Eames and Aaron Sabbs. Additional writing was completed collaboratively as a group effort. Further contributions were made by Lauren Mickelson in the area of data collection.

The advisors for the project were Professors Leonard Albano and Paul Mathisen. Professor Albano provided guidance in terms of the structural aspects of the project, while Professor Mathisen focused on the hydraulic and hydrological characteristics.

Additionally, we would like to thank Mr. Bradford Chase of the Massachusetts Division of Marine Fisheries and Michael O'Reilly, the Town of Dartmouth Environmental Affairs Coordinator. Mr. Chase and Mr. O'Reilly both provided valuable information regarding past surveys, site layouts, and herring characteristics.

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## **Graduation Requirements**

This project was authored by three students from Worcester Polytechnic Institute. Two are majoring in civil engineering with focuses in structural engineering, and the third is an environmental and sustainability studies major. During the project each person completed a graduation or capstone design requirement. The project entailed a series of designs for two fish passages.

## **Civil Engineering Capstone Design**

All students became familiar with each aspect of the project, but each became more familiar with certain topics as they were major dependent. Together, the group analyzed the hydraulic aspects involved in the fish passage design. This was comprised of an analysis of the current hydraulic characteristics of each dam and a determination of the actual hydraulic requirements needed for herring to successfully traverse the fish passage. The civil engineering majors produced designs for the fish passages, and ensured that the structure is designed so that it will continue to be effective throughout its lifetime. These accomplishments covered constructability issues.

The constraints on this project are primarily political, economic and environmental. The political constraints stemmed from the laws and regulations that surround the construction and maintenance of fish passages. The size and complexity of the project was limited by the economic capabilities of the Commonwealth of Massachusetts and the Town of Dartmouth, so a focus of the project was to minimize the resources used in construction. The size and construction of the passages was limited to ensure no destruction of any species' habitat.

## **Environmental and Sustainability Studies Core**

The environmental studies major focused on the ecological factors and legal parameters that impact fish passage design using research into ichthyology, dam and passage histories and the governing bodies aimed at maintaining proper fish passage. This research includes an in-depth study of the two species of herring, an assessment of all legal parameters and environmental regulations and an evaluation of the impact of the fish ladders on the local environment. To provide a holistic approach from an interdisciplinary point of view, research involved health, safety, social, and political issues.

The design alternatives were obtained through multifaceted investigations of river herring characteristics and the designs behind fish ladders. The desired goal was mainly to get a cheap and effective design, although alternatives were researched that could provide further ecological development but would likely cost much more. By integrating information from a variety of sources, research was done on how the decision making process behind the issues at Russells Mills Dam have occurred over time. The investigation into fish passage along the Paskamanset River has allowed for a better understanding of the relationship between environmental regulations and the objects being controlled by those regulations and has opened the door to many different areas of concern throughout the United States.

## 1. Introduction

In the Buzzards Bay watershed in Massachusetts there are over a thousand acres of ponds and hundreds of miles of streams (Reback, 2004). Before being settled by colonists, these bodies of water were important for the fish species that spend their life cycle in both fresh and marine waters. The two anadromous species of interest in this particular river system are alewife and blueback herring, collectively known as river herring. These species' populations have declined considerably over the past two centuries. River obstructions, mainly the extensive construction of mill dams during the American industrial revolution, have been a large contributor to the decline in herring population. Creating bypasses for these river obstructions will benefit the two species of herring by allowing them to migrate to suitable spawning grounds.



Figure 1: Russells Mills Dam

The focus of this project is on the Paskamanset River, which flows 10 miles from swampland and Turner's Pond, New Bedford through the Town of Dartmouth to Apponagansett Bay. Two reservoirs are formed along its course. The farthest upstream, Smith Mills Pond is formed by a 4-foot granite dam. The lower reservoir, Russells Mills Pond, is formed by a seven foot concrete dam. Russells Mills Dam also has an ineffective 60-foot fish passage. Below is an outline of the Buzzards Bay watershed, the Paskamanset River is number five (outlined in red). A locus map of the watershed surrounding Russells Mills Dam can be found in Appendix H: Russells Mills Dam and Smith Mills Dam Locus Map (see below). To determine the feasibility of passage restoration, hydraulic and

structural analyses were performed for the two locations. From these analyses, designs for repairs or new construction were prepared. Additionally, an ecological and regulatory assessment of the surrounding areas was completed to assess the degree to which the passage restoration would benefit the river herring.

Organizations that have an interest in the restoration of fish passage for the Paskamanset River include the Town of Dartmouth and the Department of Marine Fisheries. Restoration of river herring fish passage is an important environmental goal of these interested parties and for many people who live in the region.

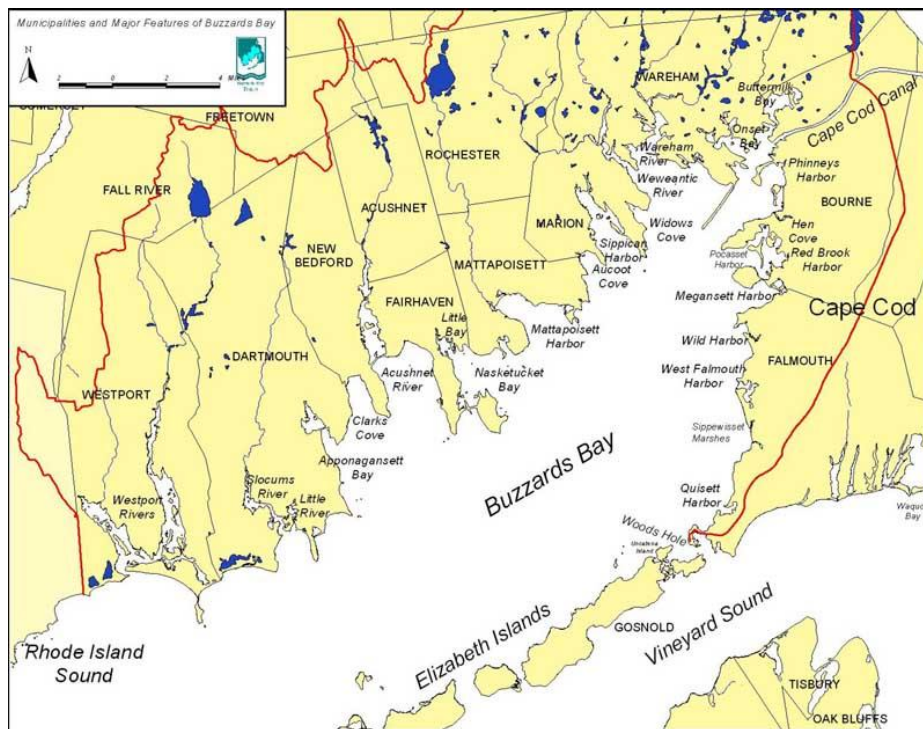


Figure 2: Buzzards Bay Watershed

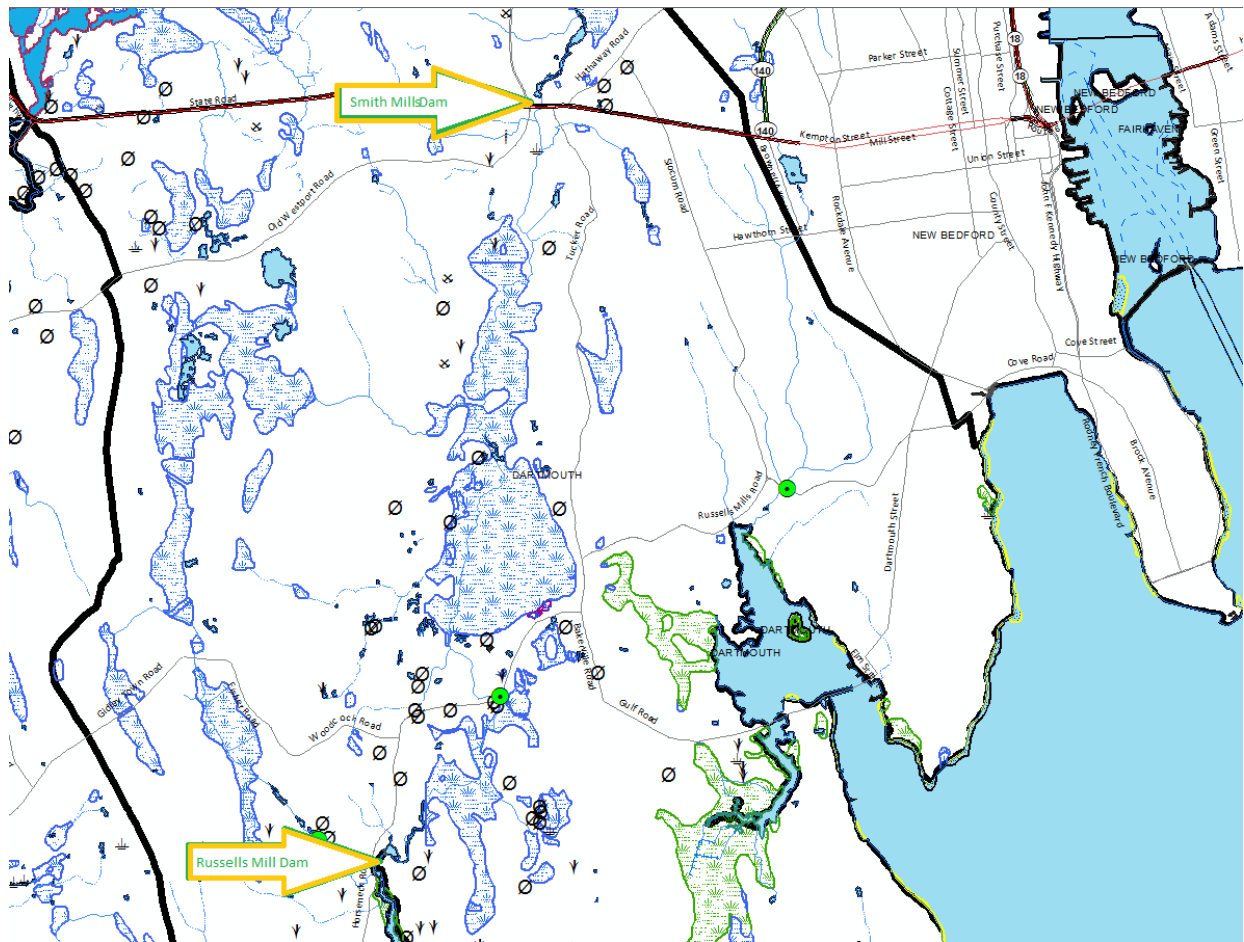


Figure 3: Locus Map of Russells and Smith Mills Dams

## 2 Background

In order to fully understand the scope of the project, background information regarding the building of dams and fish ladders, certain fish species, current site conditions (structural and ecological) and possible design alternatives were researched.

### 2.1 Data Collection

A series of tools will be used to take measurements while on site visits. It is important to understand what these tools are, and how they work. In order to properly measure the velocity of the water at each weir and at the entrance and exit of each ladder a velocity probe was used. This probe measures the speed of the water by gauging how much water flows over a rotating sensor. The United States Geographical Survey (USGS) collects flow and quality data, which will be used. Surveying equipment was used to measure elevations and distances of the ladders and the surrounding areas.

### 2.2 Site History

A decline in river herring came with progress, pollution and urban development which caused the buildup of pathogens and high nitrogen levels (USGS, 1974). All of these human-made changes altered ecologies for a variety of wildlife including red-winged blackbirds, osprey, warblers, snowy white egrets, great blue heron, snapping turtles, river herring, bass, bluefish and even deer. (Silva, 2013)

The area surrounding Dartmouth was earliest settled by Europeans in the early 1600s. At this point in history waterways were the foundations of civilization. Nearly all jobs at this time required the use of water and therefore the availability of streams and waterways was the first thing early North American pioneers settled around. Along with the developments of mills and dams, the Paskamanset River has historically supported large herring runs. Upstream of Smith

Mills Dam, the river flows under the town's former dump, under Route 195, over Smith Mills Dam, downstream over Russells Mills Dams and finally into Buzzards Bay. 115,000 acres of land was purchased in 1652 around the time Ralph Russell settled in Dartmouth. Mr. Russell needed water to run his iron mill to cool metal forgings and thus began the emergence of mills along the Paskamanset. (Silva, 2013)

By 1686, Russell had sold the land and George Babcock had obtained property rights to the mill and the water, as to be used for manufacturing (including a wastewater stream that was used until the mid-twentieth century). In 1706, Elisha Smith purchased all of Babcock's property and rights, and Smith Mills Village was born. Smith's ownership lasted until 1792, when Benjamin Cummings acquired his property. Cummings established ten mills around the Dartmouth area throughout the 1800's and owned a grocery store, meat market and the property until his death in 1863. The property remained unowned until 1938, when the Szymanski family bought the property. They established an auto parts store, Chevrolet dealership and a local garage at Smith Mills Dam which have lasted generations. (LSU, 2007)

The 1960's was a time where herring used upstream spawning grounds at full length but a sharp decline in herring occurred during the mid-1970's causing locals to think herring were eradicated from the area. The rapid decline in herring population has been correlated with rapid urbanization, the further construction of dams and the inefficiency of fish passages. Throughout the rest of the 70's and into the 80's Russells Mills Pond was stocked with adult herring. Further attempts to assist herring passage were made by adding vertical baffles into the river system below. After decades of waste had been leaching into the river system the town dump was closed and capped in 1995 to prevent further runoff. Adult herring naturally returned to the river around 1997 but have failed to make a successful run upstream. In 1999, the Szymanski family, the



Commonwealth of Massachusetts Self-Help Program, the Department of Marine Fisheries and the Town of Dartmouth financially funded projects that added a lower passage to Russells Mills Dam (completed in 2001) and that turned the area surrounding Smith Mills into a scenic park/historic landmark. (NOAA, 2009)

### 2.3 Purposes of Dams

Installation of dams into the environment has been done for centuries in order to utilize the natural landscape to a human advantage. Throughout history dams have been used for irrigation, hydropower, water supply, flood control, recreational use, navigational purposes and fish farms. The breakdown of dam usage in the United States is shown in Table 1. Dams negatively impact aquatic ecosystems by causing breaks in the flow of a river, separating ecosystems and impeding migrating species. (ICOLD, 2011)

**Table 1: Dam Use in the United States**

| <b>Dam Use</b>                                    | <b>Percent of Total Dams</b> |
|---|------------------------------|
| Irrigation (Diversion)                            | 48%                          |
| Hydropower (Diversion)                            | 17%                          |
| Water Supply (Storage and Detention)              | 13%                          |
| Flood Control (Diversion, Detention and Overflow) | 10%                          |
| Recreation (Storage)                              | 5%                           |
| Navigation + Fish Farm (Storage and Diversion)    | ~1%                          |

(ICOLD, 2011)

Dams are considered obstructions to the natural ecosystem. River fragmentation by these man-made structures can eventually lead to the decline of inhabiting species if not resolved in an appropriate manner. Species that require passage are travelling upstream for a natural, biological reason, and any change in that cycle can affect the entire ecosystem surrounding the watershed

## 2.4 Types of Dams

Due to the widespread uses of dams there are many different ways to construct a dam. Each dam can be classified by use: storage, diversion, detention or overflow. Storage dams are used to temporarily hold excess water. This could be to hold drinking water, stock fish populations, supply hydroelectric power, etc. Diversion dams are generally used to provide irrigation or a path into a reservoir. Detention dams are used solely to hold back flood waters or a reservoir. Overflow dams are designed with a spillway system as well as with enough structural integrity to withstand water flowing over the dam when overflow cannot be contained by a spillway alone. These dams are designed to be much more durable than the average dam as the forces on them are larger and more continuous than a dam not containing a spillover mechanism. Moreover, a dam with water flow over the top must be designed to maintain these conditions whereas other kinds of dams do not need to fit this kind of requirement. (NWC, 2010)

Structurally, dams are made to fulfill the requirements of each site. Several design options are available: earthfill dams, rockfill dams, gravity dams, concrete arch dams and buttress dams. Earthfill dams usually are constructed with a spillway to accommodate overflow. These dams must be made of a water-impermeable material and can contain a sub-surface water cut-off wall. In order to build a dam of this nature there must be a dry area for work which would require diverting the river while construction took place. Rockfill dams use rocks to create a wall

with some sort of water-impermeable over-structure (concrete, steel, clay, etc). Gravity dams use the gravitational force acting on the water to hold it in place. The mass of the dam is used to resist the lateral forces due to the water. These dams are made of concrete in order to hold back massive quantities of water as they must provide the most impassible dam design. If a gravity dam is constructed incorrectly, overflow and tipping of the dam can occur. Concrete arch dams are only used in narrow canyons where other types of dams cannot be constructed. The canyon is used to divert pressure on the dam and can provide invaluable support. These types of dams are less expensive and more reliable than a gravity dam. Buttress dams are concrete dams reinforced with steel buttresses on the downstream side of the dam. These require less concrete as the dam can be less supportive and rely on the support of the buttresses and surrounding land masses. Overall each type of dam is used to meet specific requirements of the land and use of water.



Figure 4: Russells Mills Dam

(Hassam, 2011)

## 2.5 Fish Ladders

Allowing proper migration of species or allowing fish to fill a pond/reservoir as food stock is a major problem with dam construction. The end design of the ladder must fit these

needs as fish are biologically coded to travel upstream but not necessarily intelligent enough to use a ladder if it is not properly applied to the landscape. Ladders must also fit the requirements of the natural habitat as nature provides constraints as well. With the varying conditions of the water system and passing species, various types of fish ladders have been developed, such as weir-pool passages, Denil passages, vertical slot passages, steep pass passages, and natural passages. (Save the Bay, 2002)

### **2.5.1 History of Fish Ladders**

A 4000-year old fish ladder structure of sorts, thought to be the world's oldest, happens to be located in Egypt where some of the first aqueducts and dams were built. As is done today, dams were built for irrigation and drinking water. The reason for their existence is unknown because no written history can be found that specifically describes fish passage in the region. The first historically documented fish ladder is found in France and was built in the 17<sup>th</sup> century, but current materials were not available so ladders were constructed out of wood. (Griffin, 2009)

### **2.5.2 Importance of Fish Ladders**

Ecological conditions change on both sides of a dam. In order to successfully bridge the gap made by a dam fish ladders are constructed to allow the fish proper seasonal migration upstream. This kind of problem has been seen throughout human history as fish have always been a major source of food. In the 1700's, fish ladders first began to arise in the United States, because a group of Native Americans filed lawsuits against possible dam construction companies as they knew it would disrupt the flow of fish throughout the watershed. Fish ladders have been important throughout history and continue to be integral in the conservation of fish species throughout the United States.

Fish ladders were used before the full nature of their environmental impacts were understood. As specific biological processes per species have been further researched and better understood, it has become easier to successfully produce fish passages. Fish ladders are designed to allow safe passage of fish when their original path has been obstructed by a dam or roadway. Each ladder needs to meet specific requirements to suit the species traveling the waterway. In order to meet the needs of different species individual characteristics of the river can be changed using different kinds of passages and dams. Passages are used to control some of these characteristics (flow rate, temperature, and stream size) in order to suit the needs of the passing species (population size, mating habits, and preferred habitat).

Problems can arise when trying to pass multiple species in one location as each species has specific requirements. Rapids are considered good in some situations because they provide a natural feeling to the passageway. Moreover, when trying to allow passage for many different species, this type of flow is good because it provides a wider range of water conditions (Griffin, 2009).

The Denil passageway, as described below, has baffles that make a rapid-like effect to the flowing river. The weir-pool passageway has a similar kind of construction where the walls that intrude into the passageway cause the same rapid effect. This creates a variety of water velocities through each individual weir, which provides higher availability of sufficient water speeds for varying species and a more natural feel (increased attractiveness) for passing species. This rapid type of water flow also has some disadvantages. Species such as the American Eel cannot travel up these kinds of ladders because the water flow is far too rapid for them to cling onto the passage walls. In that case the rapids would either have to be altered or removed to allow proper

passage in the same passageway. An efficient rapid design is one that incorporates a variety of water speeds as well as seeming to flow in a natural way that attracts fish to the passage.

### 2.5.3 Weir-Pool Passages

Weir-Pool passageways are constructed with individual pools separated by walls or weirs in order to provide a slow and steady movement up the ladder. These passages can be made of wood, concrete or aluminum depending on the species travelling and the necessary conditions of the passage. Each material has physical properties that can make the ladder better



Figure 5: Russells Mills Weir Passage

depending on the passing species and physical area the ladder must be built in. These various materials all affect the passage by changing the physical makeup. This comes down to ladder attractiveness per species. For example, an aluminum ladder may be less attractive due to its metallic qualities or the way the water flows through it.

### 2.5.4 Denil Passages

Denil passageways are designed with a downward slope into the downstream river. This structure can be concrete or aluminum. Denil passageways are very dynamic fish ladders, that can be used by many species of fish. Baffles on the ladder regulate the speed of the water, allowing for



Figure 6: Russells Mills Denil Passage

a wide range of upstream conditions. The baffles create turbulent water flow, simulating rapids in the fish ladder. Rest pools can be installed for longer sections. These passages can be used on nearly any size dam.

### **2.5.5 Vertical Slot Passages**

Vertical slot passages are usually used at large barriers. The name comes from the narrow slots that are used to regulate water speed and depth. This passageway results in a constant flow at all depths of water which makes it difficult to cause changes in upstream water surface elevation. Vertical-slot ladders are more complicated than weir-pool ladders but they allow for a wider range of species to pass, assuming the current is not too fast.

### **2.5.6 Steeppass Passages**

Steeppass passageways (also known as the Alaskan Steeppass) use baffles to create rapids in the same way Denil passageways do. This gives fish many options of water speeds, allowing a number of different species to pass through. They are often pre-fabricated out of metal (typically aluminum), and are usually made narrower than Denil passageways. Steeppass passageways are inexpensive fish ladders that are easy to install and maintain. They work best at small barriers. Maintenance personnel are able to adjust the range of upstream surface elevations by changing baffle size.

### **2.5.7 Nature-Mimicking**

Nature-mimicking passages simulate a natural stream. If designed and constructed properly they are able to accommodate all species of fish. A stream channel is made to bypass a barrier, using natural materials. This method of bypass can provide a stream habitat within the fishway and with proper design can even allow canoeing or boating through the passage. Nature-

mimicking passages can be used on any size river, although it takes up more room than any other type of fishway. Nature-mimicking fish passages are generally designed in a more conservative manner than other types of passages. This is due to the uncertainty of the dimensions and roughness of materials used, and the accumulation of sediment within the fishway pools.

## 2.6 Hydraulics

Each of the features of the Russells Mills Dam and the fish ladders has different hydraulic characteristics. Weir-pool passages, Denil passages, and dams each have varying impacts on the flow of water over (or through) them. In the case of weir-pools and Denil passages, their main purpose is to slow the velocity of water for the anadromous fish.

Slots through which water flows, such as the one located on the left side of Russells Mills Dam, are treated as contracted horizontal weirs. The flow over these areas is modeled

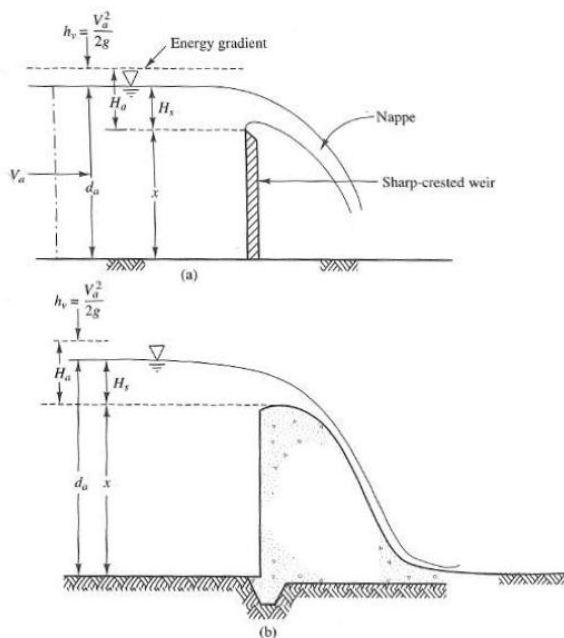


Figure 7: Weir Types

(Hwang, 1996)

using the general discharge equation. This equation is also used to model the flow of water over dams themselves, provided that they are contracted.

$$Q = C_d \left( L - \frac{nH}{10} \right) H^{2/3} \quad (1)$$

$$C_d = 3.22 + .40 \frac{H}{p} \quad (2)$$

The flow of water exiting Denil passages is calculated as a function of the flow entering the passage. The baffles work to significantly slow the velocity of the water as it

moves through channel. The resulting flow,  $Q^*$ , is calculated using the following equation.



$$Q^* = \frac{Q}{\sqrt{gS_0 b_0^5}} \quad (3)$$

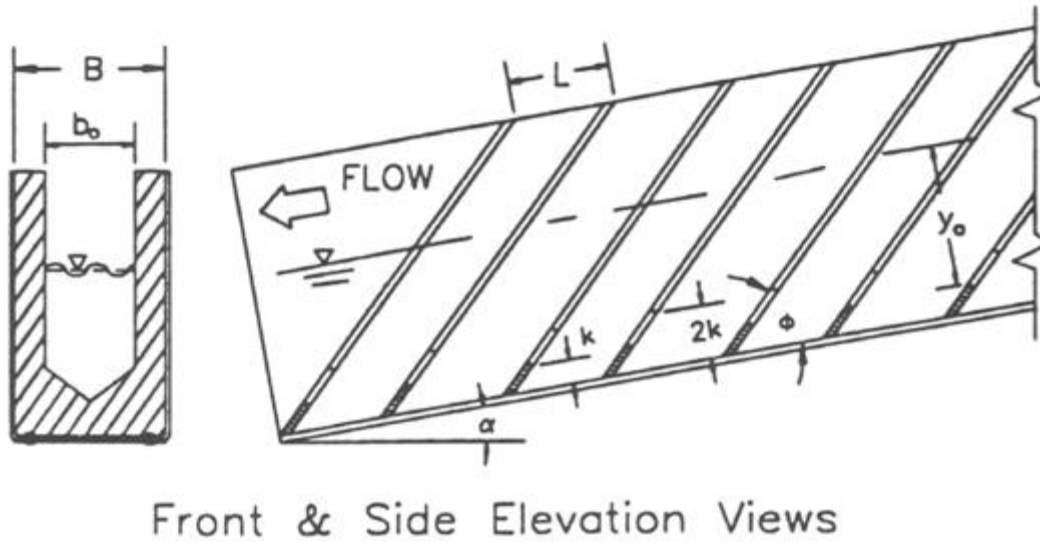


Figure 8: Denil Passage Baffle

(Kamula, 2001)

The flows at the inlet and exit of each passage are used to determine the velocities at each location using the following equation. These velocities are important in that they are the main factor in attracting the fish to the ladder and promoting fish passage.

$$v = \frac{Q}{A} = \frac{Q}{(h^* \times b_a)} \quad (4)$$

In this equation,  $h^*$  represents the height of the water in relation to the bottom of the Denil slot. This value is constrained by the height of the slot. If the water level rises to the point where  $h^*$  reaches the top of the Denil slot, water will spill over the baffles themselves.

## 2.7 Fish Constraints

Each fish ladder must be constructed to fit the requirements of the target passing species. That determination is made by those in charge of designing and building the ladder as there are guidelines for successful passage depending on the exact motive of the ladder. Some ladders are

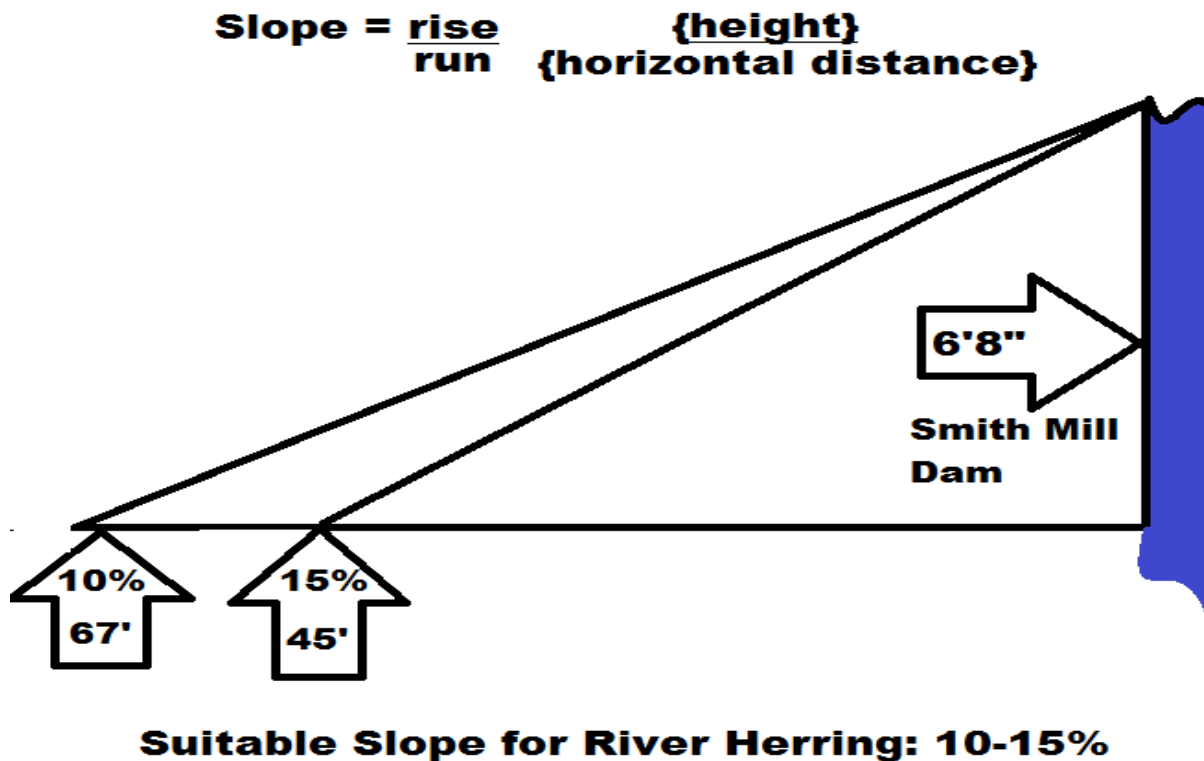
designed for a specific passing species or time of year opposed to being open year round or for any travelling species. The velocity of water coming down the passage is very important as fish are only physiologically capable of overcoming fast water velocities for a short time.

Swimming speeds are classified into three major types: burst (darting), prolonged (cruising) and sustained speeds. The burst speed is one where the fish can only travel for up to 30 seconds before it fatigues. Prolonged speed is one where the fish can travel from 30 seconds to 200 minutes with little fatigue throughout the journey. Sustained speed is a general maintainable velocity that results in virtually no fatigue to the fish. These speeds are important when assessing design options such as possible resting pools, ladder steepness, and passage and culvert lengths (Richardson, 2004) [see tables in Appendix E: Species Travelling Guides]. Significant changes in water velocity can cause a fish to stop moving, hesitate or refuse to continue along its current path. It is essential to design smooth transitions throughout the system to guide fish to the passage entrance.

New structures must provide successful fish passage and maintain river continuity. Any water flow that contains a species of concern must be connected to the watershed. In the best conditions the area designed for these fish does not affect the surrounding environment and can fully encompass their natural habitat. In order to meet specifics of the area in question, culverts can be designed to change the physical water flow to make the flow feel more natural to the travelling species. Culvert design specifications can be seen in Appendix D: Summary of the Massachusetts River and Stream Crossing Standards. When replacing a structure, the design must improve the quality of the passage for travelling species and continue to provide proper crossing for the species up the watershed. During replacement, all structures must meet general or optimal standards at this point (see Appendix D: Summary of the Massachusetts River and

Stream Crossing Standards) barring any constraints at the site. All structures, new and old, must minimize overall changes in the water system as far as flow and environmental quality are concerned. Construction standards are used to maintain storm-water, erosions, sediment, pollution, and soil and vegetation control around an affected area. (MDH, 2006)

Average velocities are not suitable for entrance design. The entrance velocity should be above the cruising speed but well below the darting speed. There is no evidence that fish will move away from a temperature differential unless it goes more than 5 degrees outside their optimum range. The amount of dissolved oxygen (DO) in the water only affects fish



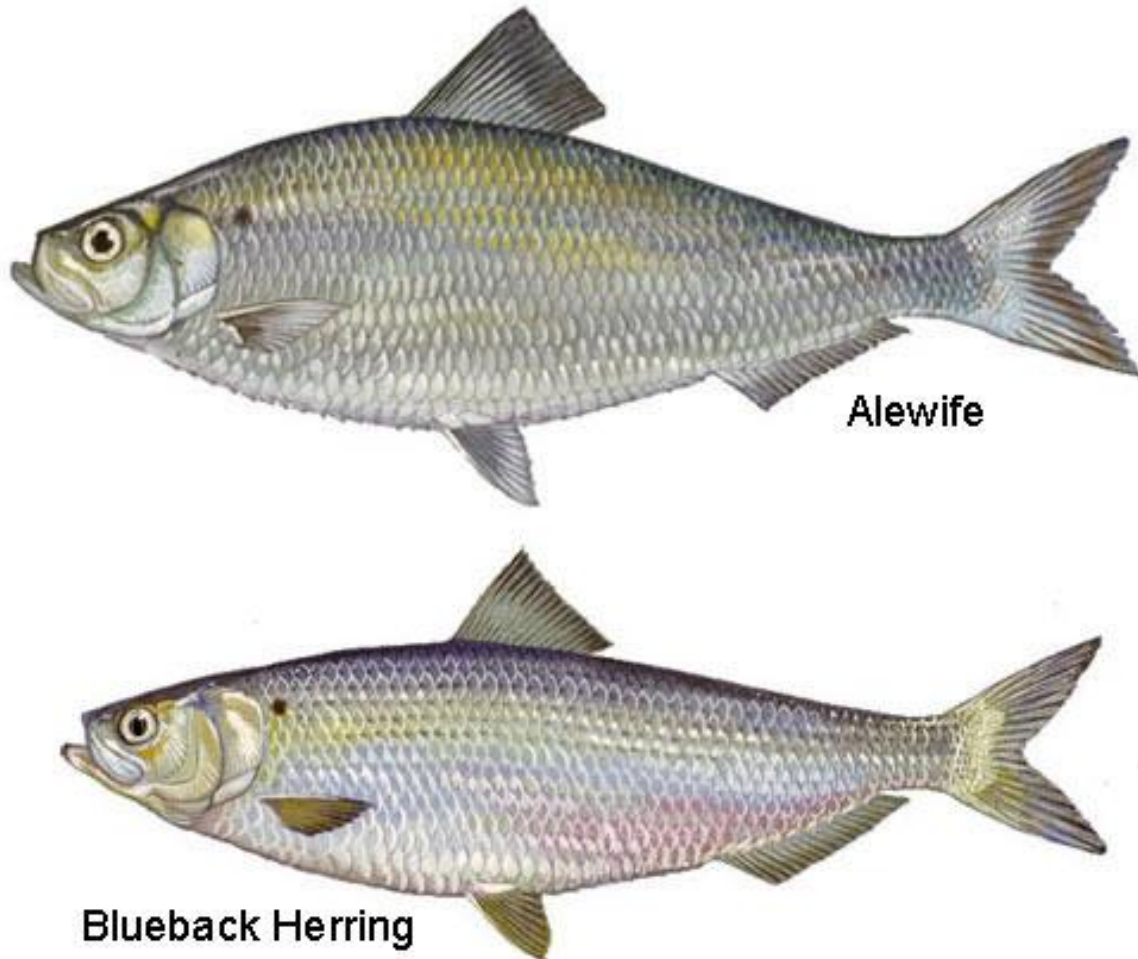
**Figure 9: Suitable Passage Slope for River Herring**

performance. DO is not seen to affect passage attraction (a 1/3 decrease in oxygen saturation level can cause a 60 percent decrease in performance in travelling fish). (Reback, 2004)

The ladder design for Dartmouth, MA must fit the requirements of river herring. These species are not strong jumpers but do have a relatively strong swimming speed. For successful

alewife migration upstream the flow must be approximately 8 ft/s. Herring are able to sense subtle velocity changes which allows herring to seek out the most complimentary area of travel for their swimming needs with relatively finer accuracy than other fish.

In order to provide proper passage the slope of the fish ladder must be in the form of



**Figure 10: River Herring**

(Capossela)

approximately 10-15% slope (see 6). If there is not sufficient room to rest in a passage a resting pool is necessary every 20 to 40 feet horizontally or 6 to 9 feet vertically in order to provide sufficient time for fish to reenergize.

The inlet and exit velocities are also important. Attraction velocities at the inlet should be approximately 8 feet per second. Cross velocities should be no more than 2 feet per second, and

the approach flow should be parallel to the axis of the fishway entrance, or at least no greater than 30 percent to the axis of the main current. The length of the exit channel should be a minimum of two standard ladder pools. (U.S. Army Corps of Engineers, 2007)

### 2.7.1 River Herring

Generally river herring refer to a combination of two species of herring: alewife and blueback herring. River herring are classified together because of their many similarities and migratory habits. The most distinguishable features are of the physical characteristics between the fish. Both fish are silver in color with variations along their bellies and spines, but the backside (dorsal region) of each species differs in that the alewife has bronze coloration while the blueback, staying true to its name, has bluish-green hue. The underbelly of the Alewife is pale with dark brown dots spotting its scales. Blueback herring, on the other hand, have a dark brown or black underbelly. Alewives have a slightly smaller average body size and therefore a more compact swimming technique. As time goes on and adult fish go through the spawning process a mark is recorded on their scales to record the amount of spawns the fish has had throughout its lifetime. (Capossela)

Blueback herring (*Alosa aestivalis*) are an anadromous (hatch in fresh water, migrate to salt water, spawn in fresh water) species that migrate up to 1,200 miles each year to come into the Eastern fresh water system. Alewife on the other hand (*Alosa pseudoharengus*) can be both anadromous and landlocked as they are better capable to survive in fresh water systems. These fish have a spawning season that lasts from February to May, and stretches from Newfoundland to Florida. Each spawn can contain 60-103 thousand eggs per fish. Juveniles usually stay in the fresh water until late spring/early summer to feed. As fall approaches river herring head to the salt water until the following spring when they start over the spawning process and migrate

inland. The decline of these species, caused by loss of proper habitat from dams, degradation, fishing, and predation, has forced the government to place them on the list of species of concern, which is one step away from being environmentally threatened. (The Alewife, 2011)

The spawning period is determined by water temperature changes and photoreceptive elements of the fish itself. These biological aspects allow for fish to know when to begin migration and continue upstream. Overall, fish ladders are seen as detrimental to proper behavioral habits, hence why nature-mimicking passages are being argued as the best solutions to date, although they are not feasible in every situation.

Proper habitat requirements are specific for the larval, juvenile and adult stages of the fishes' lives. The main sources of food for the adult river herring include phytoplankton, fish eggs, and small insects. The juvenile and larval stages (0-4 years old [US Fish and Wildlife Services, 2002]) require small crustaceans called cladocerns and copepods (phytoplankton). River herring are found in every water type on the east coast (lakes, ponds, streams, rivers). These areas can contain varying ecological characteristics (sand, assorted vegetation, swamps, intertidal zones, etc) all of which are suitable for river herring. All in all, habitat suitability standards measure the most important values of the water quality such as temperature, sediment, contaminants, and salinity. Studies imply that an average salinity of less than 12 parts per trillion (ppt) and that more than 100 phytoplankton per liter of water is suitable for proper development during spawning season. (Pardue, 1983)

Water quality is a major part of any fish habitat. The average adult living conditions range from 2 to 17 degrees Celsius (35.6 to 62.6 degrees Fahrenheit) at a depth of less than 100 meters (328 feet). The spawning temperature ranges from 10.5 to 26 degrees Celsius (50.9 to

78.8 degrees Fahrenheit) but is optimally between 12 and 16 degrees Celsius; spawning ceases altogether at any temperature greater than 27 degrees Celsius. (Pardue, 1983)

The suitability of the egg itself differs for the alewife and blueback herring. Alewife eggs hatch after 2 to 15 days (80-95 hour average) at an average of 28.9 to 7.2 degrees Celsius respectively. Blueback eggs spend 1.5 to 3.9 days (38-60 hour average) incubating at an average of 23.7 to 20 degrees Celsius respectively. Although there is a specific temperature range eggs can survive at because of their structure, they are extremely tolerant to changing conditions such as salinity, flow and sediment buildup. (Survey, 2004)

The desirable channel width is determined based on average fish size and the average flow of water through the passage during the target season. The water level of the passage must be sufficient to attract the fish to the passage and provide a water velocity around the approximate average traveling speed. It is important to note that a powerful stream must be created in order to attract species to the area. The flow down the passage must seem like a natural environment to fully attract the fish. The depth of a pool can change as the fish travel up a ladder. Channel width should range from 1.5 to 5 feet (DVWK, 2002). A proper pool should have an inflow wall depth of 3 to 5 feet while the outflow depth should be 2.5 to 4.5 feet depending on the velocity requirements of the fish. (DVWK. 2002)

Characteristics of both the travelling species and water conditions are extremely important to the successfulness of the structure per each individual organism. These characteristics include water temperature, water turbulence, water flow rates, energy dissipation, distance of passage, size of pools (if applicable), size of passage, animal endurance, passage attraction, ease-of-access, individual body length, average travelling speed, and most importantly maximum burst speed. In order for species to utilize their maximum burst speeds appropriate

resting areas must be present if fatigue can occur. Due to all of these conditions at any given pool or part of the ladder, there will be a percentage of fish that will not pass. (Richardson, 2004)

The average fork length of a river herring is approximately 15 inches (38 cm). In order to design a successful passage, various water speeds should be available for passing species. Tables D-1, D-2 and D-3 in Appendix E: Species Travelling Guides offer suggestions on varying speeds of travelling river species to show the range of speeds that could be necessary in a passage. There happened to be fish used in the experiments that measured around 15 cm and therefore were



Figure 11: American Eel

(USFWS, 2009)

assumed to be in the juvenile-adult age range. The swimming speeds of these fish increase over time. The average burst speed was 1.14 ft/s for juvenile blueback herring and 2.09 ft/s for juvenile alewife (Richardson, 2004). These numbers rapidly jump when these juveniles enter early adulthood to 8.20 ft/s for blueback herring and 9.02 ft/s for

alewife. Maximum burst speed (coinciding with full, proper development) can reach up to 15.88 ft/s for blueback herring and 14.90 ft/s for alewife.

### 2.7.3 American Eel

The American Eel is known as catadromous (hatch in salt water, migrate to fresh water, spawn in salt water). An alternative eel ladder or natural rock design for eel passage can be of low cost and easy to install because eels can travel a significant distance with minimal water.



The swimming capability of the American Eel (both adult and glass eels) is certainly lower than that of other travelling species. The eel can grow to a much longer length than river herring but until maturation (which happens after the upstream translocation) eels have much weaker swimming abilities. The maximum burst speed of the American glass eels is a mere 1.31 ft/s. It has been observed that the glass eels can use existing rough-surfaced natural structures (such as logs or rock based pathways) to travel on when water velocity is too high to overcome. Therefore even at water velocities over their maximum burst speed for completely vertical line-of-motion, glass eels can utilize a particular passage. As well as adapting to conditions, eels are known to travel up the side of rock walls along the side of dams as long as they are kept wet enough and lead into the proper progressive habitat.

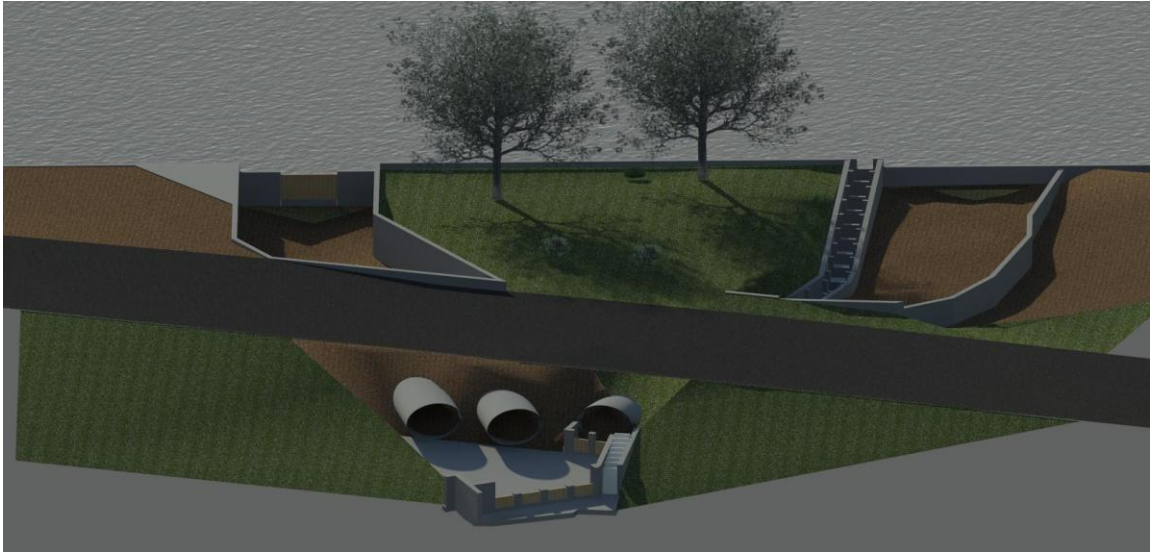
## **2.8 Site Conditions**

Each dam has unique conditions to it that will make the fish passage designs for each very different. Russells Mills Dam has an existing, ineffective fish passage and a road passing over it, while the Smith Mills Dam is much smaller and has no existing fish passage. Each dam will require an individual solution to fix the fish passage problem. (refer to figures 9 and 10)

### **2.8.1 Russells Mills Dam**

Russells Mills Dam is located on the Paskamanset River on the eastern shore of Russells Mills Pond in the town of Dartmouth, Bristol County, in the Commonwealth of Massachusetts. The dam is located at the latitude of 41° 34' 16.661" N and at the longitude of 70° 00' 16.430" W. It was rebuilt in 2001. The spillway is 6 feet high and 25 feet wide. Currently, the dam has two fish passages: a Denil passage made of concrete and fiberglass, and a weir-pool passage made solely out of concrete. The situation for this dam is unique in that Rock O'Dundee Road passes directly over the culverts between the Denil and weir-pool passages. The drawings of the

upper and lower parts of the passage are included in Appendix B: Technical Specification for Russells Mills Fish Passage. A rendering of the dam, culverts, and fish passages is shown below in Figure 12.



**Figure 12: Revit Rendering of Russells Mills Dam**

In this project, Russells Mills Dam will be referenced as if one is facing northeast looking upstream at the dam. As can be seen in Figure 12, the dam is bisected by a small park area, with water flowing through two separate channels around it. The left channel flows under Rock O'Dundee Road through two parallel culverts. This side has no means for fish to pass the dam so stop logs are put in place to prohibit them from entering this channel. The channel on the right side of the dam contains both of the existing fish passages. Connected to the dam is a weir-pool fish ladder with twelve 3' x 5.5' pools. Water that flows through the weir-pool passage or over the right side of the dam flows under Rock O'Dundee Road through a third culvert before flowing through a three-foot wide Denil passage with seven baffles. Stop logs are also put in place to ensure that the water that flows through the right culvert goes through the Denil passage, and that any fish who make it to the top of this passage are not immediately washed back downstream to the left of the Denil passage.

### 2.8.2 Smith Mills Dam

Smith Mills Dam is located on the Paskamanset River in the Town of Dartmouth, Bristol County, in the Commonwealth of Massachusetts. The dam is located at the latitude of  $41^{\circ} 38' 24.271''$  N and at the longitude of  $70^{\circ} 59' 06.675''$  W. The dam was constructed in the 19th century and is made out of granite blocks. The water flows over the dam but is dissected by a stack of granite blocks in the middle, as seen in Figure 13. On each side of the granite outcropping the dam extends approximately 28 feet. There is currently no fish passage at the dam. Additionally, it should be noted that the land on which the dam is located is owned by the local Midas.



Figure 13: Smith Mills Dam

## 2.10 Structural Design

The structural design of the fish passages has many aspects that need to be taken into consideration. The process involves designing the concrete mix, determining the needed reinforcement, analyzing the critical loads on the structure, and designing to avoid cracking of the concrete.

### 2.10.1 Concrete Mix

Concrete mix design is the process of determining the characteristics of a concrete mixture. The concrete's properties are a result of the type and proportion of ingredients in the concrete mix. To create a concrete with desirable characteristics, "mixture characteristics are selected based on the intended use of the concrete, the exposure conditions, the size and shape of building elements, and the physical properties of the concrete required for the structure" (Kosmatka, Kerkhoff, & Panarese, 149).

The most important ingredient of the concrete mix is the cementitious paste. Cementitious paste is the combination of water and cementitious material, mainly portland cement but also including blended cement, fly ash, slag, silica fume, and natural pozzolans. The quality and amount of paste used significantly affect the desirable characteristics of the concrete. The water-cementitious material ratio, mass of water divided by mass of cementitious material, is selected based on the critical compressive strength and durability requirements.

The other main ingredient in concrete mix is aggregates. The aggregates are generally a combination of sand, gravel, and crushed stone, which are bound by the cement paste. Sand and particles smaller than 3/8 inch in diameter are referred to as fine aggregate, while larger particles that are roughly 3/4 inches to one inch in diameter are known as coarse aggregate (Kosmatka, Kerkhoff, & Panarese, 149).

### 2.10.2 Reinforcement

Concrete is a material that can support a high amount of compression, but fails easily under tension forces. To make up for this weakness, concrete is reinforced with steel rods or bars, known as rebar, to handle the tension forces. The steel bars' size, grade, and required coating are all determined through ASTM and ACI standards.

### 2.10.3 Cracking

Cracking is a major concern for concrete structures that deal with directing or retaining fluids. The breakdown of a concrete structure can lead to hazardous flooding. Another issue is that the deterioration of a structure in a water system can lead to serious contamination of the environment.

The two main causes of cracking in concrete are the stress due to applied loads, and the stress due to drying shrinkage or temperature changes when the concrete is restrained. Drying shrinkage is an unavoidable problem, but it can be lessened with the use of reinforcing steel.

The steel, if properly positioned, will reduce the crack widths. Additionally, if the concrete goes through fluctuations in temperature, thermal stresses may occur from restrained deformations. Thermal stresses occur throughout the structure's entire lifespan. It should be noted that if the concrete is not restrained, then there will be no cracking. Sources of restraint include the reinforcing steel bars in the concrete, the interconnected parts of the concrete structure, and the friction of the surface that the concrete structure is placed on. Additionally, the moist interior of the drying concrete puts restraint on the concrete near the surface. This will be an important aspect of behavior to be taken into consideration for the final designs. (Kosmatka, Kerkhoff, & Panarese, 2002)

## 2.11 United States Fishery History

In the mid-1900's scientists believed the sea could feed the world. Unfortunately scientists made an egregious overestimation: there was discrepancy between actual catches and the estimated yield. The high estimation of marine life caused fishermen to overexploit marine resources. Various regulatory agencies began to perceive the ecological damage caused by overfishing and marine regulators changed as environmentalists succeeded in getting their arguments across. As research continued major laws were enacted to protect marine life.

The first was in 1976 with the Magnuson-Stevens Management Act, which gave fisherman coastal water control out to 200 miles. Furthermore the act also limited foreign fisherman from fishing in those areas. Next came the Marine Mammal Protection Act in 1972. Environmentalists, specifically marine conservationists, pushed to further regulate policies on mega-fauna, such as whales. With fishery depletion on the rise and the food industry under media scrutiny, the Magnuson-Stevens act was morphed into the Sustainable Fisheries Act in 1996. The new policy was aimed at closing loopholes that allowed unsustainable fishing practices such as reducing the accidental catching of unwanted species (by-catch) and fishing fleets.

Over time marine specialists have grown more concerned with the preservation of habitats rather than the protection of marine populations. Fish function off a very tightly organized ecosystem that is reliant on specific habitat requirements. They are less domesticated than livestock in the United States. Marine regulations are very difficult to research as life has presented diverse regulatory and conservation histories. For example by-catch is not afforded the same protection as megafauna like the turtle, whale, or dolphin. (Miller, 2002)

## 2.12 Laws and Regulations

In order to build a dam and fish ladder, specific state laws and regulations must be met and maintained throughout the lifetime of the dam and passageway. The Massachusetts Department of Transportation's (MA DOT) development and design process incorporates design standards from the *Massachusetts River and Stream Crossing Standards*, the *Massachusetts Highway Project Development and Design Guide*, and the *Bridge Design Manual*. The US Army Corp of Engineers (US ACE) requires each project to follow the MA Wetlands Protection Act and coastal zoning laws as well as obtain waterways and water quality certification from the Massachusetts Department of Environmental Protection (MA DEP).

All aspects of the structures (composition, environmental impact, watershed impact, etc.) must be analyzed and approved. Laws and regulations for the following aspects must be assessed before a design can be installed: current passage location (relation to roadways, wetlands, etc.), maintenance of the roadways surrounding the structures, construction materials, structure size, pollution control and other environmental impacts (See Appendix D: Summary of the Massachusetts River and Stream Crossing Standards). In order to provide optimal passage for travelling species it is important that the structures do not interfere with species' lifecycles, by not affecting the time it takes or the quality of the water for safe living conditions.

Multiple sources of information make sure that the project processes (initiation, planning, development, and design) consider the implications of the construction process. These include habitat stability crossings, proper permitting from affected environmental agencies and the conformity with pertinent regulations. Design standards are regulated for the following characteristics: adequate flow capacity, structural integrity, and wildlife habitat continuity. When all standards are met in the planning and design processes a final review determines if the

structure will be constructed. The review takes into consideration the aforementioned socioeconomic and environmental conditions affected by the structure and its construction process.

### **2.13 Environmental Impact**

Before design and construction can take place proper planning must ensure that fish passage can be sustained, and that the construction does not interfere with state laws and regulations. An interdisciplinary approach is the best way to get an innovative and sound design. Planning should involve local and community officials, design personnel (civil and structural engineers), ecology, biology (marine preferred) and environmental experts, building and landscape architects and recreational consultants

Dam and fish passage construction has many environmental impacts as they change the ecology of the surrounding environment. When holding back water via a dam/reservoir construction, a proper fish passageway must be constructed as well to allow for proper ecological development. Environmental aspects included in assessing the impacted areas consist of access to feeding areas, access to shelter and refuge from predators, allowing for various water habitats (varying temperatures), suitable spawning and breeding areas, availability of new habitats and interaction with other wildlife (biodiversity). If any design is seen as too damaging to any one of these aspects then it can be deemed unsuitable for proper dam and passage construction. (MA DCR)

Conserving natural resources is becoming more and more of a problem every day. The survival of each organism is paramount to the survival of the ecosystem as we know it today. Natural resources include trees, oil, soil, local fauna and flora, the sun, etcetera. As the world population continues to rapidly increase, it becomes more important to preserve and even aid in



allowing these natural ecosystems flourish. Damming systems should provide aesthetic value for fisherman and those wanting to hunt their own fish as well as a place for these fish to reproduce successfully. The environmental impact must be minimized while also providing a necessary value to society. In order to compromise on both sides and maintain some sort of balance, construction must fit the demands of the natural habitat with the social aspects (economic, political) of design and construction. Specific considerations for each specific passing species must be met. These include habitat availability, proper feeding grounds and sufficient mobility through the watershed. (Seaman, 1977)

### **3 Methodology**

The purpose of this project was to develop design alternatives, and provide cost effective solutions for the fish passage problem of two dams: the Russells Mills Dam and the Smith Mills Dam. The main tasks involved in this project were: collecting data, reviewing literature, assessing the existing conditions, designing the passage, checking the designs against environmental regulations and laws, and writing the report.

#### **3.1 Data Collection**

The first step in beginning the research was the collection of field data from the individual sites. On September 12, 2012, a field visit was made to the Russells Mills and Smith Mills Dams, where general data was collected and initial observations were made. A detailed set of plans was obtained from Michael O'Reilly, the Environmental Affairs Coordinator for the Town of Dartmouth. These included dam and fish ladder blueprints.

A second field visit was completed on October 22, 2012, where water velocities and structure dimensions were recorded. This information, along with that from the initial site visit, is detailed in section 2.6: Site Conditions.

#### **3.2 Literature Review**

The background information used during this project was found from journals or textbooks on the relevant topics. The books came from a range of subjects, including biology, concrete design, structural analysis, fluid mechanics, soil mechanics, and environmental law. Each topic is pertinent to the investigation of the fish passages. The information secured from these books provided an understanding in all areas of work.

### 3.3 Assessment of Existing Conditions

One of the first topics investigated was the amount of water that passes through each of the sites. Expected flow and the seasonal variations are imperative for both the structural and hydraulic designs of the fish passages. The hydraulic aspects, such as flow and drainage conditions, must be evaluated to design a fish passage that is usable by alewife and blueback herring. Additionally, the current structural aspects of the fish passages were collected. This information was obtained through review of the structural drawings of the current fish passage, as well as site visits to both of the locations, and use of the online flow data.

#### 3.3.1 Site Visits

Site visits were completed for a few different reasons: to gain a general understanding of water flow through the passages, to take velocity measurements of the water at different locations, and to measure the dimensions of the structure that were unclear in blueprints. The visits provided real data to compare to theoretical calculations, as well as better understanding of the functionality of each passage.

#### 3.3.2 3D Modeling

In order to create a visual representation of the dam, passages, and surrounding area, a three-dimensional model was constructed. The surveying data that was collected and the information provided in the dam blueprints were manually imported into *Revit* to create a topographic map of the area. Next, three-dimensional models of the Denil passage and culverts were created using *Revit* and *AutoCAD* respectively. A topographic surface was then added to the model to represent the surrounding environment.

### 3.3.3 Structural Conditions

Blueprints of the Russells Mills fish ladder provided information on the passage dimensions, as well as information on the culvert and dam. As the weir-pool dimensions were not included in the blue prints, they were measured during the second site visit. The dimensions of the Smith Mills Dam were also assessed in a site visit. Any assumptions or estimations made are clearly defined and explained during the analysis.

### 3.3.4 Hydraulic and Hydrologic Analysis

The current hydraulic and hydrologic conditions of this area of the Paskamanset River were determined through measurements taken during site visits, as well as from blueprints and hydrologic data. The U.S. Army Corps of Engineers' Hydrologic Engineering Center software was used to calculate the peak runoff for storms of different magnitudes in the watershed.

Once the hydrologic information was used to determine the river's total flow, estimates were developed for the characteristics of the water flow through the fish passage. For the dam itself, it was assumed that the water either flowed over the top of the dam or through the weir-pool passage. The dam was treated as a sharp-crested weir (shown by Figure 14) with a water level above the top of the dam, and the weir-pool passage was treated as a broad-crested weir. The heights of the different sides of the dam can be seen in Figure 15.

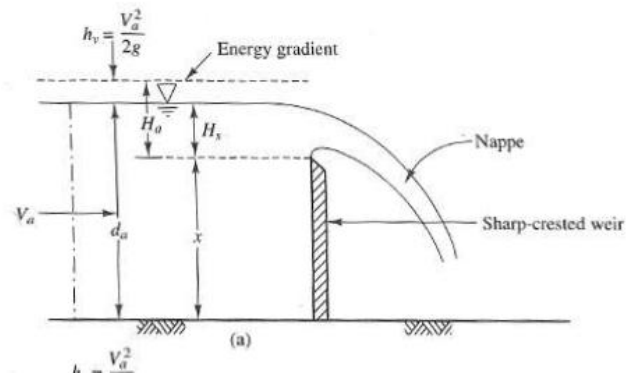


Figure 14: Sharp-Crested Weir

(Hwang, 1996)



**Figure 15: Russells Mills Dam Heights**

The velocity of the water during herring spawning season was found using data obtained from the United States Geological Survey's National Water Information System. The USGS operates a flow gauge located on the Paskamanset River. The gage is located on Russells Mills Road, which is located between the two dams. It measures the river's discharge in fifteen-minute increments. These data were used to create a graph of the peak annual discharge, and to determine the return periods for discharge rates. Next, the annual flow during fish passage season was analyzed. The average flow during this period was used to model the general discharge that herring would encounter. The average was taken from 2007 to 2011. Data for 2012 was left out because the data are considered to be provisional until verified by the USGS

The geometry of Russells Mills Dam and the existing fish passages were evaluated to determine the areas that would require alterations in order to create more desirable hydraulic characteristics. To accomplish this, the heights of the dam and weir-pool passage were analyzed to determine the discharge rate that would be required in order for water to rise above each respective crest. This approach allowed the flow path to be defined based on the flow rate.

During the lowest flow periods, water will only rise over the slot on the left side of the dam, meaning the only flow path will be through the two left culverts. In this scenario, no water will enter the weir-pools, the right culvert, or the Denil passage. However, flows that are this weak are unlikely to occur. With moderately higher flows, the water level of the dam will rise and exceed the height of the opening to the weir-pool passage. At this point, water will also flow through the weir-pools, the right culvert, and the Denil passage. Characterizing the flow this way is important as it will provide magnitudes of flows through different areas of passages, which aids in selecting the necessary equation for hydraulic modeling and analysis.

As the river's discharge rate increases, and the water level rises even more, the water will also spill through the slot located to the right of the weir-pool passage, and finally over the dam itself. The flows that will create high enough water levels to flow through the different dam areas can be seen in

Table 2 and Figure 16. A small increase in water level from just below the top of the dam to just above it will cause a large, immediate increase in the flow through each section of the passage.

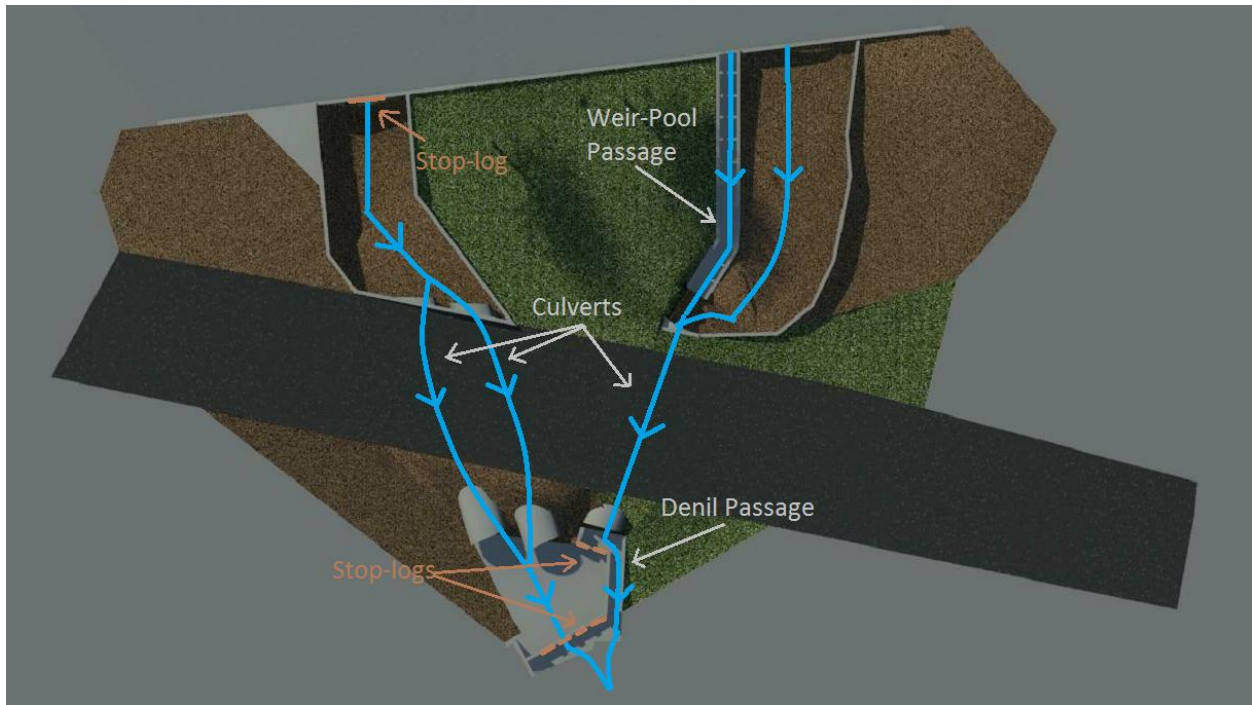


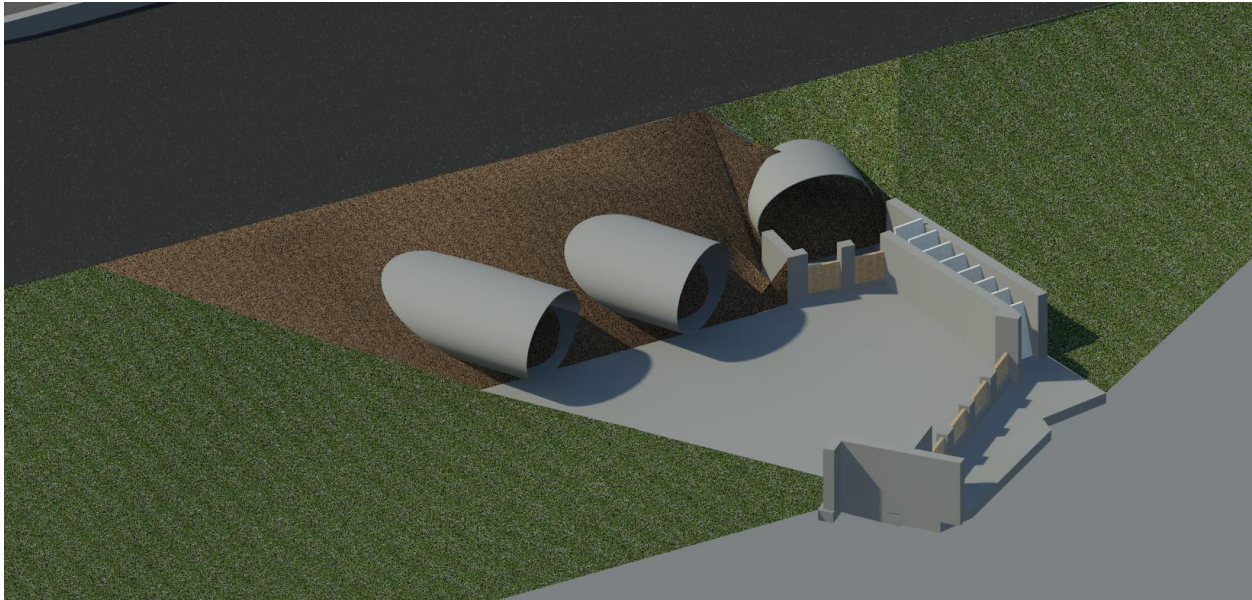
Figure 16: Plan View of Russells Mills Dam with Annotations

Table 2: Flow Guide

| Flow (cfs) | Maximum water level at dam (ft) | Flow areas  |
|------------|---------------------------------|---|
| <4.8       | <13                             | Left channel, two left culverts   |
| 4.8 to 37  | 13.3                            | Left channel, two left culverts, weir-pool passage, right culvert, Denil passage                |
| >37        | >14.1                           | Left channel, two left culverts, weir-pool passage, right channel, right culvert, Denil passage |

Water flowing through the weir-pool passage and over the dam itself was modeled using the general discharge equation for contracted weirs (See Equation 1). Assuming that the upper stop-logs are in place, the entirety of the water that flows through the right culvert will then flow through the Denil passage. The culverts and Denil are shown in Figure 17. To calculate the velocity of the water in the Denil passage Equation 2 was used. The resulting discharge velocities from the Denil passage are a function of the river's total discharge rate. These

velocities are important in that they are the main factor in attracting the fish to the ladder.



**Figure 17: Lower Passage**

In order to measure the velocity within the fish passage, a velocity probe was used during a site visit to assess the differences in flow throughout the passage. These values were then checked for accuracy against values calculated based on USGS flow data. The water velocities that the two species of herring are capable of swimming against were then compared to the passage velocity. The geometry of the fish passage was designed to allow the correct velocity of water through the passageway so that the herring can make it through.

Using the information from the USGS gage along the Paskamanset River, data were obtained for the months of February through May (the months that the herring would be using the fish ladder). This flow data was then used to determine the hydraulic forces in action through the passages.



### 3.4 Design of Fish Passage

The design of the fish passage is based on the physical capabilities of the river herring. Each species of fish has a certain water speed that they are comfortable swimming against for certain periods of time. The passages on the Paskamanset River took blueback and alewife river herring into consideration when determining the fish ladders' passability. Due to the herring's physical constraints, the hydraulic conditions of the passage were analyzed first to verify that the herring would be capable of swimming the full length of the passage without fatiguing. After the hydraulics of the passage were determined, the geometry of the passage could be set. Finally, the structural design was based off the geometry determined from the hydraulic analysis and checked against a design event, which in this case is a 100-year flood.

#### 3.4.1 Hydraulic Forces

The three main forces on the structure caused by the water flowing through passageway are the force due to hydrostatic pressure, the force due to the change in momentum of the water, and the weight of the water on the base of the passage.

The force due to hydrostatic pressure is found through the following equation:

$$F_r = \gamma(h/2)A. \quad (5)$$

Where “ $\gamma$ ” is the specific weight of water, “ $h$ ” is the height of the water in the passage, and “ $A$ ” is the affected area. This is a resultant force that acts at a depth that is one third the height of the water as measured from the bottom of the water body.

The force due to the change in momentum can be estimated using a conservation of momentum approach. A simple equation that provides a conservative estimate of the net force due to momentum at a channel transition:

$$F = Q\rho(v_1 - v_2) \quad (6)$$

Where  $\rho$  is the density of the liquid,  $Q$  is the flow,  $v_1$  is the velocity of the water in between the baffles, and  $v_2$  is the velocity of the water in the weir-pools. This force is located on the baffles and walls that jut out into the passage. The assumption that allows this equation to be a good approximation is that the water is experiencing uniform flow. Although the passage does not actually experience uniform flow, this approximation is a more conservative method to determine the resulting force due to the change in momentum.

The last force due to the water in the passageway is the weight of the water on the concrete slabs. This is calculated by multiplying the volume of water in the passage by the specific weight of water. The structure will be designed to resist all of these forces.

### 3.4.2 Structural Design

Once the ecological and hydraulic conditions of the area had been determined, they were analyzed to explore the necessary geometric shape of the fish passage. This new shape, was then checked for structural stability against a design event, in this case a 100-year flood.

#### 3.4.2.1 Load Conditions

The structural design of the ladders is based, in part, on the different loads that the structure is required to resist. To calculate the stresses and strains on the structure, the moduli of elasticity are necessary. According to the *ACI Manual of Concrete Practice*, the modulus of elasticity of concrete is equal to  $57000\sqrt{f'c}$ . The modulus of elasticity of the steel reinforcement is equal to 29,000,000 psi.

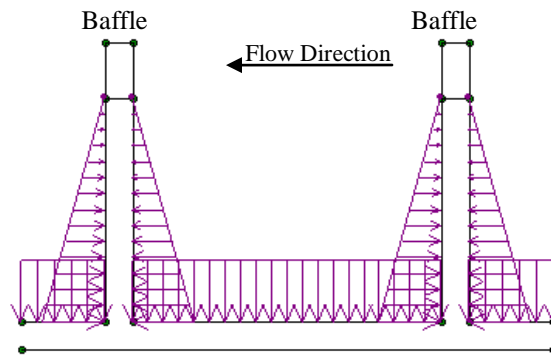
The load combination that is used to determine the factored load on the structure is  $U = 1.6H$ . This equation takes into account the water pressure ( $H$ ). In addition to the load

combination, strength reduction factors are also required. According to ACI standards, tension controlled sections require a strength reduction factor of 0.90. For compression controlled it is equal to 0.65, for shear and torsion it is 0.75, and for bearing on concrete, it is equal to 0.65.

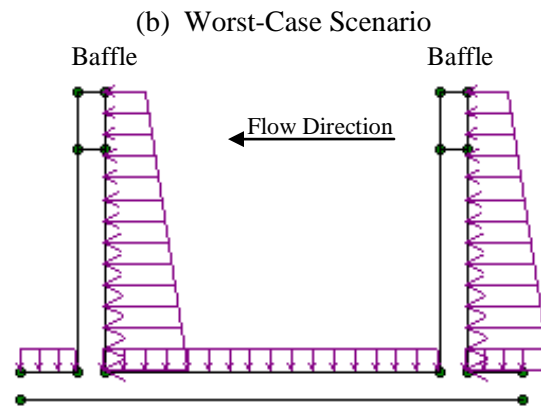
The load combinations and the strength reduction factors are put in place so that there is an appropriate factor of safety and consistent level of structural reliability. Additionally, the walls of the weir-pool and Denil passages were treated as cantilever retaining walls for the analysis. This will give a conservative estimate for the force on the walls.

#### **3.4.2.2 Load Analysis**

To determine the necessary structural capabilities, the worst-case scenario was identified so that the maximum possible forces could be determined. A 100-year flood was investigated to determine the design base for flooding. This condition of flooding was then combined with the possibility of a blockage in the channel to determine the worst-case scenario. The diagrams below, in , illustrate the differences between worst-case scenario conditions and normal conditions.



(a) Normal Condition



(b) Worst-Case Scenario

Figure 18: Loading Scenarios

In Figure 18 (a) the baffles of the weir-pool experience hydrostatic pressure from either side and so the forces cancel each other out. The only force that affects the baffles is that caused by the momentum of the water at its normal flow rate, which is not illustrated in either figure. Figure 18 (b) shows what would happen if a flood occurred and if the upper passage was suffering from a blockage which then burst, effectively flooding the passage in one sweep. The pressure is dramatically increased because the deeper the passage is underwater, the higher the hydrostatic pressure. Additionally, as the water in the passage would be low, due to the blockage, the hydrostatic pressure on the opposing side would be low. This means that the hydrostatic pressures would not cancel each other out as they do in the Figure 18 (a).

In addition to the hydrostatic loads, the forces due to the momentum of the water were also necessary to evaluate. Equation 6 was used calculate the forces due to momentum in the weir-pool and Denil passages, as it is a conservative estimate of the magnitude of the forces.

For calculations, the force due to momentum and the force due to hydrostatic pressure were combined. The shear and moment capacities of the baffles were then checked against the forces to determine the structural capabilities required by the passage. Additionally, the walls lining the passages were subjected to the same load conditions, excluding the forces due to momentum.

#### **3.4.2.3 Shear and Moment**

For the purpose of determining shear and moment, the baffles of the weir-pool and Denil passages were treated as plates that were fixed on three sides and free on the top. The deepest weir-pool was selected for analysis as it would have the greatest forces on it. To complete an analysis of plates like these, William T. Moody's monograph *Moments and Reactions for Rectangular Plates* was used. In this book, Moody provides tables of coefficients, calculated using the finite difference method, that are organized by the height to width ratio of the plates, as well as the type of distributed load that is acting on it. For an example of what the tables look like see Figure 19. The coefficients need only to be multiplied by the intensity of the distributed load and the plate height to determine the moments and reactions at different points throughout the plate.

|             |     |                      |         |         |         |         |         |         |
|-------------|-----|----------------------|---------|---------|---------|---------|---------|---------|
| $a/b = 1/2$ | 1.0 | + .0326              | + .0151 | + .0088 | + .0015 | - .0046 | - .0084 | - .0097 |
|             | 0.8 | + .1315              | + .0216 | + .0099 | + .0007 | - .0059 | - .0099 | - .0112 |
|             | 0.6 | + .1972              | + .0273 | + .0108 | - .0005 | - .0079 | - .0119 | - .0132 |
|             | 0.4 | + .2421              | + .0277 | + .0092 | - .0019 | - .0082 | - .0115 | - .0125 |
|             | 0.2 | + .1607              | + .0160 | + .0041 | - .0017 | - .0044 | - .0055 | - .0058 |
|             | 0   | - .0045              | 0       | + .0014 | + .0033 | + .0050 | + .0061 | + .0065 |
|             |     | $R_x \backslash R_y$ | - .0045 | + .0744 | + .1942 | + .2699 | + .3108 | + .3236 |

Figure 19: Table from *Moments and Reactors for Rectangular Plates*

(Moody, 1960)

The walls that line the weir-pool passage were treated as cantilever retaining walls for their analysis. For the Denil structure, only the wall that was not already retaining earth was analyzed, as it would have no forces to counteract the flood of water from the 100-year flood. Additionally, a second analysis of the baffles was completed where the baffles were also treated as cantilever retaining walls. This was completed to provide more information on the forces that affect the baffles. The equation used to determine the maximum moment was:

$$M_u = 1.6Py \quad (7)$$

In this equation,

$$P = \frac{1}{2}Wh(h + 2h') \quad (8)$$

$$y = \frac{h^2 + 3hh'}{3(h + 2h')} \quad (9)$$

where, h is the height of the retaining wall and h' is the height of the water above the wall.  $M_u$  can then be used to calculate the required thickness,  $d$ , and the required reinforcement,  $A_s$ .

Additionally the retaining wall is checked against shear at a distance,  $d$ , above the base of the wall. This shear value,  $V_u$ , can be found through the following equations:

$$V = 1.6P \quad (10)$$

The maximum allowable shear load was calculated with the equation:

$$\phi V_c = \phi 2\lambda\sqrt{f'_c}bd \quad (11)$$

where  $\phi$  is equal to 0.75, and  $\lambda$  is equal to 1.

After establishing the shear and moment on the walls and baffles, resistance factors were applied to all the values to determine the allowable shear and moment. Finally, the shear and moment forces were compared to the allowable shear and moment of the concrete sections to verify that the passage is structurally sound.

#### **3.4.2.4 Concrete Mix**

To design the necessary concrete mix for the passages the *ACI Manual of Concrete Practice* was resulted. The *ACI Manual* provided tables on exposure conditions and how they should affect the concrete mix. Conditions pertain to freezing / thawing, permeability, and corrosion protection. The degree of freezing and thawing that occurs in the region will affect the maximum water/cement ratio, the minimum design strength, the maximum aggregate size, and the air content. The level of permeability required also influences the water/cement ratio and the minimum design strength. Corrosion protection affects the water/cement ratio, minimum design strength, and the maximum water-soluble chloride ion content. (American Concrete Institute)

Evaluating the exposure conditions gives the required minimum design strength and the maximum water/cement ratio. These two values can be created by altering different factors involved in the concrete mix, such as proportioning, maximum aggregate size, air content, and the addition of admixtures (Kosmatka et al, 149).

#### **3.4.2.5 Reinforcement**

Reinforcement bars are necessary for concrete so that it can resist loads in tension. *ACI 318* provides code for all aspects of steel reinforcement, such as minimum bar diameter, the allowable spacing between bars, reinforcement placement, and proper reinforcement covering.

Additionally, another good source of information on reinforcement requirements is the ASTM.

The required area for the reinforcement,  $A_s$ , was found using equation:

$$A_s = \rho bd \quad (12)$$

where  $\rho$  is equal to the reinforcement ratio, and  $b$  and  $d$  are equal to the width and thickness, respectively, of the concrete cross section. The reinforcement ratio is determined by using a

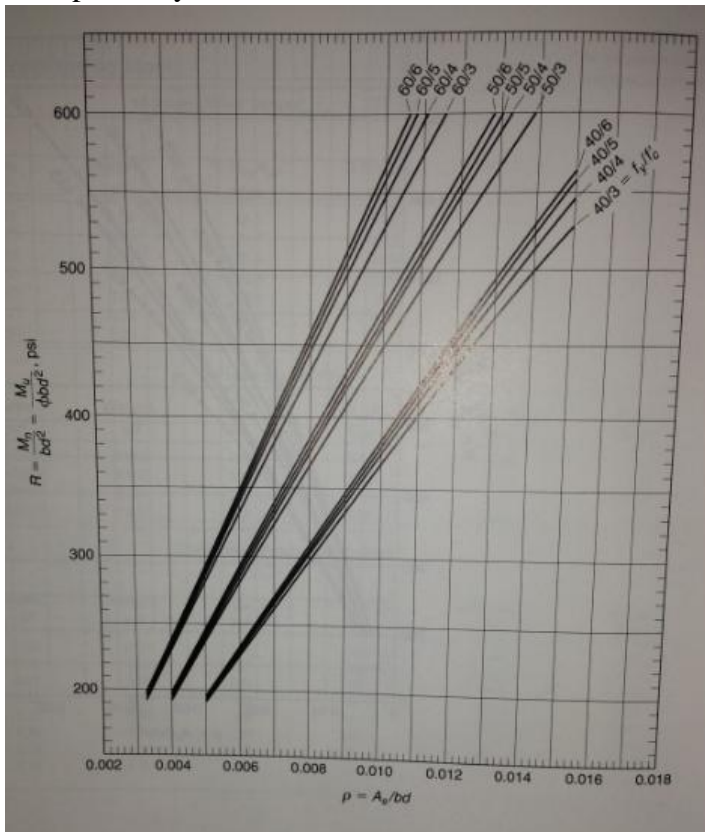


Figure 20: Moment Capacity of Rectangular Sections

(Nilson, et al. 2010)

### 3.5 Environmental Regulations

In order to maintain and successfully use a fish passage, all designs must fit environmental regulations set forth by the Town of Dartmouth, the Commonwealth of Massachusetts, and the Federal Government. The State government and Federal government have regulations (general environmental guidelines) on many aspects of watersheds from flow

graph of the moment capacity of rectangular sections, shown in Figure 20. In these graphs, the ratio of  $f_y/f_c'$  is used to determine the relationship between the reinforcement ratio,  $\rho$ , and the value  $R$ , where:

$$R = M_u / \phi bd^2 \quad (13)$$

Calculating  $R$  and knowing the ratio of  $f_y/f_c'$  allowed the use of the moment capacity graph to calculate  $\rho$ , which can then be used to calculate  $A_s$ .



rates, water oxygen concentration, habitat change etc. Regulations were researched and the final designs were checked to verify that they complied with all laws and regulations.

### **3.6 Deliverables**

Finally, this project includes a CAD design, cost estimates, design calculations, a written report, and any recommendations as the deliverables. These documents will help to supply the Town of Dartmouth with viable solutions to the fish passage problem along the Paskamanset River.

## 4 Results

The results of this project include an in depth assessment for river herring characteristics, a hydraulic analysis, a structural analysis, and an assessment of environmental regulations. All design recommendations abide by Massachusetts laws and regulations. Additionally, the structural design followed the code set down by American Concrete Institute.

### 4.1 River Herring

Since the purpose of this project was to restore fish passage for river herring, it was important to gain a full understanding of the average herring's physical capabilities. Table 2 below summarizes their capabilities when it comes to speed, endurance, slope preference, and jump height.

Table 3: River Herring Characteristics

| River Herring Characteristics |                       |
|-------------------------------|-----------------------|
| <b>Burst Speed</b>            | <b>Endurance</b>      |
| 15 fps                        | 30 seconds            |
| <b>Cruising Speed</b>         | <b>Endurance</b>      |
| 7-8 fps                       | 200 min               |
| <b>Sustained Speed</b>        | <b>Endurance</b>      |
| 3-5 fps                       | >200 min              |
| <b>Preferred Slope</b>        | <b>Jumping Height</b> |
| 10-15%                        | 0-6 in                |

### 4.2 Site Information

To gain a better understanding of the fish passage, beyond the site plans of the locations, multiple site visits were completed at Russells Mills Dam and Smith Mills Dam. The site visits

provided information that was integral to the creation of an *Autodesk Revit* model. The model was important for providing the complexities of the passage at Russells Mills Dam.

#### 4.2.1 Site Plans

The site plans received from Michael O'Reilly, the Environmental Affairs Coordinator of the Town of Dartmouth, provided information on the dimensions and materials used at the Russells Mills Dam.

The concrete mix that was used for Russells Mills Dam was designed according to ACI and ASTM standards in 2001. The maximum water cement ratio was 0.48. The minimum design strength required was 4000 psi. The maximum aggregate size allowed was 1.5. Air was entrained in the concrete to produce an air content of four to six percent. Lastly, the concrete mix included a water-reducing admixture with no chlorides in it.

The reinforcement required for the concrete was determined from the ASTM Standards. The reinforcement used at Russells Mills Dam was Grade 60 deformed bars. The bars were epoxy coated, and surrounded by 2 inches of concrete on the top and side, and 3 inches on the bottom.

#### 4.2.2 Site Visits

The first site visit, on September 12, 2012 served as an opportunity to become familiar with the area, and view each dam in person for the first time. During this site visit, Michael O'Reilly and Brad Chase provided the group with information regarding the history of the dams and current ladders, knowledge of herring and eel behavior, and details about environmental regulations.

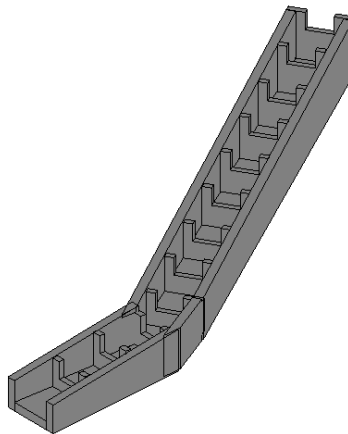
A second site visit was performed on October 22, 2012. The purpose of this visit was to conduct detailed measurements of the fish ladders. The dimensions of the weir-pool ladder were

recorded. The width of the weir-pool walls was found to be 1 foot. The step heights for each weir-pool are shown in Table 4 below.

**Table 4: Weir-pool Dimensions**

| Weir-pool | Weir-pool step height (in.) | Water level (in.) (10/22/12) |
|-----------|-----------------------------|------------------------------|
| 1         | 21.5                        | 23                           |
| 2         | 15                          | 24                           |
| 3         | 19.5                        | 23                           |
| 4         | 20.75                       | 28                           |
| 5         | 24                          | 28.5                         |
| 6         | 24.75                       | 31                           |
| 7         | 28.75                       | 33                           |
| 8         | 31.5                        | 36                           |
| 9         | 34                          | 37.5                         |
| 10        | 35.5                        | 41                           |
| 11        | 40                          | 43.5                         |
| 12        | 41                          | 46                           |

The weir-pool dimensions were then used to create a *Revit* BIM model of the ladder. This model was used to provide spatial and structural analysis and to visualize the ladder without the flow of water.



**Figure 21: Weir-pool passage**

During our third site visit on December 7, 2012, a more comprehensive testing of water velocities was performed at Russells Mills Dam. Water velocities were measured using a velocity probe at multiple levels within each weir-pool, and at locations downstream from the passage. The downstream measurements were taken at locations that are marked on the existing conditions blueprint that was provided, so that each measurement corresponds to a known elevation.

This site visit was also used as an opportunity to make observations involving the geometry of Smith Mills Dam. It was observed that the streambed directly adjacent to the park is essentially flat. The change in height from the base of the dam to an area 23.5 feet downstream was measured to be approximately six inches. The height of the dam itself is four feet, and the distance from the dam to a culvert running under State Road is approximately 148 feet.

Our fourth and final site visit took place on March 15, 2013. The purpose of this site visit was to observe the passage under high-flow conditions. According to the USGS gage, the discharge at the time of this site visit was about



Figure 22: Weir-Pool Passage Under High Flows

220 cfs. The difference in flow between this site visit and the previous ones was evident. Water was flowing over the entire width of both sides of the dam and there was considerable seepage

under the park area. The water level in the channel to the right of the weir-pool was higher than the weir-pool walls, causing water to spill over the sidewalls into the lower weir-pools as shown in Figure 22. The flow through the Denil passage was also extremely high, with the water completely filling the baffle openings.

### 4.2.3 3D Model

The passage dimensions, obtained from site visits and passage blueprints, were used to create an accurate Autodesk Revit drawing of the fish passage at Russells Mills Dam. This drawing helped to better communicate the geometry of the current passageway during discussion. A rendering of the model is shown by Figure 23.

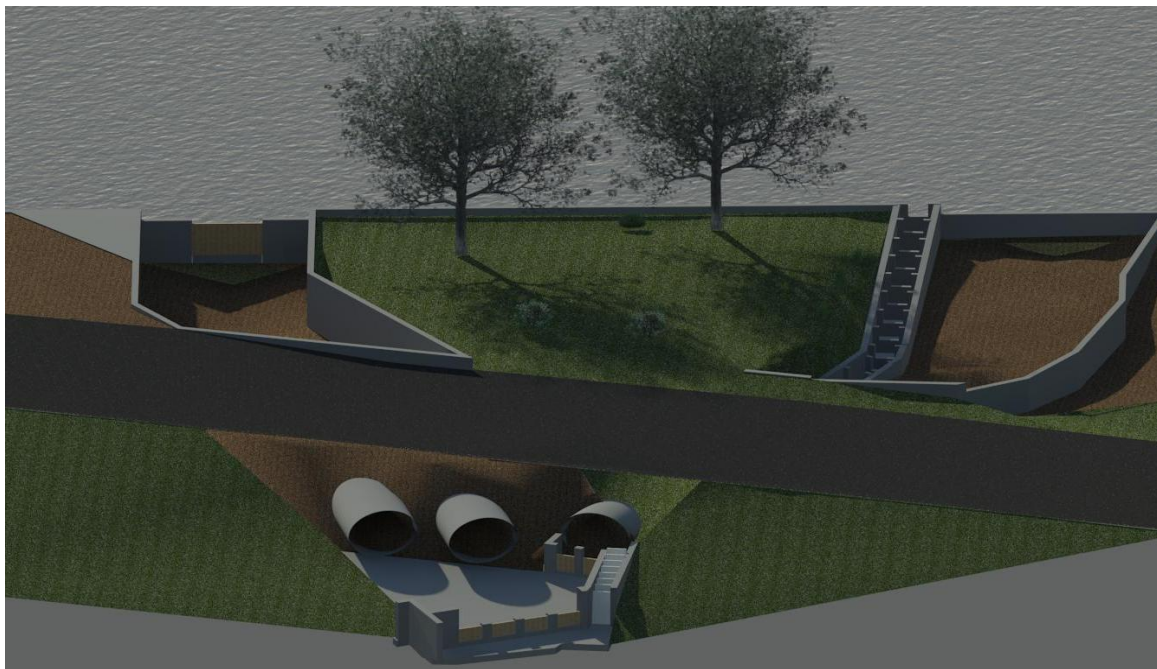
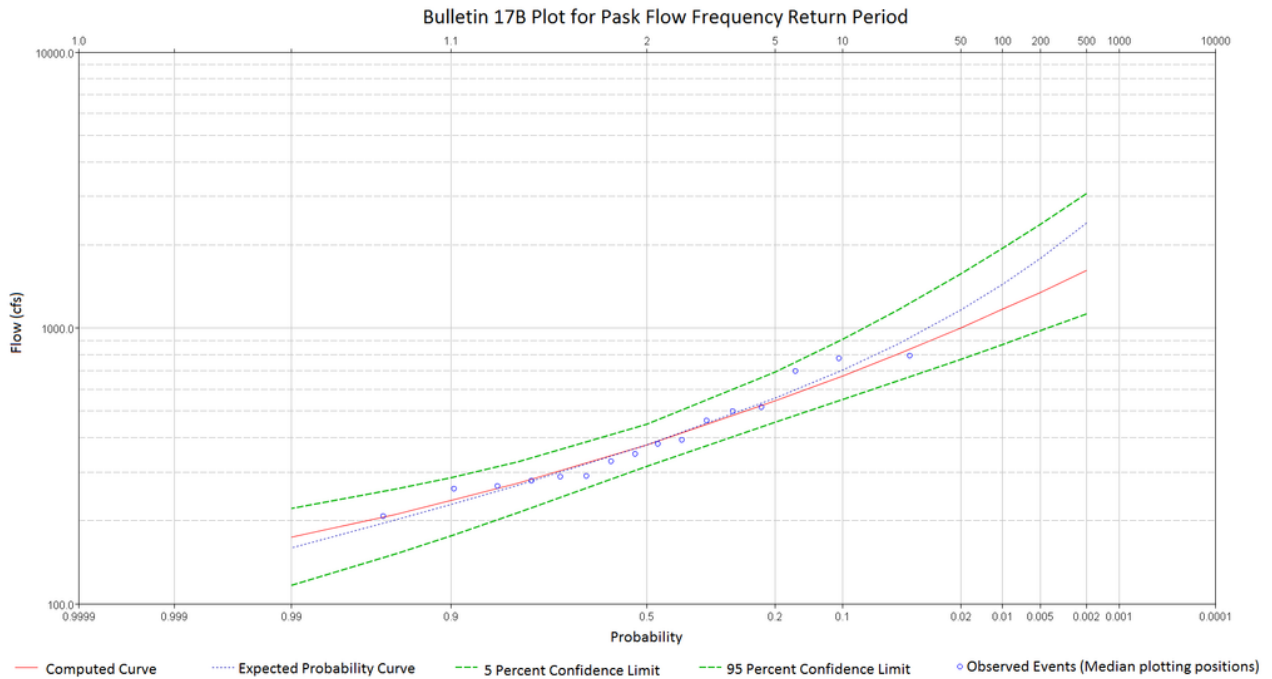


Figure 23: Rendering of Russells Mills Dam

## 4.3 Hydrologic Calculations

To analyze the historical flow data for the Paskamanset River, the U.S. Army Corps of Engineers *HEC-SSP* software was used. The Paskamanset River's peak annual flow was analyzed to graph its flow frequency, taking into account data from 1996 to 2010. The graph can

be used to determine both the return period and probability of occurrence for a given flow. An expected probability curve was created that calculated the flow for return periods. This curve and the graph of peak annual flow are shown below in Figure 24. The graph was used to determine the 100-year flow, so that the structural design could be checked against the forces caused by this flow.



**Figure 24: Annual Peak Flow Frequency**

#### 4.4 Hydraulic Calculations

The total river flows were used to determine the velocities at different areas in the passages. The geometry of the passage greatly affects the velocity which water will flow through it. In order to define optimal water velocities for fish passage, the current passage was analyzed to determine the changes that would have the greatest impact on defining these velocities.

#### 4.4.1 Weir-Pool Passage

The contracted weir equation, Equation 1, was used to calculate the total flow through the weir-pool passage. Calculations were performed during low flow to high flow conditions at heights over the lowest section of the dam in increments of 0.05 feet. A sample of these calculations is detailed as follows.

$$C_d = 3.22 + .40 \frac{H}{p}$$

$$C_d = 3.22 + .40 \frac{.71}{1.79} = 3.38$$

$$Q = C_d \left( L - \frac{nH}{10} \right) H^{2/3}$$

$$Q = 3.38 \left( 3 - \frac{.3 * .71}{10} \right) .71^{2/3} = 6.02 \text{ cfs}$$

The calculations use an H value of 0.71 feet. This is the difference between the height of the stop-log at the entrance to the weir-pool and the height of the dam. If the water level is more than 0.71 feet above the stop log, it will spill over the dam as well.

#### 4.4.2 Denil Passage

The flow through the Denil passage was calculated using the Equation 3. First, an h-value of 6 inches was used to model a relatively low flow as this was the value observed on site visits during low flow. This h-value resulted in a water level only slightly above the notches in the baffles but still high enough for herring to pass over.

$$Q = 1.35(b_a)^{\frac{5}{2}} \sqrt{g \times I} \left( \frac{h_*}{b_a} \right)^{1.584}$$
$$Q = 1.35(1')^{\frac{5}{2}} \sqrt{32.2 \left( \frac{ft}{s^2} \right) \times 23.5 ft^4} \left( \frac{.5}{1} \right)^{1.584} = 12.4 \text{ cfs}$$



The calculated flow of 12.4 cfs is reasonable in that it is greater than the flow through the weir-pool passage due to the additional flow over the right side of the dam. This flow will be forced down the Denil passage by the stop logs.

#### **4.4.3 Weir-Pool, Denil Passage Combination**

Next, the discharge equations were combined to model the total flow over the dam. This includes the flow through the weir-pool passage, over the stop logs, and over the dam itself. The water level at the dam was adjusted so that the resulting discharge would match the average flow during the spring months. The discharge through the right culvert was then used to determine the water level in the Denil passage.

### **4.5 Structural Calculations**

A structural analysis was completed to determine the structural stability of the current structure, as well as the effects caused by modifications. The structural calculations were completed by following *ACI 318: Building Code Requirements for Reinforced Concrete*. Utilizing this and Moody's monograph *Moments and Reactions for Rectangular Plates*, the forces due to a 100-year flood were determined and compared to the allowable loads the sections could withstand. The components that required structural analysis were the baffles and the sidewalls of the weir-pool and Denil passages. These are the sections of the fish passage that experience the greatest forces and are most likely to fail.

#### **4.5.1 Analysis of the Baffles**

The design load conditions of the baffles of the weir-pool and Denil passages were determined two different ways. The first method treated the baffles as plates fixed on three sides

and free on the third and utilized Moody's monograph (Moody, 1960). The second method treated the baffles as cantilever retaining walls and followed the *ACI 318* guidelines (ACI 2010).

#### **4.5.1.1 Weir-pool Baffles**

From the first method it was determined that the maximum moment that the tallest weir-pool baffle experienced was equal to 8,659 ft-lbs. Additionally, it was determined that the maximum reaction, located at the bottom-right of the plate, was 19,782 lbs. Following the equation  $V = R$ , it is determined that the maximum shear experienced by the weir-pool baffles is 19,782 lbs.

The second method utilized equations 7, 8, and 9. The calculations follow:

$$P = \frac{1}{2}(62.4)(5)(5 + 2(3)) = 1716 \text{ lbs.}$$

$$y = (5^2 + 3(5 \times 3))/3(5 + 2(3)) = 2.121 \text{ feet}$$

$$M_u = 1.6(1716 \times 2.121) = 5824 \text{ ft-lbs.}$$

The calculations of shear utilized equations 8 and 10. The calculations were as follows:

$$P = \frac{1}{2}(62.4)(5)(5 + 2(3)) = 1716 \text{ lbs.}$$

$$V_u = (1.6 \times 1716) = 2745.6 \text{ lbs.}$$

#### **4.5.1.2 Denil Baffles**

From the first method it was determined that the maximum moment that the Denil baffles experience was equal to 5,224 ft-lbs. Additionally, it was determined that the maximum reaction was 13,286 lbs. Following the equation  $V = R$ , it is determined that the maximum shear experienced by the weir-pool baffles is 13,286 lbs.

The second method utilized equations 7, 8, and 9. The calculations follow:

$$P = \frac{1}{2}(62.4)(4.5)(4.5 + 2(3)) = 1474.2 \text{ lbs.}$$

$$y = (4.5^2 + 3(4.5 \times 3))/3(4.5 + 2(3)) = 1.643 \text{ feet}$$

$$M_u = 1.6(1474.2 \times 1.643) = 3875.04 \text{ ft-lbs.}$$

The calculations of shear utilized equations 8 and 10. The calculations were as follows:

$$P = \frac{1}{2}(62.4)(4.5)(4.5 + 2(3)) = 1474.2 \text{ lbs.}$$

$$V_u = (1.6 \times 1474.2) = 2358.7 \text{ lbs.}$$

As the Denil baffles are not made of concrete, no reinforcement can be added to them. It is because of this that the Denil baffles should be made out of fiberglass, as it will be strong enough to resist the maximum moment, or easily replaceable after a major flood.

#### 4.5.2 Analysis of Sidewalls

The sidewalls of the Denil and weir-pool passages were treated as cantilever retaining walls for the analysis. The equations 7, 8 and 9 were used to calculate the maximum moment. To determine the shear of the sidewalls, the equations 8 and 10 were utilized. The results were as follows:

##### 4.5.2.1 Weir-pool Sidewalls

The moment calculations for the sidewalls were completed using Equations 7, 8, 9:

$$P = \frac{1}{2}(62.4)(5)(5 + 2(3)) = 1716 \text{ lbs.}$$

$$y = (5^2 + 3(5 \times 3))/3(5 + 2(3)) = 2.121 \text{ feet}$$

$$M_u = 1.6(1716 \times 2.121) = 5824 \text{ ft-lbs.}$$

The shear calculations for the sidewalls were completed using Equations 8, 10:

$$P = \frac{1}{2}(62.4)(5)(5 + 2(3)) = 1716 \text{ lbs.}$$

$$V_u = (1.6 \times 1716) = 2745.6 \text{ lbs.}$$

#### 4.5.2.2 Denil Sidewalls

The moment calculations for the sidewalls were completed using Equations 7, 8, 9:

$$P = \frac{1}{2}(62.4)(4.5)(4.5 + 2(3)) = 1474.2 \text{ lbs.}$$

$$y = (4.5^2 + 3(4.5 \times 3))/3(4.5 + 2(3)) = 1.643 \text{ feet}$$

$$M_u = 1.6(1474.2 \times 1.643) = 3875.04 \text{ ft-lbs.}$$

The shear calculations for the sidewalls were completed using Equations 8, 10:

$$P = \frac{1}{2}(62.4)(4.5)(4.5 + 2(3)) = 1474.2 \text{ lbs.}$$

$$V_u = (1.6 \times 1474.2) = 2358.7 \text{ lbs.}$$

#### 4.5.3 Structural Reinforcement

As the site plans of the current structures at Russells Mills Dam did not provide information on the reinforcement used, the current structure could not be checked for its ability to resist the design base. Instead, the required reinforcement was calculated based off the numbers above for any new sections that may be added. Additionally, for the following calculations, the unit length of the wall will be 12 inches, and the effective depth will be equal to 9.5 inches.

##### 4.5.3.1 Reinforcement of Weir-Pool Baffles

The maximum  $M_u$  calculated for the weir-pool baffles was 5,224 ft-lbs. To calculate the reinforcement required the R value was found using equation 13.

$$R = 8,659/0.9(12)9.5^2 = 8.88$$

This R-value is low enough that when the moment capacity graph, see Figure 18, was consulted, it was found that the minimum reinforcement would be required. ACI 318 stipulates that the minimum horizontal reinforcement ratio is equal to 0.002 (ACI, 2010). Following equation 12, the calculations for the minimum reinforcement are as follows:

$$A_s = (.002)(12)(9.5) = 0.228 \text{ in}^2$$

The minimum required area of reinforcement is equal to  $0.228 \text{ in}^2$ , which means that one no. 5 bar is needed to reinforce the baffles.

#### ***4.5.3.2 Reinforcement of Weir-Pool Sidewalls***

The maximum  $M_u$  calculated for the weir-pool baffles was 5,224 ft-lbs. To calculate the reinforcement required the R value was found using equation 13.

$$R = 5,824/0.9(12)9.5^2 = 5.98$$

This R-value is low enough that when the moment capacity graph, see Figure 18, was consulted, it was found that the minimum reinforcement would be required. ACI 318 stipulates that the minimum horizontal reinforcement ratio is equal to 0.002 (ACI, 2010). Following equation 12, the calculations for the minimum reinforcement are as follows:

$$A_s = (.002)(12)(9.5) = 0.228 \text{ in}^2$$

The minimum required area of reinforcement is equal to  $0.228 \text{ in}^2$ , which means that one no. 5 bar per foot length is needed to reinforce the sidewalls.

#### ***4.5.3.3 Reinforcement of Denil Sidewalls***

The maximum  $M_u$  calculated for the weir-pool baffles was 5,224 ft-lbs. To calculate the reinforcement required the R value was found using equation 13.

$$R = 3,875/0.9(12)9.5^2 = 3.98$$

This R-value is low enough that when the moment capacity graph, see Figure 18, was consulted, it was found that the minimum reinforcement would be required. ACI 318 stipulates that the minimum horizontal reinforcement ratio is equal to 0.002 (ACI, 2010). Following equation 12, the calculations for the minimum reinforcement are as follows:

$$A_s = (.002)(12)(9.5) = 0.228 \text{ in}^2$$

The required area of reinforcement is equal to 0.228 in<sup>2</sup>, which means that one no. 5 bar per foot length is needed to reinforce the baffles.

#### 4.5.4 Shear Analysis

A shear analysis was performed to verify that the shear forces due to the water would not cause the structure to fail. The analyses of the weir-pool and Denil baffles resulted in very different shear values. The weir-pool baffle's shear analyses resulted in shear values of 19,782 lbs and 2,745.6 lbs. The value calculated through the tables from Moody's monograph was unusually high, so the alternate value was chosen to check the shear against. Equation 13 was used to calculate the shear capacity of a one foot section:

$$\phi V_c = (0.75)2(1)\sqrt{4000}(12)(9.5) = 10,814 \text{ lbs.}$$

As 10,814 lbs. is greater than the shear on the weir-pool baffles, 2,745 lbs., it was found that the baffles will not fail under shear.

The lower value of shear calculated for the Denil pool baffles was then checked against the shear capacitance. Although these baffles are made of fiberglass, the shear capacitance was calculated for concrete because the fiberglass baffles are placed into 2-inch slots in the concrete Denil sidewalls. It is more likely that the concrete located at the slots will fail than the fiberglass, which has a much higher compressive strength. The shear value calculated for the Denil baffles was 2,358 lbs. Equation 13 was used to calculate the shear capacity of a one foot section:

$$\phi V_c = (0.75)2(1)\sqrt{4000}(2)(24) = 4,554 \text{ lbs.}$$

The values for  $b$  and  $d$  of the equation were 2 inches and 24 inches, respectively, because the slots were 2 inches deep, and it was 24 inches till the next slot.

Next, the shear capacitance was checked for the sidewalls of the Denil and weir-pool passages. The dimensions, other than height, are the same for both walls, so the capacity was

checked against both simultaneously. Equation 13 was used to calculate the shear capacity of a one foot section:

$$\phi V_c = (0.75)2(1)\sqrt{4000}(12)(9.5) = 10,814 \text{ lbs.}$$

The weir-pool and Denil passage shear values were 2359 lbs. and 2746 lbs., respectively. Both of these values are much lower than the shear capacity, so it is clear that they will not fail.

#### **4.6 American Eel Passage**

The potential for eel passage normally exists when a fish ladder is built. American eels can survive outside of the water for several hours and crawl up the walls, rocks, and ground if necessary to make it to the upstream water source. This ability also makes a separate eel ladder generally unnecessary and only in cases where passage is imperative to their survival. The American eel has been a high priority animal due to its status on the endangered species list for the past several years (American Eel, 2009). Russells Mills Dam is perfectly suited for eel passage up the Denil passage, and therefore into the water below. Elvers, juvenile eels, should be able to make it through the culvert and into the weir-pool passage where, excluding high flow conditions where river velocities are too strong, they should be able to make it through the passage.

#### **4.7 Environmental Regulations**

Anadromous Fish Passage in Coastal Massachusetts is primarily regulated by the Massachusetts Division of Marine Fisheries (MA DMF). Under the MA DMF waterways used by anadromous fishes are subject to the General Laws of the Commonwealth of Massachusetts. Chapter 130 of the General Laws establishes specific laws for the supervision of a range of fish

including river herring in coastal waters and empowers the director of the DMF to create regulations for the protection of these species. (Reback, 2004)

Current state regulations are intended to protect existing populations while simultaneously being a useful resource to the public. In order to maintain these populations, fisheries have imposed a no fishing period and restrictions on daily catch (Appendix G: River Herring Regulatory Guide (Reback, 2004)). In addition to general state regulations, Sections 93 and 94 of Chapter 130 allow individual cities, towns or the creators of a fishery to develop their own regulations on individual fish with the approval of DMF. Section 19 of Chapter 130 gives the director of the DMF the authority to remove an obstruction to fish passage and to construct a passage at the expense of the property owner or local government. Sections 95 and 96 of Chapter 130 prohibits unauthorized taking of herring from created fisheries or passageways and prevents the seizure of herring after June 15 to allow for proper spawning. The other sections of this document outline regulations for other fish species travelling through/into this state. (Reback, 2004)

#### **4.7.1 Project Funding**

In order to pay for the projects the US Fish and Wildlife Service (USFWS) and the Massachusetts Department of Conservation and Recreation (DCR) must work not only within the regulatory limitations set forth by the State but within economic limitations as well. In order to obtain funding the project must be proved to aid in the area of fish passage and habitat loss. The USFWS focuses on the enforcement of federal wildlife laws, endangered species protection, migrating species management, restoration of national fisheries and wildlife habitats, and assisting foreign nations with their own conservation efforts. In conjunction with the local Department of Marine Fisheries and Department of Wildlife Conservation, local and national



organizations have the ability to get federal funding for projects of this nature. These organizations include the National Oceanic and Atmospheric Association (NOAA), the National Resource Conservation Service (NRCS) and the United States Army Corps of Engineers (USACE).

The NOAA is a federal organization that aims to maintain the oceans and surrounding atmosphere (connected waterways). Primarily the NOAA is a leader in sponsoring improvements to waterway systems throughout the US. By judging other projects and the NOAA website, the NOAA would be a great place to look for funding for both projects. The NRCS provides similar services as the NOAA although the NCRS primarily focuses on private land owners that are trying to conserve soil, water and other natural resources. They have aimed to provide scientific background and financial resources for a slew of environmental projects. If the NOAA is unable to provide significant support, the NCRS is the next available resource. The USACE is a national organization that provides a wide range of engineering services to the US. The USACE is a multifaceted organization that tries to incorporate all sides of a problem in order to fully understand each project. Because of their prestige and national attention hiring them to work on the project, as opposed to a private contractor, is generally less time and cost effective and therefore is the last line of offense in tackling this problem.

#### **4.7.2 Russells Mills Dam Regulations**

The Town of Dartmouth was issued an easement from local officials during the initial construction of the Russells Mills fish ladders that allow them the right at any time to construct, maintain, repair, replace and remove walls, stone or any other material affecting the area surrounding Russells Mills Dam. This takes off all pressure from surrounding agencies and political groups regulating Massachusetts waterways as long as ecological conditions are not

significantly affected. The agreement is seen in Appendix J: Russells Mills Dam Construction Agreement.

#### **4.7.3 Smith Mills Dam Regulations**

As Smith Mills Dam is a brand new project, the Town of Dartmouth's Departments of Marine Fisheries, and Conservation and Recreation must abide by state regulations. The necessary Massachusetts requirements are set by the Massachusetts Departments of Transportation, Highways, and Conservation and Recreation. The Mass Highway Department (MHD) uses thorough investigative tools seen in the Project Development and Design Guide (MHD, 2006). As a matter of focus Chapters 2, 8, 10 and 14 are essential to the Dartmouth project. Chapter 2: Project Development outlines the evolution of an original idea or improvement into the construction process. The MHD's guidelines on how to conduct meetings, allocate resources, contact necessary personnel and achieve an overall efficient planning and design process are designed to allow for maximum organization when including necessary groups, ironing out details and beginning the next step. Chapter 8: Drainage and Erosion Control outlines the best ways to maintain natural surrounding ecologic and hydraulic conditions. This chapter contains guidelines on how to prepare for storms and runoff, contain drainage and efficiently dissipate energy throughout the system. Chapter 10: Bridges outlines maximum traffic conditions and valuable bridge departments in MA. Bridge standards must be maintained via this pathway. Chapter 14: Wildlife Accommodations outlines the potential effects on the surrounding environment as well as ways to minimize negative side effects caused to specific habitats, land areas and species. (MHD, 2006)

The design must meet the MHD Project Development and Design Guide (2006). These standards were made in conjunction with the MA Highway and the MA DOT for all construction

projects affecting public land or interests. The US Army Corp of Engineers design requirements essentially mimic the state standards and function to oversee and maintain those requirements post-production.

## **5 Conclusions and Recommendations**

The main objectives of the project were to establish attractive and effective fish ladders in order to provide successful fish passage of river herring through the watershed while minimizing ecological effects and economic burdens. This section outlines any conclusions or recommendations that were determined through the investigation of the Russells Mill and Smith Mills Dams.

### **5.1 Russells Mills Dam Recommendations**

The first objective at Russells Mills Dam was to analyze the current fish ladders to determine why the river herring were not passing. The second objective was to determine what modifications were necessary to re-establish an attractive and effective fish ladder for the river herring. The optimal passage modifications were decided upon by evaluating the economic and environmental effects of the design solution.

After thorough hydraulic and hydrologic analyses, it was determined that the Denil passage was the section that was most detrimental to the effectiveness of the fish ladder. The Denil passage had three issues of concern: the slope of the passage was too high, its entrance was in an area that was too turbulent for fish, and the velocities in the section were frequently too great for the herring to pass.

Therefore, to address these issues the following adjustments are recommended. First, to reduce the amount of water that flows through the Denil passage, and therefore reduce the velocity, it is recommended that the dam height be raised on the right side of the dam by 4 inches. This will divert water away from the right channel, which contains both fish ladders, and into the left channel. This occurs because as the river experiences higher flows, the water level rises. Raising the dam on the right side, but not the left, will result in more of the higher flow

going through the left channel, circumventing the weir-pool and Denil passages. The effect of this modification on the relationship between the river's flow and the Denil passage's water velocity is plotted in Figure 25. The graph shows that the velocities will be lower in the modified passage. This results in a wider range of river flow values that the herring will find passable.

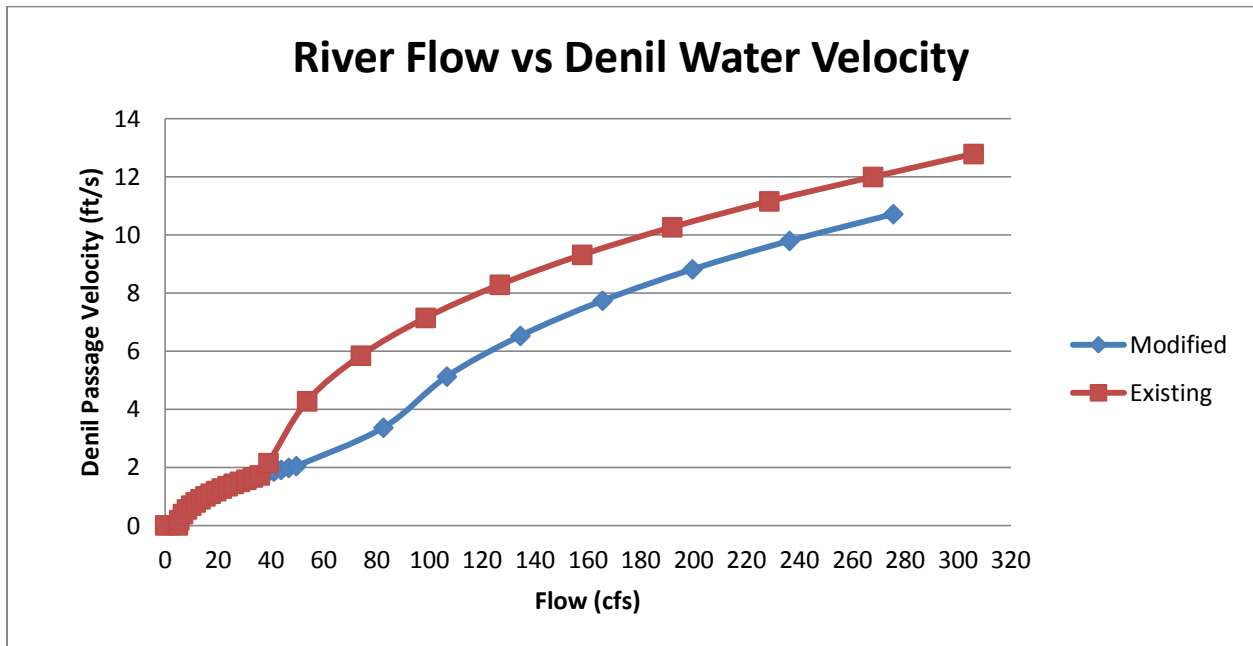


Figure 25: River Flow vs Denil Water Velocity

Second, the slope of the Denil section needs to be decreased as river herring require a slope of less than 15% to be capable of passing. The current slope in the passage is 16.7%. To decrease the slope of the Denil passage and give it a more attractive entrance, it is recommended that the Denil passage be extended 7 ft, and the baffles be modified to create a lower slope. This is illustrated

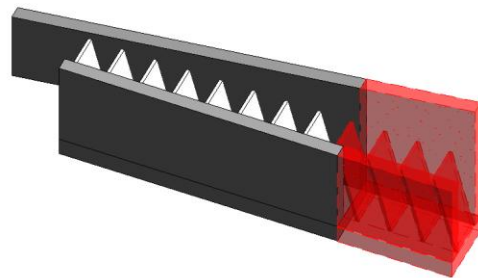
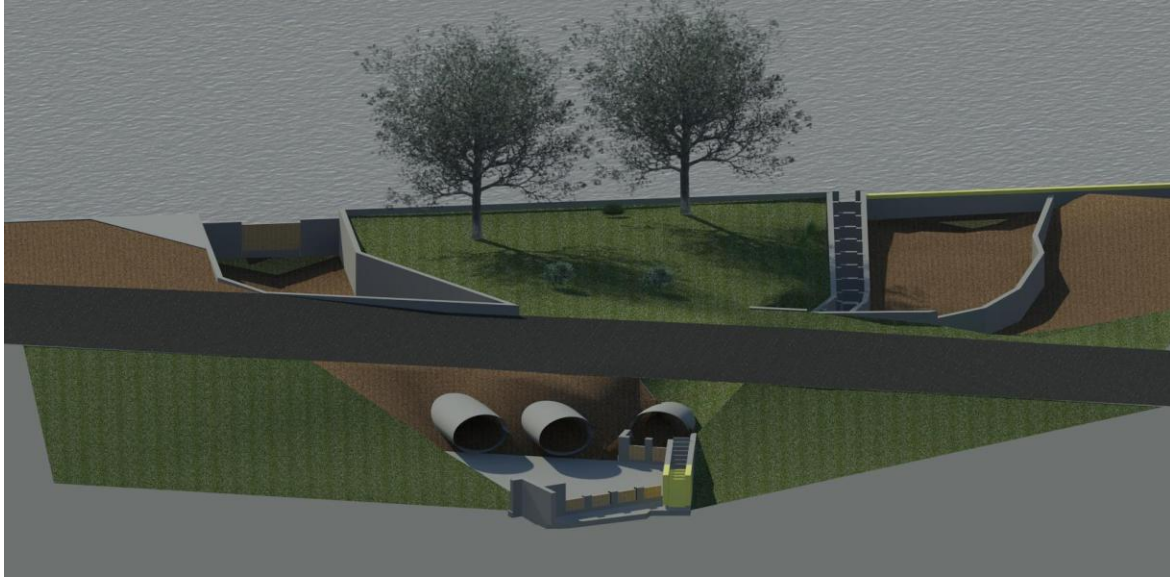


Figure 26: Denil Extension

by Figure 26. Extending the passage will decrease the slope from over 15% to 12.5%, which is a much more desirable angle. Additionally, the extension of the passage places the entrance farther into the river where the water is calmer.



**Figure 27: Russells Mills Dam Recommended Modifications**

These two recommendations, shown by Figure 27 with modifications in yellow, will help increase the likelihood that river herring will be able to traverse the Russells Mills Dam and continue up the Paskamanset River to begin spawning. As a final recommendation to ensure fish passage, it is recommended that annual maintenance be given to the passage prior to spawning season as debris can cause damage to the current structure over the years. Removing detritus build up, and checking for cracks or other flaws can go a long way in helping the herring have the best chance at getting over the dam.

## **5.2 Smith Mills Dam Recommendations**

Smith Mills Dam is currently without a fish ladder but has sufficient space to design passage if river herring are able to make it upstream of Russells Mills Dam. The current conditions of the pond make for suitable habitat for herring spawning but currently do not have a passable dam. The park above has been quoted as “a gorgeous place to listen to the hypnotic, steady stream of water running by and capture some amazing wildlife smack dab in the middle of

the busiest part of the Town of Dartmouth” (Silva, 2013). One of the local homeowners would like to see fish passage restored to the area as an added aesthetic benefit.

The topography of the Paskamanset River directly below Smith Mills Dam makes it an ideal location for a nature-mimicking fishway. There is sufficient area downstream of the dam to produce a slope that could reach the peak of the dam. A horizontal length of 45 feet from the dam would produce a change in height of about six feet. This length can be seen in Figure 28. If a nature-mimicking fish passage were built into this area, maintaining the existing elevation at the base, it would produce a slope of 13%.

To design the step pools of a nature-mimicking fish passage according to the U.S. Fish and Wildlife Service recommendations, the step heights should be limited to less than one foot in order to maintain drops that would be acceptable for both blueback and alewife herring (EA Engineering, 2007). Creating a passage with step heights of one foot would require six steps to reach a vertical height of six feet. In order to utilize the entire horizontal length, the six steps could be a maximum of 7.5 feet.



Figure 28: Smith Mills Dam Aerial View

(Google Earth, 2012)

To construct a nature-mimicking fish passage, numerous stones of varying sizes are required. The stones should be large and heavy enough to stay in place during high flow

conditions. Ideally, rectangular stones are used to maintain relatively uniform shapes and consistent roughnesses (EA Engineering, 2007). The streambed below the dam at Smith Mills already has many stones of varying sizes and shapes. Using these stones will help minimize the cost by reducing the amount of resources to be purchased.

### **5.3 Alternative Research**

The Buzzards Bay Drainage report (Reback, 2004) indicates, on page 118, the same problems with the Denil passage as found in the MQP report. Conclusions in this report are in line with the DMF findings 1 and 2 (Appendix H) which state that “fish passage must be improved either by full or partial removal of the obstructions or by construction of efficient fishways.” More specifically it recommends that Russells Mills Dam’s Denil passage must be extended in order to be more noticeable for herring in the Paskamanset River. Permits for such reconstruction at Russells Mills Dam have been established and maintained since its original construction but progress was not made to further the conclusions made in 2004. Environmental consideration and improvement plans have historically been met with insufficient funding and other priorities from local politicians. More importantly, current research indicates that the Denil passage be extended further than originally planned. Furthermore, that flow, specifically during high flow conditions, should be minimized through the Denil passage and therefore a small addition to the dam should be made. (Reback, 2004)

### **5.4 Future Research**

Future research that could benefit the restoration of fish passage to the Paskamanset River include: further investigation into Smith Mills Dam, restoration efforts on the river at



Turner's Pond Dam, efforts to restore American Eel passage, further assessment of the upstream habitats, and investigation of dam removal. These would all greatly increase the possible effectiveness of changes along the watershed to aid in restoring passage to migrating marine life.

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WPI

# Fish Passage Restoration on the Paskamanset River

*Proposal*

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Presented to Professors  
Leonard Albano  
Paul Mathisen

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by  
Nathaniel Eames  
Richard Breault  
Aaron Sabbs

## Abstract

River obstructions, such as the Paskamanset River mill dams, are large contributors to the decline in the population of river herring in Massachusetts. Creating bypasses for these river obstructions will benefit the herring by allowing them to migrate to suitable spawning grounds. Designs will be created for these bypasses through hydraulic and structural analyses of the dam locations. Additionally, an ecological assessment of the fish and surrounding areas will be accomplished. The deliverables from this project will include a written report, CAD drawings, and a cost estimate.

### Authorship and Acknowledgements

The proposal was completed by three students, two civil engineering majors and one environmental studies major, Nathaniel Eames, Aaron Sabbs, and Richard Breault, respectively. It was completed during A and B terms of the 2012-2013 academic year. Research and writing involving dams, fish ladders, and environmental constraints was done by Richard Breault. Site Conditions and Structural information were researched by Nathaniel Eames and Aaron Sabbs. Additional writing was completed collaboratively as a group effort. Further contributions were made by Lauren Mickelson, including data collection and hydraulic design.

The advisors for the project are Professors Leonard Albano and Paul Mathisen. Professor Albano mainly provided guidance in terms of the structural aspects of the project, while Professor Mathisen generally focused on the hydraulic and hydrological aspects.

Additionally, we would like to thank Mr. Brad Chase of the Massachusetts Division of Marine Fisheries and Michael O'Reilly, the town of Dartmouth Environmental Affairs Coordinator. Mr. Chase and Mr. O'Reilly both provided us with valuable information regarding past surveys, site layouts and herring.

## Introduction

In the Buzzards Bay watershed in Massachusetts there are over a thousand acres of ponds and hundreds of miles of streams. Before being settled by colonists, these bodies of water were important for the fish species that spend their life cycle in both fresh and marine waters. The two anadromous species of interest in this particular river system are the river herring, specifically alewife and blueback herring. These species' populations have declined considerably over the past two centuries. River obstructions, mainly the extensive construction of mill dams during the American industrial revolution, are a large contributor to the decline in herring population. Creating bypasses for these river obstructions will benefit the two species of herring by allowing them to migrate to suitable spawning grounds.

### 1.1 Project

The focus of this project is on the Paskamanset River, which flows 10 miles from Turner Pond through the Town of Dartmouth to Buzzards Bay. Two reservoirs are formed along its course. The farthest upstream, Smith Mills Pond, is formed by a 3.5-foot stone and concrete dam. The lower reservoir, Russell's Mills Pond, is formed by a seven foot concrete dam. Russell's Mills Dam also has an ineffective 60-foot fish passage. The purpose of this project is to analyze the current conditions of each dam and design a fish ladder that is capable of restoring passage for blueback and alewife herring.

### 1.2 Capstone Design

This project will be authored by three students from Worcester Polytechnic Institute working on the Paskamanset River fish restoration project. Two are majoring in civil engineering with focuses in structural engineering, and the third is an environmental studies major. During



the project each person must complete a capstone design requirement. The project entails a series of designs for two fish passages and a cost analysis of each.

All students will learn all aspects of the project, but each will become more familiar with certain topics as they are major dependent. The environmental studies major will focus on the ecological factors that go into fish passage design. This includes an in-depth study of the two species of herring, an assessment of all legal parameters and environmental regulations, and an evaluation of the impact of the fish ladders on the local environment. In summation, this will cover ethical, health and safety, and social and political issues. Together, the group will analyze the hydraulic aspects involved in the fish passage design. This is comprised of an analysis of the current hydraulic characteristics of each dam, and a determination of the actual hydraulic requirements needed for herring to successfully traverse the fish passage. This is a sustainability issue. The civil engineering majors will produce the structural designs for the fish passages, determining the optimal concrete mixture necessary, and ensuring that the structure is designed so that it will continue to be effective for an extended period of time. This is also a manufacturability and a health and safety issue.

The constraints on this project are primarily political, economic and environmental. The political constraints stem from the laws and regulations that surround the construction and maintenance of fish passages. The size and complexity of the project is limited by the economic capabilities of the Town of Dartmouth. The size and construction of the passages is also limited environmentally. The environmental impact of the work must be kept at a minimum, as the purpose of the project is to increase numbers of wildlife and not reduce.

## 2 Background

In order to fully understand the scope of the project, background information regarding the building of dams and fish ladders, particular inhabiting species, current site conditions (structural and ecological) and possible design alternatives were researched.

### 2.1 Data Collection

A series of tools will be used to take measurements while on site visits. It is important to understand what these tools are, and how they work. In order to properly measure the velocity of the river flow at each weir and at the entrance and exit of each ladder a velocity probe was used. This probe measures the speed of the water by gauging how much water flows through a rotating sensor. The United States Geographical Survey (USGS) collects flow and quality data, which will be used. Surveying equipment was used to measure elevations and distances of the ladders and the surrounding areas.

### 2.2 Purposes of Dams

Installation of dams into the environment has been done for centuries in order to utilize the natural landscape to a human advantage. Throughout history dams have been used for irrigation, hydropower, water supply, flood control, recreational use, navigational purposes and fish farms. Because dams fragment aquatic ecosystems they can negatively affect species inhabiting the watershed containing the dam. The breakdown of dams is seen below in Table 1.

Dams are considered obstructions to the natural ecosystem. River fragmentation by these man-made structures can eventually lead to the decline of inhabiting species if not resolved in an appropriate manner. Species that require passage are travelling upstream for a natural, biological reason and any change in that cycle affects the entire ecosystem surrounding the entire watershed.

### Dam Use in the United States of America

| Dam Use   | Percent of Total Dams |
|---|-----------------------|
| Irrigation (Diversion)                            | 48%                   |
| Hydropower (Diversion)                            | 17%                   |
| Water Supply (Storage and Detention)              | 13%                   |
| Flood Control (Diversion, Detention and Overflow) | 10%                   |
| Recreation (Storage)                              | 5%                    |
| Navigation + Fish Farm (Storage and Diversion)    | ~1%                   |

(ICOLD, 2011)

### 2.3 Types of Dams

Due to the widespread uses of dams there are many different way to construct a dam. Each dam can be classified by use: storage, diversion, detention or overflow. Storage dams are used to temporarily hold excess water. This could be to hold drinking water, stock fish populations, supply hydroelectric power etc. Diversion dams are generally used to provide a path into a reservoir or irrigation. Detention dams are used solely to hold back flood waters or a reservoir. Overflow dams are designed with a spillway system as well as with enough structural integrity to withstand water flowing over the dam when overflow cannot be contained by a spillway alone. These dams are designed to be much more durable than the average dam as the forces on them are larger and more continuous than a dam not containing a spillover mechanism. Moreover a dam with water flow over the top must be designed to maintain these conditions whereas other kinds of dams do not need to fit this kind of requirement. (NWC, 2010)

Structurally dams are made to fulfill the requirements of each area. Several design options are available: earthfill dams, rockfill dams, gravity dams, concrete arch dams and buttress dams. Earthfill dams usually are constructed with a spillway to stop overflow. These dams must be made of a water-impermeable material and can contain a sub-surface water cut-off wall. In order to build a dam of this nature there must be a dry area for work which would require diverting the river while construction took place. Rockfill dams use rocks to create a wall with some sort of water-impermeable over-structure (concrete, steel, clay, etc). Gravity dams use the gravitational force acting on the water to hold it in place. The mass of the dam is used to resist the lateral forces due to the water. These dams are made of concrete in order to hold back massive quantities of water as they must provide the most impassible dam design. If a gravity dam is constructed incorrectly, overflow and tipping of the dam can occur. Concrete arch dams are only used in narrow canyons where other types of dams cannot be constructed. The canyon is used to divert pressure on the dam and can provide invaluable support. These types of dams are less expensive and more reliable than a gravity dam. Buttress dams are concrete dams reinforced with steel buttresses on the downstream side of the dam. These require less concrete as the dam can be less supportive and rely on the support of the buttresses and surrounding land masses. Overall each type of dam is used to meet specific requirements of the land and use of water. (Hassam, 2011)



Weir-Pool (2001)

## Fish Ladders

Allowing proper migration of species or allowing fish to fill a pond/reservoir as food stock is a major problem with dam construction. The end design of the ladder must fit these needs as fish are biologically coded to travel upstream but not necessarily intelligent enough to use a ladder if it is not properly applied to the landscape. Ladders must also fit the requirements of the natural habitat as nature provides constraints as well. With the varying conditions of the water system and passing species, various types of fish ladders have been developed. These are weir-pool passages, Denil passages, vertical slot passages, steep pass passage and natural passages. (Save the Bay, 2002)

### 2.4.1 History of Fish Ladders

A fish ladder structure of sorts, thought to be the world's oldest ladder, happens to be located in Egypt (~4000 years old) where some of the first aqueducts and dams ever made are also found. As is done today, dams were built for irrigation and drinking water. Although these structures are there, the reason for their existence is unknown because no written history can be found that specifically describes fish passage in the region. The first historically documented ladder is found in France and was built in the 17<sup>th</sup> century but of course current materials were not available so ladders were constructed by wood. (Griffin, 2009)

### 2.4.2 Importance of Fish Ladders

Ecological conditions change on both sides of a dam. In order to successfully bridge the gap made by a dam fish ladders are constructed to allow the fish proper seasonal migration habits upstream. This kind of problem has been seen throughout human history as fish have always been a major source of food. In the 1700's, when fish ladders first began to arise in this country, a group of Native Americans filed lawsuits against possible dam construction companies as they knew it would disrupt the flow of fish throughout the watershed. Fish ladders have been

important throughout history and continue to be integral in the conservation of fish species throughout the United States.

Originally fish ladders were used before the full nature of the travelling species and environments were known. As specific biological processes per species have been further researched and better understood, it has become easier to successfully produce fish passages. Fish ladders are designed to allow safe passage of fish when their original path has been obstructed by a dam or roadway. Each ladder needs to meet specific requirements to suit the species traveling the waterway. In order to meet the needs of different species individual characteristics of the river can be changed using different kinds of passages and dams. Passages are used to control some of these characteristics (flow rate, temperature, stream size, etc.) in order suit the needs of the passing species (population size, mating habits, preferred habitat, etc.).

Problems can arise when trying to pass multiple species at once as each species requires a specific water velocity range. Rapids are considered good in some situations because they provide a natural feeling to the passageway. Moreover when trying to pass many different species this rapid cycling water flow is good because it provides a place for a wider range of fish than if it was kept at a smaller range (less rapid) (Griffin, 2009).

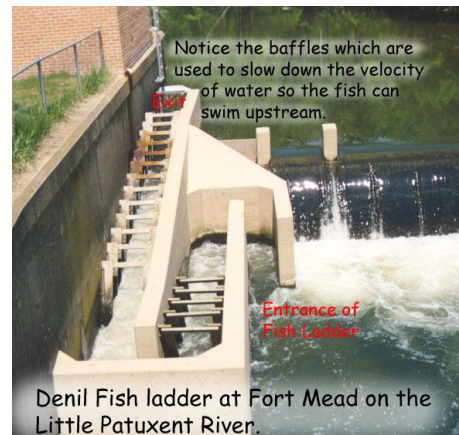
The Denil passageway, as described below, has baffles that make a rapid-like effect to the flowing river. The weir-pool passageway has a similar kind of construction where the side of each pool connector piece to the next pool has a baffle like design which causes the same rapids effect. This provides the water flow with a variety of water velocities through each individual baffle or weir, which can be good for a number of reasons: higher availability of sufficient water speeds for varying species and a more natural feel (increased attractiveness) to passing species. This rapid type of water flow also has some disadvantages. Species such as the American Eel

cannot travel up these kinds of ladders because the water flow is far too rapid for them to cling onto the passage walls. In that case the rapids would either have to be lessened or removed to allow proper passage in the same passageway. An efficient rapid design is one that incorporates a variety of water speeds as well as seeming to flow in a natural way that attracts fish to the passage.

### 2.4.3 Weir-Pool Passages

Weir-Pool passageways are constructed with individual pools separated by walls or weirs in order to provide a slow and steady movement up the ladder. These passages can be made of wood, concrete or aluminum depending on the species travelling and the necessary conditions of the passage. Each material has physical properties that can make the ladder better depending on the passing species and physical area the ladder must be built in. These various materials all affect the passage by changing the physical makeup. This comes down to ladder attractiveness per species. For example, an aluminum ladder may be less attractive due to its metallic qualities or the way the water flows through it. A weir-pool passage is one of the first passage designs to be used but has lost popularity because it only provides passage for fish that jump due to the

movement from one individual pool to the next.



Little Patuxent River

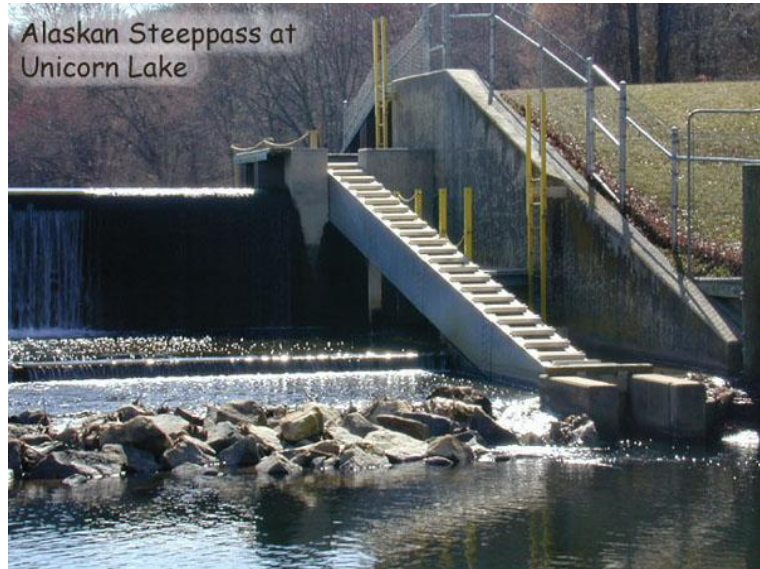
### 2.4.4 Denil Passages

Denil passageways are designed as a downward slope into the downstream river. This structure can be concrete or aluminum (retrofitting). Denil passageways are very dynamic fish ladders, that can be used by many species of fish. Baffles on the ladder regulate the speed of the water, allowing for a wide range of upstream conditions. The baffles create turbulent water flow,

simulating rapids in the fish ladder. Rest pools can be installed for longer sections. These passages can be used on nearly any size dam.

#### 2.4.5 Vertical Slot Passages

Vertical slot passages are usually used at large barriers. The name comes from the narrow slots that are used to regulate water speed and depth. This passageway results in a constant flow at all depths of water which makes it difficult to cause changes in upstream water surface elevation. Vertical-slot ladders are more complicated than weir-pool ladders but they allow for a wider range of species to pass, assuming the current is not too fast.



#### 2.4.6 Steeppass Passages

Steeppass passageways (also known as the Alaskan Steeppass) use baffles to create rapids in the same way Denil passageways do. This gives fish many options of water speeds, allowing a number of different species to pass through. They are often pre-fabricated out of metal (typically aluminum), and are usually made narrower than Denil passageways. Steeppass passageways are inexpensive fish ladders that are easy to install and maintain. They work best at small barriers. Maintenance personnel are able to adjust to a range of upstream surface elevations by changing baffle size.

Unicorn Lake

#### 2.4.7 Natural Bypass

Natural bypasses look almost exactly like a natural stream. If designed and constructed properly they are able to accommodate all species of fish. A stream channel is made to bypass a barrier, using natural materials. This method of bypass can provide a stream habitat within the



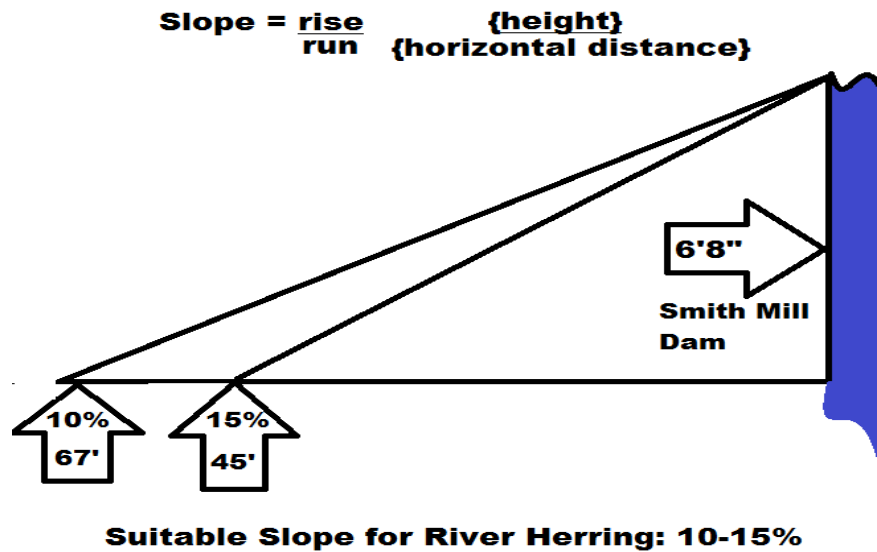
fishway and with proper design can even allow canoeing or boating across the fishway. Natural bypasses can be used on any size river, although it takes up more room than any other type of fishway.

### Fish Constraints

Each fish ladder must be constructed to fit the requirements of important passing species. That determination is made by those in charge of designing and building the ladder as there are guidelines for successful passage depending on the exact motive of the ladder. Some ladders are designed specifically for a specific passing species or a specific time of year opposed to being open year round or for any travelling species. The velocity of water coming down the passage is very important as fish can only overcome fast water velocity for a short time, physiologically.

The ladder design for Dartmouth, MA must fit the requirements of river herring. These species are

not strong jumpers but do have a relatively strong swimming speed. For successful alewife migration upstream the flow must be less than 1.5 m/s. In order to provide proper passage the slope of the staircase (rise/run) must be in the form of approximately 10-15% slope (see figure above). Swimming speeds are classified into three major types: burst (darting), prolonged (cruising) and sustained speeds. The burst speed is one where the fish can only travel for up to 30 seconds before it fatigues. Prolonged speed is one where the fish can travel from 30 seconds to 200 minutes with little fatigue throughout the journey, ending with fatigue. Sustained speed is a



general maintainable speed that results in virtually no fatigue to the fish. These speeds are important when assessing design options such as possible resting pools, ladder steepness and passage and culvert lengths. (Richardson, 2004) [see tables in appendix D]

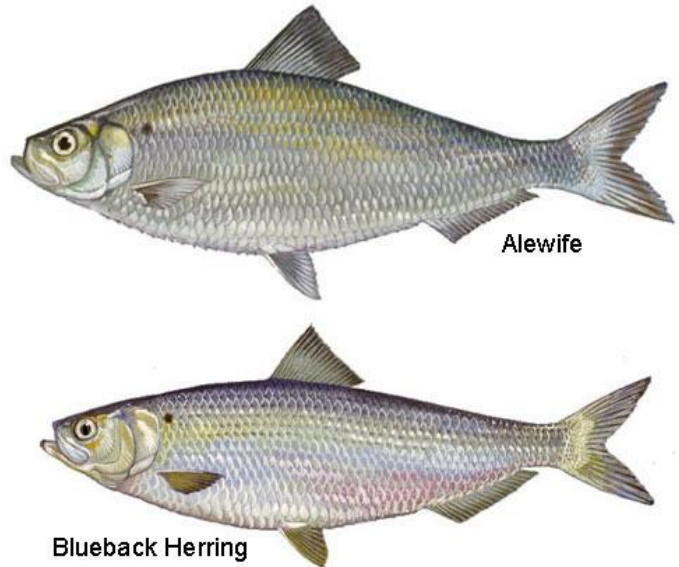
New structures must provide successful fish passage and maintain river continuity. Any water flow that contains a species of concern must be connected to the watershed. In the best conditions the area designed for these fish does not affect the surrounding environment and can fully encompass their natural habitat. In order to meet specifics of the area in question culverts can be designed to change the physical water flow culverts can be designed to make the flow feel more natural to the travelling species. Culvert design specifications can be seen in Appendix C. When replacing a structure the design must improve the quality of the passage of travelling species and continue to provide proper crossing of the species up the watershed. When replacing culverts must meet General or Optimal standards at this point (see Appendix C) barring any constraints at the site. All structures, new and old, must minimize overall changes in the water system as far as flow and environmental quality are concerned. Construction standards are used to maintain storm-water, erosions, sediment, pollution, and soil and vegetation control around an affected area.

#### River herring

Generally river herring refer to a combination of two species of herring: alewife and blueback herring. River herring are classified together because of their many similarities and migratory habits. The most distinguishable features are of the physical characteristics between the fish. Both fish are a silvery color with variation along their bellies and spine but the backside (dorsal region) of the species differ in that the alewife has bronze coloration while the blueback, staying true to its name, has bluish-green coloration. The underbelly of the Alewife is pale with

dark brown dots spotting its scales. Blueback herring on the other hand have a dark brown or black underbelly. Alewives have a slightly smaller average body size and therefore a more compact swimming technique. As time goes on and adult fish go through the spawning process a mark is recorded on their scales to record the amount of spawns the fish has had throughout its lifetime. (Capossela)

Blueback herring (*Alosa aestivalis*) are an Anadromous (hatch in fresh water, migrate to salt water, spawn in fresh water) species that migrate up to 1,200 miles each year to come into the Eastern fresh water system. Alewife on the other hand (*Alosa pseudoharengus*) can be both Anadromous and landlocked as they are better capable to survive in



Capossela, River Herring

fresh water systems. These fish have a spawning season (laying and fertilizing of eggs) that lasts from February-May that stretches from Newfoundland to Florida and can contain 60-103 thousand eggs per fish. Juveniles usually stay in the fresh water until late spring/early summer to feed. As fall approaches river herring head to the salt water until the following spring when they start over the spawning process and migrate inland. The decline of these species, caused by loss of proper habitat from dams, degradation, fishing, and predation, has forced the government to place them on the list of species of concern, which is one step away from being environmentally threatened (the intermediate step between concern and endangered). (Alewife, 2011)

The spawning period is determined by water temperature changes and photoreceptive elements of the fish itself. These biological aspects allow for fish to know when to begin migration and continue upstream. Overall ladders are seen as detrimental to proper behavioral habits hence why natural bypasses are being argued as the best solutions to date, although they are not feasible in every situation.

Proper habitat requirements are specific for the larval, juvenile and adult stages of the fishes' lives. The main sources of food for the adult river herring include phytoplankton, fish eggs, and small insects. The juvenile and larval stages (0-4 years old [US Fish and Wildlife Services, 2002]) require small crustaceans called cladocerns and copepods (phytoplankton). River herring are found in every water type on the East coast (lakes, ponds, streams, rivers). These areas can contain varying ecological characteristics (sand, assorted vegetation, swamps, intertidal zones etc) all of which are suitable for river herring. All in all habitat suitability measures the most important values of the water quality such as temperature, sediment, contaminants and salinity. Studies imply that an average salinity of less than 12 ppt and that more than 100 phytoplankton per liter of water is suitable for proper development during spawning season. (Pardue, 1983)

Water quality is a major part of any fish habitat. The average adult living conditions range from 2-17 degrees Celsius (35.6-62.6 degrees Fahrenheit) and a depth of less than 100 meters (328 feet) (average adult living conditions). The spawning temperature ranges from 10.5-26 degrees Celsius (50.9-78.8 degrees Fahrenheit) but is seen to function best at 12-16 degrees Celsius but spawning ceases all together at any temperature greater than 27 degrees Celsius. (Pardue, 1983)

The suitability of the egg itself differs for the alewife and blueback herring. Alewife eggs spend 2.1-15 days (80-95 hour average) at an average of 28.9-7.2 degrees Celsius respectively. Blueback eggs spend 1.5-3.9 days (38-60 hour average) at an average of 23.7-20 degrees Celsius respectively. Although there is a specific temperature range eggs can survive at because of their structure, they are extremely tolerant to changing conditions such as salinity, flow, sediment etc. (Survey, 2004)

If there is not sufficient room to rest in a passage a resting pool is necessary every 20-40 ft horizontally or 6-9 feet vertically in order to provide sufficient time for fish to reenergize. Channel width is determined based on average fish size and the average flow of water through the passage during the target season. Channel width should range from .5-1.5 meters (DVWK, 2002). The water level of the passage must be high enough to attract the fish to the passage (to provide a flow around the approximate average traveling speed. It is important to note that a powerful stream must be created in order to attract species to the area. The flow down the passage must seem like a natural environment to get full attractiveness of the fish. The depth of a pool can change as you travel up a ladder containing pools. A proper pool should have an inflow wall depth of 3-5 feet while the outflow depth should be 2.5-4.5 feet depending on the velocity requirements of the fish. (DVWK. 2002)

Characteristics of both the travelling species and water conditions are extremely important to the successfulness of the structure per each individual organism. These characteristics include water temperature, water turbulence, water flow rates, energy dissipation, distance of passage, size of pools (if applicable), size of passage, animal endurance, passage attraction, ease-of-access, individual body length, average travelling speed, and most importantly maximum burst speed. In order for species to utilize their maximum burst speeds appropriate

resting areas must be present if fatigue can occur. Due to all of these conditions at any given pool or part of the ladder there will be a percentage of fish that will not pass. Because the average swimming speed for river herring is at 1.5 m/s this would be the optimal average speed of the passageway. (Richardson, 2004)

The average fork length of a river herring is approximately 15 inches (38 cm). In order to design a successful passage, various water speeds should be available for passing species. Tables D-1, D-2 and D-3 1 in Appendix D offer suggestions on varying speeds of travelling river species to show the range of speeds that could be necessary in a passage. There happened to be fish used in the experiments that measured around 15 cm and therefore were assumed to be in the juvenile-adult age range. The swimming speeds of these fish increase as maturity increases (over time). The average burst speed was .347 m/s for juvenile blueback herring and .636 m/s for juvenile alewife (Richardson, 2004). These numbers rapidly jump when these juveniles enter early adulthood to 2.5 m/s for blueback herring and 2.75 m/s for alewife. Maximum burst speed (coinciding with full, proper development) can reach up to 4.84 m/s for blueback herring and 4.54 for alewife.

### 2.5.3 American Eel

The American Eel is known as catadromous (hatch in salt water, migrate to fresh water, spawn in salt water) An alternative Eel ladder or natural rock design for eel passage can be of low cost and easy to install because eels can travel a significant distance with minimal water. The swimming capability of the American Eel (both adult and glass eels) is certainly lower than that of other



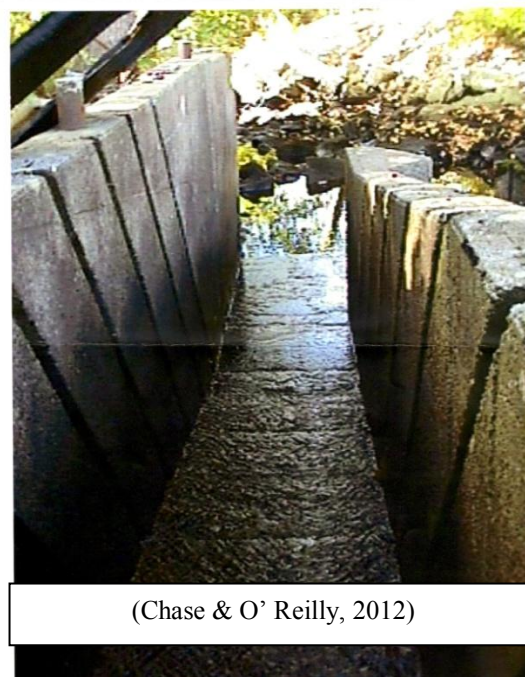
travelling species. The eel can grow to a much longer length than river herring but until maturation (which happens after the upstream translocation) eels have much weaker swimming abilities. The maximum burst speed of the American glass eels is a mere .40 m/s. It has been observed that the glass eels can use existing rough-surfaced natural structures (such as logs or rock based pathways) to utilize the passage when velocity is too high to overcome. Therefore even at water velocities over their maximum burst speed for completely vertical line-of-motion, glass eels can utilize a particular passage. As well as adapting those conditions eels are known to travel up the side of rock walls along the side of dams as long as they are kept wet enough and lead into the proper progressive habitat.

## 2.6 Site Conditions

Each dam has unique conditions to it that will make the designs for each very different. Russells Mills Dam has an existing, ineffective fish passage and a road passing over it, while the Smith Mill Dam is much smaller and has no existing fish passage. Each dam will require an individual solution to fix the fish passage problem.

### 2.6.1 Russells Mills Dam

Russells Mill Dam is located on the Paskamanset River on the eastern shore of Russells Mill Pond in the city of Dartmouth, Bristol County, in the state of Massachusetts. The dam is located at the latitude of  $41^{\circ} 34' 16.661''$  N and at the longitude of  $70^{\circ} 00' 16.430''$  W. It was rebuilt in 2001. The spillway is 6 feet high



(Chase & O' Reilly, 2012)

and 25 feet wide. Currently, the dam has two ineffective fish passages: a Denil passage made of concrete and fiberglass, and a weir-pool passage made solely out of concrete. The situation for this dam is unique in that there is a road, Rock O'Dundee Road passes directly over the section of the passage between the Denil and weir-pool passages. The road necessitates a culvert between the two passages. The drawings of the upper and lower parts of the passage are included in Appendix A.

#### 2.6.1.1 Structural Conditions of Russells Mills Dam

The concrete mix that was used for the Russells Mills Dam was designed according to ACI and ASTM standards in 2001. The maximum water cement ratio was 0.48. The minimum design strength required was 4000 psi. The maximum aggregate size allowed was 1.5. Air was entrained in the concrete to produce an air content of four to six percent. Lastly, the concrete mix included an water-reducing admixture with no chlorides in it.

The reinforcement required for the concrete was determined from the ASTM Standards. The reinforcement used at Russells Mills Dam was Grade 60 deformed bars. The bars were epoxy coated, and surrounded by 2 inches of concrete on the top and side, and 3 inches on the bottom.

#### 2.6.2 Smith Mill Dam

Smith Mill Dam is located on the Paskamanset River in the Town of Dartmouth, Bristol County, in the state of Massachusetts. The dam is located at the latitude of 41° 38' 24.271" N and at the longitude of 70° 59' 06.675" W. The dam was constructed in the 19th century and is made out of granite blocks. The water flows over the dam but is dissected by a stack of granite blocks. On each side of the granite outcropping the dam extends approximately 25 feet out. There is currently no fish passage at the dam. Additionally, it should be noted the land that the dam is located on is owned by the local Midas.



## 2.7 Hydraulic Design

The field data, along with the data at the gage site will be used to calibrate calculations.

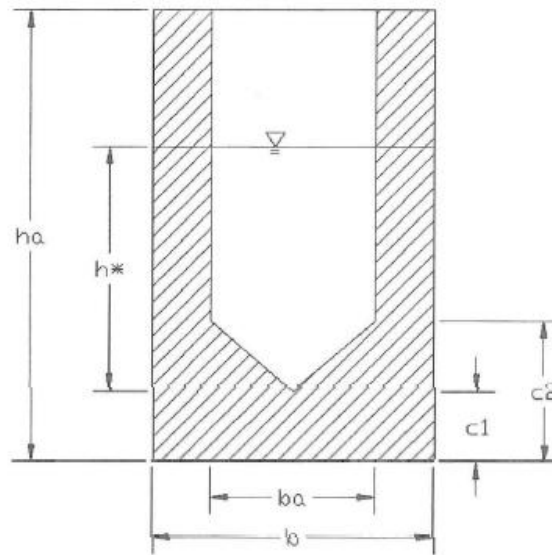
This data can be applied to the appropriate equation. The equation for the velocity of the water running through a Denil passageway is:

$$v = \frac{Q}{A} = \frac{Q}{(h_* \times b_a)} \quad (1)$$

Where

$$Q = 1.35(b_a)^{\frac{5}{2}} \sqrt{g \times I} \left(\frac{h_*}{b_a}\right)^{1.584} \quad (2)$$

According to the figure:



For a weir-pool, the velocity equation is as follows:

$$v = \frac{Q}{0.67 \times L \times H}$$

Where

$$Q = kA(2gh)^{0.5}$$

Where k is the flow coefficient, A is the area of opening, g is the acceleration due to gravity, and h is the head differential.

The inlet and exit velocities are also important. Attraction velocities at the inlet should be approximately 8 feet per second. Cross velocities should be no more than 2 feet per second, and

auxiliary water velocities should be between 0.5 and 1 feet per second. Approach flow should be parallel to the axis of the fishway entrance or at least no greater than 30 percent to the axis of the main current. The length of the exit channel should be a minimum of two standard ladder pools (Fish Passage and Screening Design). (Engineers)

The velocity of the water in the passageway needs to be calculated (and eventually altered) in order to allow the herring to swim through the passage. A fish of fork length  $x$  can swim at velocity  $y$ . If the velocity of the water in the fish passage exceeds velocity  $y$ , then the fish cannot overcome it, and traverse the passage.

#### Reconstruction vs retrofit

Two general options are available to restore fish passage to the Denil passageway. The Denil structure below Rock O'Dundee Road can be reconstructed or retrofitted with a prefabricated structure. Any type of reconstruction will likely be the more expensive than simply retrofitting a prefabricated structure on the current section.

#### 2.8.1 Reconstruction

Reconstruction options include replacing the entire structure with an alternate design, consolidating the channels, and creating a natural fishway.

One option for restoring fish passage to the Russells Mill Dam would be to reconstruct the Denil passageway. This would be an expensive project because it would include both the deconstruction and reconstruction costs. The deconstruction cost will be complicated because the pond would need to be drained to below the dam level, so that the concrete can be laid on a dry riverbed. There is also a difficulty with this option where the road is concerned. Rock O'Dundee Road crosses over the culverts at a point between the weir-pool and Denil passages. This would cause many issues during the construction and deconstruction processes as access to certain parts

of the streambed would be limited. Design work and a cost analysis will need to be performed to determine the viability of this option.

Consolidating the two separate channels is a possibility that could theoretically have a great impact on fish passage. Currently, the main channel of the dam separates from the fish ladder downstream from Rock O' Dundee Road. Two corrugated metal pipe culverts pass under the road, leading to the dam. It is possible that the fish follow the main channel, missing the first stage of the fish ladder. Consolidating the two channels into one would alleviate the problem of attracting fish to the first stage of the ladder. However, it would require extensive structural alterations to the area, and a cost analysis of this option may find it impractical.

Another possibility that must be evaluated is a nature-mimicking (natural) fishway, similar to one that is currently in Freetown, MA on the Acushnet River. The objective of a natural fishway is to maintain the specific environment it is constructed in. Nature-mimicking fishways can also be very expensive compared to retrofitted structures. In the case of the Russells Mill Dam, it would require extensive change to the area below Rock O' Dundee Road in order to lessen the slope of the descent.

### 2.8.2 Retrofit

A less intensive option would be to retrofit the existing structures. This would involve making modifications to either the weir-pools or the Denil passage. This is a less costly project as it would not require complete deconstruction of the current passageway. The reservoir may still need to have its water level lowered for certain redesigns. As with the reconstruction, design work and a cost analysis will need to be completed to establish the retrofit's feasibility.

A common type of retrofitted structure is the Alaskan Steeppass. The Alaskan Steeppass is a prefabricated aluminum structure which could be placed on the existing concrete sides of the

Denil ladder. This would be a fairly simple fix, as the fiberglass baffles could be removed.

Additional information regarding steepass ladders is available in Chapter 2.4.6.

## 2.9 Structural Design

The structural design of the fish passages has many aspects that need to be taken into consideration. The process involves designing the concrete mix, determining the needed reinforcement, analyzing the critical loads on the structure, and finding the settlement of the structure, the creep of the concrete, and the degree of cracking.

### 2.9.1 Concrete Mix

Concrete mix design is the process of determining the characteristics of a concrete mixture. The concrete's properties are a result of the type and proportion of ingredients in the concrete mix. To create a concrete with desirable characteristics, "mixture characteristics are selected based on the intended use of the concrete, the exposure conditions, the size and shape of building elements, and the physical properties of the concrete required for the structure" (Kosmatka, Kerkhoff, & Panarese, 149).

The most important ingredient of the concrete mix is the cementitious paste. Cementitious paste is the combination of water and cementitious material, mainly portland cement but also including blended cement, fly ash, slag, silica fume, and natural pozzolans. The quality and amount of paste used significantly affect the desirable characteristics of the concrete. The water-cementitious material ratio, mass of water divided by mass of cementitious material, is selected based on the critical compressive strength and durability requirements.

The other main ingredient in concrete mix is aggregates. The aggregates are generally a combination of sand, gravel, and crushed stone, which are bound by the cement paste. Sand and particles smaller than 3/8 inch in diameter are referred to as fine aggregate, while larger particles

that are roughly  $\frac{3}{4}$  in to one inch in diameter are known as coarse aggregate (Kosmatka, Kerkhoff, & Panarese, 149).

### 2.9.2 Reinforcement

Concrete is a material that can support a high amount of compression, but fails easily under tension forces. To make up for this weakness, concrete is reinforced with steel rebar to handle the tension forces. The steel bars' size, grade, and required coating are all determined through ASTM and ACI standards.

### 2.9.3 Settlement

Structures put a certain amount of stress on the soil below them. Because of this, the soil compresses and the structure sinks into the earth. This is called settlement. The height of the structure will be adjusted in the design to compensate for the predicted amount of settlement. The magnitude of settlement can be determined by finding the change in stress (the weight of the structure), and the stress-strain properties of the soil being built on. The three types of settlement to be taken into consideration are distortion, consolidation, and secondary compression.

Distortion settlement,  $\delta_d$ , results from lateral movements of the soil in response to the vertical stress. This type of settlement occurs without a change in the volume of the soil. It can be explained by Poisson's effect where an object loaded in the vertical direction expands laterally or vice versa.

Consolidation settlement,  $\delta_c$ , also referred to as *primary consolidation settlement*, takes place when a soil is affected by a vertical stress and the individual particles respond by reorienting into a tighter packing. This happens because the stress causes a decrease in the number of air voids in the soil. This settlement will be minimal but still present in the riverbed, as the existing voids will be filled with water if the soil is completely saturated. The only consolidation settlement will be from the water being pressed out of the soil. (Coduto, Yeung, &

Kitch, 2011)

Secondary compression settlement,  $\delta_s$ , is due to particle rearrangement, creep, and decomposition of organic materials. The particle reorientation causes a reduction in the volume of the voids, similar to the consolidation settlement. This settlement is not due to a change in the vertical stress though; it is dependent on time. (Coduto, Yeung, & Kitch, 2011)

The total settlement which will be needed for the design is the sum of the three different settlement types. Because secondary compression settlement is time dependent, the total settlement is split into categories: immediate settlement, and delayed settlement. Immediate settlement is the settlement over a short amount of time, while delayed settlement is the long-term settlement of the structure. The delayed settlement will be the category that is most important as the structure will need to function over a longer period of time. The settlement of the structure is important to the project as the height of the passage is an important factor for the fish. (Coduto, Yeung, & Kitch, 2011)

#### 2.9.4 Creep

Creep is the time-dependent deformation that occurs when the concrete structure is loaded. The amount of creep is dependent on many factors, including the magnitude of the stress, the age and strength of the concrete used, the length of time that the concrete has been under stress, the quality of the concrete mixture, and the conditions of exposure (i.e. the volume to surface ratio of the concrete). It is also affected by the amount of steel reinforcement used (Kosmatka, Kerkhoff, & Panarese, 2002). As there is no large load that will be placed on the fish passage structure, it is likely that the creep will be minimal. Factors affecting creep that will be considered are concrete composition, curing and loading history, environment, and stress conditions. (ACI Part 1)

### 2.9.5 Cracking

The two main causes of cracking in concrete are the stress due to applied loads, and the stress due to drying shrinkage or temperature changes when the concrete is restrained. Drying shrinkage is an unavoidable problem, but it can be lessened with the use of reinforced steel. The steel, if properly positioned, will reduce the crack widths. Additionally, if the concrete goes through fluctuations in temperature, thermal stresses may occur from restrained deformations. Thermal stresses occur throughout the structure's entire lifespan. It should be noted that if the concrete is not restrained, then there will be no cracking. Sources of restraint include the reinforcing steel bars in the concrete, the interconnected parts of the concrete structure, and the friction of the surface that the concrete structure is placed on. Additionally, the moist interior of the drying concrete puts restraint on the concrete near the surface. This will be an important aspect of behavior to be taken into consideration for the final designs (Kosmatka, Kerkhoff, & Panarese, 2002).

### 2.10 Laws and Regulations

In order to build a dam and fish ladder, specific state laws and regulations must be met and maintained throughout the lifetime of the dam and passageway. First the project must be approved by the Massachusetts Department of Environmental Protection local Department of Public Works and Water. All aspects of the structures (composition, environmental impact, watershed impact etc) must be analyzed and approved. Laws and regulations for the following aspects must be assessed before a design can be installed: current passage location (relation to roadways, wetlands etc), maintenance of the roadways surrounding the structures, construction materials, structure size, pollution control and other environmental impacts (See Appendix C).

(Widing, 2010). In order to provide optimal passage for travelling species it is important that the structures allow for proper completion of one's lifecycle, without affecting the time it takes or the quality of the water for safe living conditions.

#### Environmental Impact

Dam and fish passage construction has many environmental impacts as they change the ecology of the surrounding environment. When holding back water via a dam/reservoir construction, a proper fish passageway must be constructed as well to allow for proper ecological development. Environmental aspects included in assessing the areas consist of access to feeding areas, access to shelter and refuge from predators, allowing for various water habitats (varying temperatures), suitable spawning and breeding areas, availability of new habitats and interaction with other wildlife (biodiversity). If any design is seen as too damaging to any one of these aspects then it can be deemed unsuitable for proper dam and passage construction. (MA DCR)

### 3 Methodology

The purpose of this project was to develop design alternatives, and provide cost effective solutions for the fish passage problem of two dams: the Russells Mills Dam and the Smith Mill Dam. The main tasks involved in this project were: collecting data, reviewing literature, assessing the existing conditions, designing the passage, checking the designs against environmental regulations & laws, and writing the report.

#### 3.1 Collect Data

The first step in beginning the research was the collection of field data from the individual sites. On September 12, 2012, a field visit was made to the Russells Mills and Smith Mills dams, where general data was collected and initial observations were made. A detailed set of plans was obtained from Michael O'Reilly, the Environmental Affairs Coordinator of the Town of Dartmouth. These included dam and fish ladder blueprints.



A second field visit was completed on October 22, 2012, where water velocities and structure dimensions were recorded. This information, along with that from the initial site visit, is detailed in section 2.6: Site Conditions.

### 3.2 Literature Review

The background information used during this project was found from journals or textbooks on the subjects. The books came from a range of subjects, including biology, concrete design, structural analysis, fluid mechanics, soil mechanics, and environmental law. Each topic is pertinent to the investigation of the fish passages. The information secured from these books provided an understanding in all areas of work.

#### Assessing Existing Conditions

One of the first topics investigated was the amount of water that passes through each of the sites. Expected flow and the seasonal variations are imperative for both the structural and hydraulic designs of the fish passages. The hydraulic aspects, such as flow and drainage conditions, must be evaluated to design a fish passage that is usable by alewife and blueback herring. Additionally, the current structural aspects of the fish passages were collected. This information was obtained through review of the structural drawings of the current fish passage, as well as site visits to both of the locations, and use of the online flow data.

#### 3.3.1 Structural Conditions

Blueprints of the Russells Mills fish ladder provided information on the passage dimensions, as well as information on the culvert and dam. As the weir-pool dimensions were not included in the blue prints, they were measured during the second site visit. The dimensions of the Smith Mill Dam were also assessed in a site visit. Any assumptions or estimations made are clearly defined and explained during the analysis.

#### 3.3.2 Hydraulic and Hydrological Conditions

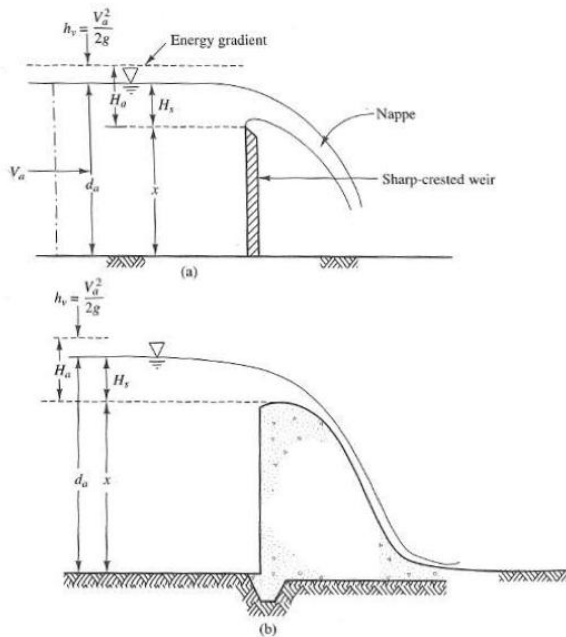
The current hydraulic and hydrological conditions of this area of the Paskamamansett River were determined through measurements taken during site visits, as well as from blueprints and hydrological data. The U.S. Army Corps of Engineers' Hydrologic Engineering Center software was used to simulate watershed runoff and calculate the peak runoff for storms of different magnitudes.

Once the hydrologic information was used to determine the river's total flow, estimations were made as to what course the water would take down the passage. For the dam itself, it was assumed that the water either flowed over the top of the dam or through the weir-pool passage. The dam was treated as a sharp-crested weir with a water level above the top of the dam, and the weir-pool passage was treated as a broad-crested weir. For the area downstream of the dam, calculations were made using models with different stop-log arrangements in an attempt to create an optimal flow through the Denil passage.

Two different values for the magnitude of flow were used for calculations in the project. For calculations involving the progression of fish through the passages, the flow magnitude was calculated using the average flow during the period each year in which most fish passage occurs. For calculations involving the structural analysis of the passage, the magnitude of the flow was calculated based on the flow frequency return period.

The average flow during herring migration was found by taking the daily flow values that are recorded on the United States Geological Survey's National Water Information System. This website keeps track of the data sent from the flow gage in the Paskamansett River. The average was taken from 2007 to 2011. 2012 was left out because the data is considered to be provisional until verified by the USGS.

To determine the magnitude of flow for structural considerations, the flow frequency was analyzed in order to model the return period and probability that a magnitude of flow will occur. This was completed using the U.S. Army Corps of Engineers HEC-SSP software. The flow frequency curve shown includes flows with non-exceedance probabilities ranging from 1 to 99.8 percent. For these structural calculations, a return period of \_\_\_\_\_ was used. This corresponds to a flow of \_\_\_\_\_, meaning that each year there is a \_\_\_\_\_ percent chance that the flow will exceed \_\_\_\_\_.



The two stop-logs over which water flows during normal conditions were measured to be 10' and 4'. These represent the areas of the dam that were treated as sharp-crested weirs. The channel discharge over these areas was calculated using Manning's uniform flow formula.

$$Q = \frac{1}{n} AR^{2/3} S^{1/2}$$

The area upstream of the dam is assumed to have a Manning's coefficient of  $n=.030$ , as a natural stream bed. The pond's average depth at the dam was found to be 3', and the wetted perimeter is 14'. This is used to determine the channel discharge.

$$Q = \frac{1}{.030} (42) \left( \frac{42}{14} \right)^{2/3} .001^{1/2} = 92.09 ft^3/s$$

$$V = \frac{Q}{A} = \frac{92.09}{42} = 2.2 \text{ ft/s}$$

### 3.3.3 Site Visits

The first site visit, on September 12, 2012 served as an opportunity to become familiar with the area, and see each dam in person for the first time. During this site visit, Michael O'Reilly and Brad Chase provided the group with information regarding the history of the dams and current ladders, knowledge of herring and eel behavior, and details about environmental regulations.

A second site visit was performed on October 22, 2012. The purpose of this visit was to conduct detailed measurements of the fish ladders. The dimensions of the weir-pool ladder were recorded. The width of the weir-pool walls was found to be 1'. The step heights for each weir-pool are shown in the table below.

| Weir-pool | Weir-pool<br>step height (in.) | Water<br>level (in.) |
|-----------|--------------------------------|----------------------|
| 1         | 21.5                           | 23                   |
| 2         | 15                             | 24                   |
| 3         | 19.5                           | 23                   |
| 4         | 20.75                          | 28                   |
| 5         | 24                             | 28.5                 |
| 6         | 24.75                          | 31                   |
| 7         | 28.75                          | 33                   |
| 8         | 31.5                           | 36                   |
| 9         | 34                             | 37.5                 |
| 10        | 35.5                           | 41                   |
| 11        | 40                             | 43.5                 |
| 12        | 41                             | 46                   |

The weir-pool dimensions were then used to create a Revit BIM model of the ladder. This model can be used to provide spatial and structural analysis and to visualize the ladder without the flow of water.

During our third site visit on December 7, 2012, a more comprehensive testing of water velocities was performed. Water velocities were measured using a velocity probe at multiple levels within each weir-pool, and at locations downstream from the passage. The downstream measurements were taken at locations that are marked on the existing conditions blueprint that was provided, so that each measurement corresponds to a known elevation.

### 3.4 Design of Fish Passage

The design of the fish passage was based on the physical ability of the fish. The fish have a certain water speed that they are comfortable swimming against. The passages were designed so that the herring could swim the length of the passageway without getting too tired. It is because of this that the hydraulic conditions of the passage were analyzed first to verify that the herring would be able to swim the passage. The structural conditions came after this, as they could be changed and only affect the hydraulics in a minor way.

#### 3.4.1 Hydraulic Design

The velocity of the water during herring spawning season was found using data obtained from the USGS flow gauge located on the Paskamanset River. In order to measure the velocity within the fish passage, a velocity probe will be used during a site visit to assess the differences in flow throughout the passage. This value will then be checked for accuracy against values calculated based on USGS flow data. Adjustments will be made based on The passage design will be based on the fluid velocity that the two species of herring are capable of swimming against.

The geometry of the fish passage will be designed to allow the correct velocity of water through the passageway.

Using the information from the USGS gage along the Paskamanset River, this data was obtained for the months of February through May (the months that the herring would be using the fish ladder):

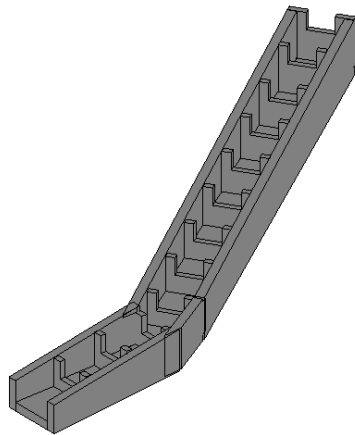


Figure x: Table of the Average and Peak Flows (in cubic feet per second) During Feb-May  
If one inputs the avgAVERAGE and the avgPEAK into the velocity equations for the Denil and the weir-pool equations, one will conclude that the average velocity that the herring will have to overcome inside the Denil passage (assuming all stream water flows through the passage) will be 90.08 ft/s, and the average peak velocity the herring will have to overcome in the Denil passage will be 414.17 ft/s.

#### 3.4.1.1 Hydraulic Forces

The three main forces on the structure caused by the water flowing through passageway are the force due to hydrostatic pressure, the force due to the change in momentum of the water, and lastly the weight of the water on the base of the passage.

The force due to hydrostatic pressure is found through the equation  $F_r = \gamma(h/2)A$ .

Where “ $\gamma$ ” is the specific weight of water, “ $h$ ” is the height of the water in the passage, and “ $A$ ” is the affected area. This is a point load that is located at one third the height of the water.

The force due to the change in momentum is found through the equation  $F = Q\rho(v_1 - v_2)$ . Where  $\rho$  is the density of the liquid,  $Q$  is the flow, and  $v$  is the velocity of the water. This force is located on the baffles and walls that jut out into the passage.

The last force due to the water in the passageway is the weight of the water on the concrete slabs. This is calculated by multiplying the volume of water in the passage by the specific weight of water. The structure will be designed to resist all of these forces.

### 3.4.2 Structural Design

Once the ecological and hydraulic conditions of the area have been found, they will be analyzed to determine the necessary geometric shape of the fish passage. The structural design will then be possible to create by using the passage geometry as a basis of the design.

#### 3.4.2.1 Concrete Mix

The design of the concrete mix is an important step in the passages’ designs. The concrete mix must be durable enough to last a long time, and strong enough to handle the forces acting on it. The ACI Manual of Concrete Practice provides a table on exposure conditions and how they affect the concrete mix. Conditions pertain to freezing / thawing, permeability, and corrosion protection. The degree of freezing and thawing that occurs in the region will affect the maximum water/cement ratio, the minimum design strength, the maximum aggregate size, and the air content. The level of permeability required also influences the water/cement ratio and the

minimum design strength. Corrosion protection affects the water/cement ratio, minimum design strength, and the maximum water-soluble chloride ion content. (American Concrete Institute)

Evaluating the exposure conditions gives the required minimum design strength and the maximum water/cement ratio. These two values can be created by altering different factors involved in the concrete mix, such as proportioning, maximum aggregate size, air content, and the addition of admixtures (Kosmatka et al, 149).

#### 3.4.2.2 Load Analysis

The structural design of the structure is based, in part, on the different loads that it is required to resist. To calculate the stresses and strains on the structure, the moduli of elasticity are necessary. According to the ACI Manual of Concrete Practice, the modulus of elasticity of concrete is equal to  $57000\sqrt{f'c}$ . The modulus of elasticity of steel is equal to 29,000,000 psi.

The load combination that is used to determine the factored load on the structure is  $U = 1.4(D + F)$ . This equation takes into account the dead load (D) and the load due to the water (F). There is no live load for this structure as nothing is supposed to operate on the top of the passage.

In addition to the load combination, strength reduction factors are also required. According to ACI standards, tension controlled sections require a strength reduction factor of 0.90. For compression controlled it is equal to 0.65, for shear and torsion it is 0.75, and for bearing on concrete, it is equal to 0.65.

The load combinations and the strength reduction factors are put in place so that there is a large factor of safety. Additionally, the walls of the weir-pools will be treated as cantilevers for the analysis; the walls are actually connected on two sides, but the analysis will be done as if it was only connected on one side. This will give us a conservative estimate for the force on the cantilevers. This means that the structure will be able to handle a load higher than the maximum it is expected to encounter, ensuring that it will be less likely to fail.



#### 3.4.2.3 Reinforcement

Reinforcement bars are necessary for concrete so that it can resist loads in tension. The ACI provides code for all aspects of steel reinforcement, such as minimum bar diameter, the allowable spacing between bars, reinforcement placement, and proper reinforcement covering. Additionally, another good source of information on reinforcement requirements is the ASTM. The required area for the reinforcement,  $A_s$ , is found through an analysis of the loads on the structure.

#### 3.5 Environmental Regulations

In order to maintain and successfully use a fish passage, all designs must fit environmental regulations set forth by the Town of Dartmouth, the Commonwealth of Massachusetts, and the Federal Government. The state government and federal government have regulations (general environmental guidelines) on many aspects of watersheds from flow rates, water oxygen concentration, habitat change etc. Regulations must be researched and complied with in order to make sure the final design is in the bounds of such regulations.

#### 3.6 Deliverables

Finally, this project will include a CAD design, cost estimates, design calculations, a written report, and any recommendations as the deliverables. With these documents we hope to supply the Town of Dartmouth with viable solutions to the fish passage problem along the Paskamanset River.

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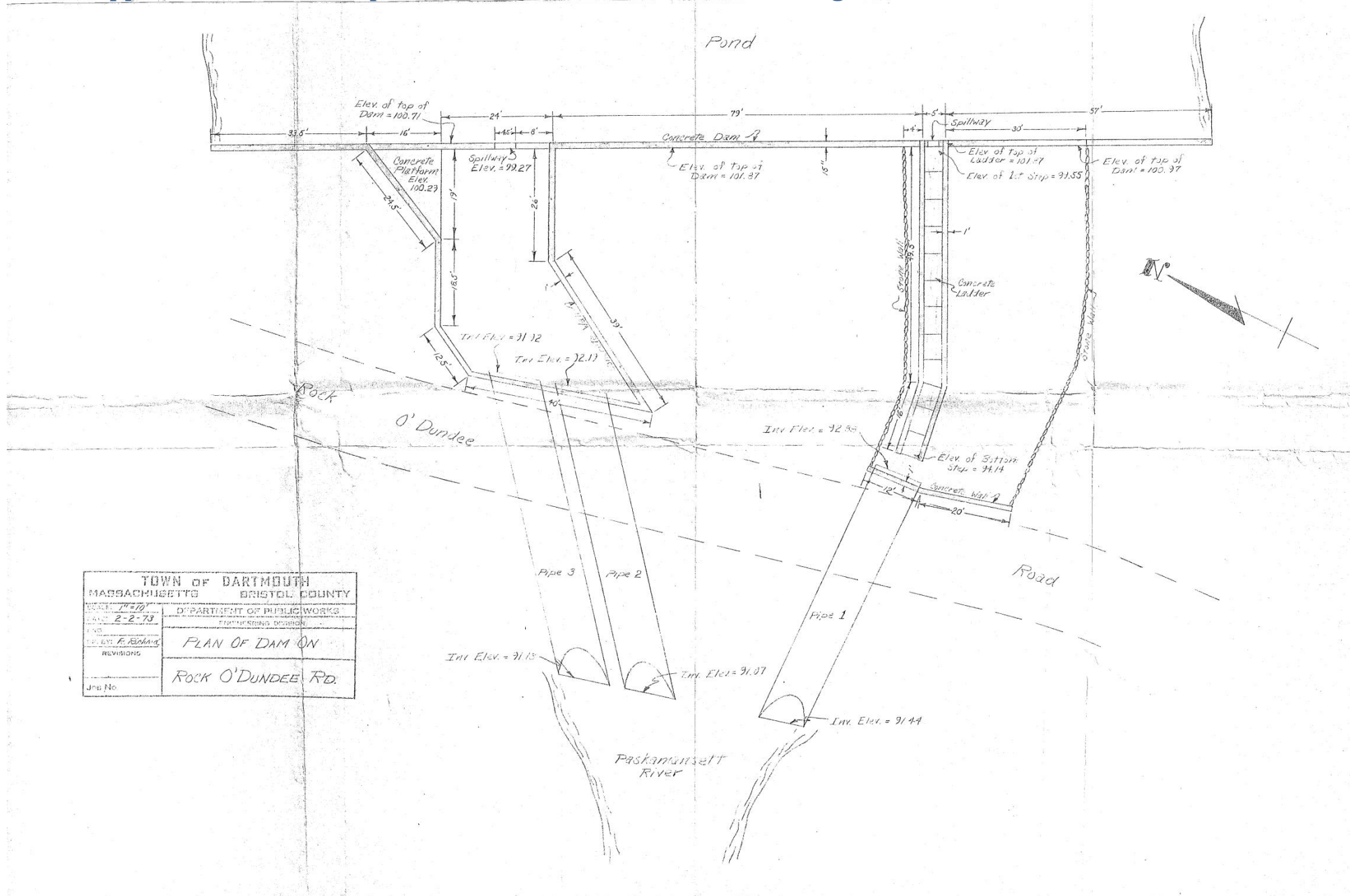
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## Appendix B: Technical Specification for Russells Mills Fish Passage



|                   |                            |
|-------------------|----------------------------|
| TOWN OF DARTMOUTH |                            |
| MASSACHUSETTS     | BRISTOL COUNTY             |
| DATE: 7-10        | DEPARTMENT OF PUBLIC WORKS |
| DATE: 2-2-73      | ENGINEERING DIVISION       |
| BY: E. F. BROWN   | PLAN OF DAM ON             |
| REVISIONS:        | ROCK O'DUNDEE RD.          |
| JOB No.           |                            |

# Appendix C: Technical Specifications for Russells Mills Dam Repairs

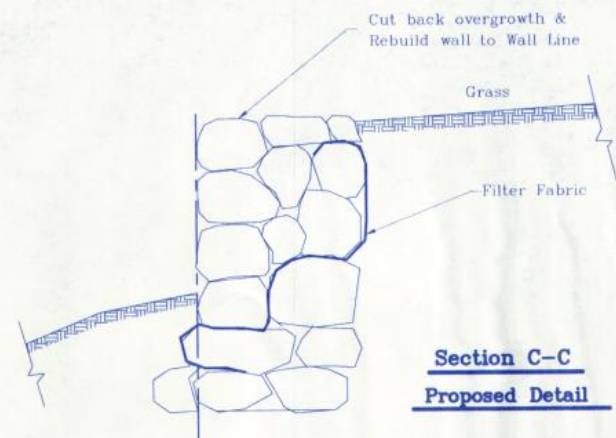
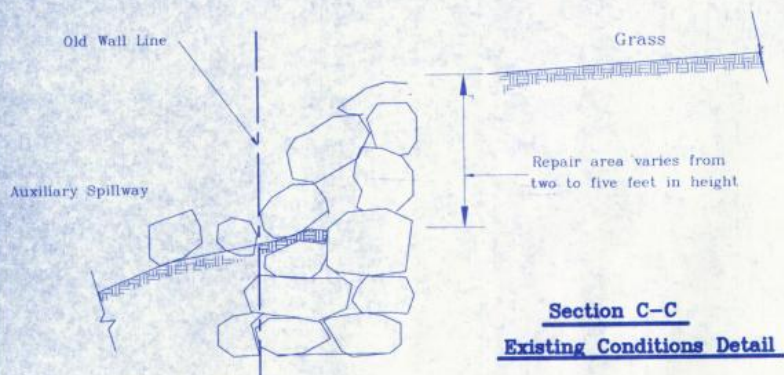
**tec** tibbetts engineering corp  
 716 COUNTY STREET TAUNTON, MA 02780  
 Tel: (508) 822-8934 - Fax: (508) 850-7911  
 EMAIL: teck@tec.com

civil engineering  
 land surveying  
 transportation  
 environmental permitting  
 testing & construction services

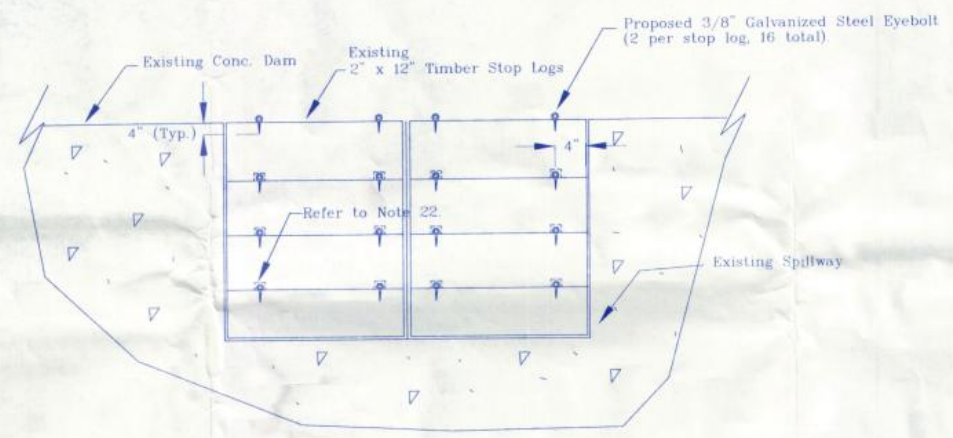
## TECHNICAL SPECIFICATIONS FOR RUSSELLS MILLS DAM REPAIRS

**NOTE:** THE STANDARD SPECIFICATIONS REFERENCED BELOW REFER TO THE COMMONWEALTH OF MASSACHUSETTS HIGHWAY DEPARTMENT STANDARD SPECIFICATIONS FOR HIGHWAYS AND BRIDGES, 1988 EDITION, INCLUDING ANY AND ALL ADDENDA AND REVISIONS THERETO.

- 1.) The reconstructed auxiliary spillway concrete wall section shall bear on soils with a minimum bearing capacity of 2 TSF. Unsuitable soils or loosely compacted soils shall be removed to suitable bearing materials. Where the soils are found unsuitable they shall be replaced with Gravel Borrow, M1.03.0 type c (Max. 2" size). All backfill shall be compacted to a minimum of 95% of its maximum dry density as determined by ASTM D1557 "Proctor" testing and ASTM D1556 "Field Density Sand Cone" tests.
- 2.) Reinforcing steel shall be in accordance with ASTM A615 for Grade 60 deformed bars and epoxy coated in accordance with ASTM A775. All reinforcing steel shall be placed with a minimum of 2 inches of cover for top and side steel and with 3 inches of cover at the pad base. Steel that is lapped shall be placed with a minimum of a 40 bar diameter length overlap and be securely tied and fastened to prevent movement during placement. Corner steel shall be placed continuous around corners by either lapping with bent angles or bending the reinforcing bars. All steel shall be securely tied and fastened to prevent movement during placement.
- 3.) Concrete shall obtain 4000 PSI at 28 days cure and be proportioned in accordance with ACI-211.1 using a maximum water/cement ratio of 0.48. Cement shall meet ASTM C 150 for Type II or IIA cement. The desired maximum size aggregate is 1-1/2" graded to ASTM C33 for Size # 407. An alternate maximum size aggregate mix may be used if approved by the Engineer. Concrete shall be air-entrained to produce 4-6% air content. A water-reducing admixture shall be used in the mix that does not contain chlorides and meets ASTM C-494 for Type A admixtures. The proposed mix design shall be submitted to the Engineer for approval previous to placement of any concrete.
- 4.) Mixing, Transporting and Placing of concrete shall be in accordance with ACI 304. Mixes shall be placed at a maximum 5.0' slump and sufficiently consolidated using a vibrator specifically designed for such use. If necessary, hot or cold weather protection with mix modifications shall be employed in accordance with ACI 305R or ACI 306R standards.
- 5.) The concrete shall be sampled and tested for slump, air content and temperature. A minimum of two sets of three 6 x 12 inch diameter cylinders shall be fabricated by a Mass. Licensed Class A concrete technician during slab placement. Compression testing of the samples shall be performed by a Mass. Licensed concrete laboratory. For each set of test specimens, one cylinder shall be tested at 7 days cure and two at 28 days. The average strength of the two samples for each set tested at 28 days shall meet the minimum design strength of 4000 PSI.
- 6.) The reconstructed portion of the decayed concrete dam wall shall be chipped, cut and removed to sound concrete as indicated on the plans as required by field conditions and as approved by the Engineer. Dowel holes shall be drilled and the chipped surface cleaned by powerwashing previous to forming. A bonding agent shall be applied to the surface previous to placement of the concrete.
- 7.) Dowels shall be installed in clean drill holes and grouted solid with non-shrink grout previous to placing the concrete for the new wall. The proposed grout shall be approved by the Engineer previous to use.
- 8.) Miscellaneous rip rap furnished by the Contractor shall consist of sound, hard, durable granite quarry stone ranging in weight from 600 to 900 lbs each. Stone shall be angular in shape and have at least three flat faces to enable the units to be interlocked when placed in the spillway areas as indicated on the plans. The intent is to place the stones such that each unit is interlocked with the adjacent units.
- 9.) Contractor shall provide manufacturers product data to the Engineer for approval of the proposed filter fabric to be installed under the stone at the locations shown and directed. Only products manufactured for the specific use of erosion control under stone subject to hydraulic filtration will be approved.
- 10.) Rebuild dry laid stone walls in accordance with Section 695 of the Standard Specifications using salvaged and new stone of similar size and shape as presently exists. Wall stone shall be of varying sizes with at least two flat faces to enable the units to be interlocked within the existing dry laid stone wall. Sizes shall be similar to the existing wall stone to allow the rebuilding of the wall to dimensions and at locations as indicated on the plans.
- 11.) Reposition (2) large channel boulders by excavating holes southwest of their present location & repositioning the rocks into the holes. The top elevation of each boulder shall be positioned to align with the top elevation of the new rip rap stone. If it is found that the existing boulders cannot be moved, break into smaller pieces and reposition as approved by the Engineer.
- 12.) Install new 36 inch high Type 1, zinc-coated chain link fence with black vinyl coated wire fence fabric in accordance with Section 644 of the Standard Specifications at the locations as shown on the plans.
- 13.) Remove trees, shrubs and related stumps and root systems in locations as indicated on the plans. Backfill excavated areas in layers to 95% compaction as determined by ASTM D1556 "Field Density Sand Cone" testing.
- 14.) Epoxy inject concrete vertical wall cracks at the locations indicated on the plans using materials in accordance with Section M4.05.5 for Type I, Grade 3, Class B epoxy in accordance with manufacturer's approved specifications.
- 15.) 6 to 8 CF size Rip Rap fractured stone shall be placed in locations as indicated on the plans such that the entire mass is compact and individual stones will not move from their set positions due to flowing water.
- 16.) Training wall concrete surfaces (140: SF Vertical and 130: SF Horizontal) shall be coated with a polymer modified thin coat repair mortar such as Sikatop III & 123 or Fosroc All-Crete & Rendocor 1822. Surfaces shall be prepared by powerwashing, chipping, patching & applying a bonding agent. Clean & patch with thin coat along 25 feet of wall on north side of dam and along the fish ladder as directed by the Engineer (165: SF).
- 17.) Guardrail and Transition rail timber shall be Southern Yellow Pine - Grade 2 or better (S4S). Posts shall be CCA treated with a minimum retention rate of 0.6 PCF meeting AWPA Standard C14. Structural steel plate shall meet ASTM A36 for Carbon Structural Steel.
- 18.) All guardrail hardware & steel products shall be hot-dipped galvanized in accordance with ASTM A153 & A123 respectively (Min. 2.0 oz/SF Zinc). Bolts shall meet ASTM A307 or ASTM A325 (where detailed) for carbon steel bolts & studs, zinc coated as specified above.
- 19.) Existing concrete posts shall remain the property of the Town and be removed and stacked in a location as approved by the Town.
- 20.) Clear and grub brush and vegetation along the north side of the vertical slot fish ladder.
- 21.) Eyebolts shall be lagged into stop logs 4 inches 1-3/4" diameter x 1-3/4" deep holes shall be counterbored in the bottom of each stop log at eyebolt locations as shown on the Detail.
- 22.) Miscellaneous project site work shall be performed by the Contractor at the locations shown. This work shall consist of the removal and on-site stacking of selected facilities for subsequent removal from the site by the Owner, or the removal and off-site disposal by the contractor of materials or facilities determined by the Owner to be unsuitable or unnecessary for future project use.
- 23.) Excavation of pits, placing of planting mix, mulches, fertilizer, and planting methods for trees furnished and planted at the locations shown on the Plans shall conform with the applicable provisions of Sections of 771, and Section M6 of the Standard Specifications.
- 24.) Provide siltation control at guardrail installations. See General Requirements Section 01568 for detail.

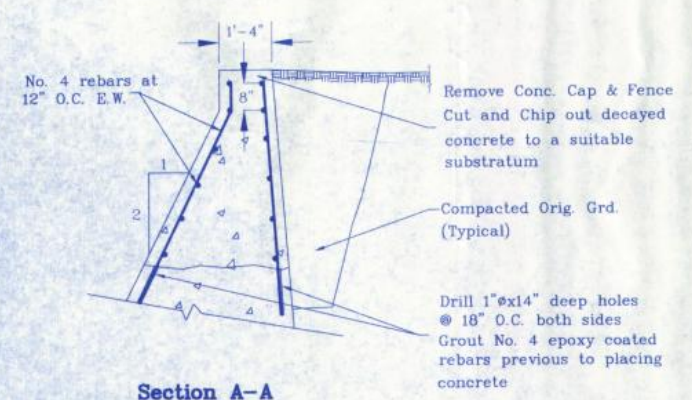


**DETAIL "C"**  
 Not to Scale

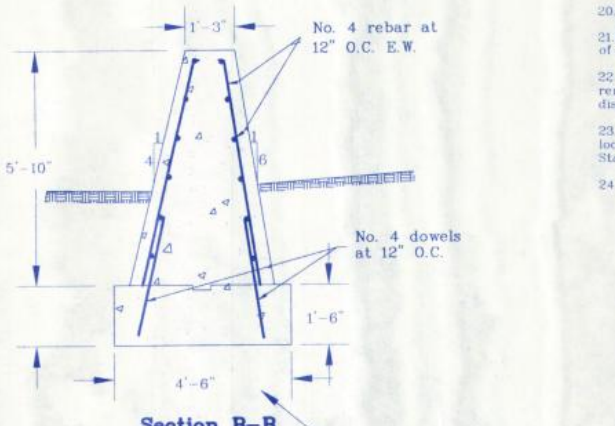


**Note:** Eyebolts to be installed in auxiliary spillway & fish ladder stop logs (12 Eyebolts total).

**DETAIL "D"**  
 Not to Scale



**DETAIL "A"**  
 Not to Scale



**DETAIL "B"**  
 Not to Scale

**CONSERVATION COMMISSION**  
**APPROVED**  
**PLAN OF RECORD**  
**15-115**

| Rev. | Date | Description | By |
|------|------|-------------|----|
|      |      |             |    |



*Christopher M. White*  
 Project Location

**Russells Mills Pond Dam**  
**Dartmouth, Ma.**  
**(Bristol County)**

Prepared For  
**Town of Dartmouth**  
**Department of Public Works**

Drawing Title  
**Wall Repairs, Sections and Details**

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| Design by:   | CMW           |                |  |
| Reviewed by: | WPG           |                |  |
| Approved by: | CMW           |                |  |
| Project No:  | 10000.020     |                |  |
| Date:        | JANUARY, 2001 |                |  |

Project: 040 P.O. Box 10000  
 Project Director: J.A. Hughes  
 Plot Date: 09/07/01  
 Plot Time: 11:12:35

**Appendix D: Summary of the Massachusetts River and Stream Crossing Standards**

|                        | GOALS   | APPLICATION  | STANDARDS   |
|------------------------|---|--|---|
| New Structures         | <b>General Standards</b><br>To provide:<br>■ Fish passage<br>■ River/stream continuity<br>■ Some wildlife passage                   | Permanent stream crossings on fish bearing streams <sup>1</sup>  | <ul style="list-style-type: none"> <li>■ Bridges are generally preferred, but well designed culverts and open-bottom arches may be appropriate</li> <li>■ If the structure is a culvert, then it should be embedded to a depth of:                             <ul style="list-style-type: none"> <li>- ≥ 2 feet for box culverts and other culverts with smooth internal walls</li> <li>- ≥ 1 foot for corrugated pipe arches</li> <li>- ≥ 1 foot and at least 25 % for corrugated round pipe culverts</li> </ul> </li> <li>■ The structure must span the channel width by a minimum of 1.2 times the bankfull width</li> <li>■ The structure must contain natural bottom substrate</li> <li>■ The structure must be designed with appropriate bed forms and streambed characteristics so that water depths and velocities are comparable to those found in the natural channel at a variety of flows</li> <li>■ The openness ratio must be ≥ 0.82 feet (0.25 meters). See Note 2.</li> <li>■ Use bridge spans</li> <li>■ The structure must span the streambed and banks with a minimum opening of at least 1.2 times the bankfull width.</li> <li>■ The structure must contain natural bottom substrate</li> <li>■ The structure must be designed with appropriate bed forms and streambed characteristics so that water depths and velocities are comparable to those found in the natural channel at a variety of flows</li> <li>■ Maintain a minimum height of 6 feet (1.83 meters) and an openness ratio of ≥ 2.46 feet (0.75 meter) if conditions are present that significantly inhibit wildlife passage. See Note 2.</li> <li>■ If conditions do not significantly inhibit wildlife passage, maintain a minimum height of 4 feet (1.22 meters) and an openness ratio of ≥ 1.64 feet (0.5 meter). See Note 2.</li> </ul> |
|                        | <b>Optimum Standards</b><br>To provide:<br>■ Fish passage<br>■ River/stream continuity<br>■ Wildlife passage                        | Permanent stream crossings on fish bearing streams <sup>1</sup> in areas of regional significance for their contribution to landscape level connectedness or river/stream ecosystems that provide for important aquatic habitat for rare or endangered species |   |
| Replacement Structures | <b>Design Standards for Culvert Replacement</b><br>To improve:<br>■ Fish passage<br>■ River/stream continuity<br>■ Wildlife passage | Existing permanent stream crossings on fish bearing streams <sup>1</sup>   | <ul style="list-style-type: none"> <li>■ Whenever possible, replacement culverts should meet the design guidelines for either General Standards or Optimal Standards</li> <li>■ If it is not possible or practical to meet all of the general or optimal standards, replacement crossings should be designed to:                             <ul style="list-style-type: none"> <li>- meet the General Standards for crossing width (1.2 x bankfull width)</li> <li>- meet other General Standards to the extent practical</li> <li>- avoid or mitigate the following:                                     <ul style="list-style-type: none"> <li>• Inlet drops, outlet drops, flow contractions and turbulence, tailwater armoring, tailwater scour pools, and physical barriers to fish passage</li> </ul> </li> </ul> </li> <li>■ Use scour analyses, assessment of longitudinal profiles, and other methods to design the structure with appropriate grade controls to ensure that the replacement will not destabilize the river/stream</li> <li>■ To the extent practical, conduct stream restoration as needed to restore river/stream continuity and eliminate barriers to aquatic organism movement.</li> <li>■ Avoid using high density polyethylene (HDP) or plastic pipes</li> </ul>  |
| All structures         | <b>Construction Best Management Practices</b><br>To minimize disturbance to the water body during construction                      | Applicable to all work affecting the conditions of a fish bearing stream <sup>1</sup>  | <p style="text-align: center;"><b>CONSTRUCTION GUIDANCE</b></p> Construction best management practices for minimizing construction impacts address the following topics:<br><ul style="list-style-type: none"> <li>■ Dewatering</li> <li>■ Stormwater management, erosion, and sediment control</li> <li>■ Pollution control</li> <li>■ Constructing stream bed and banks within structures</li> <li>■ Soil stabilization and re-vegetation</li> <li>■ Monitoring</li> </ul>  |

(Widing, MA DOT, 2010)

## Appendix E: Species Travelling Guides

Table E-1: Relative Swimming speeds of young (Richardson, 2004)

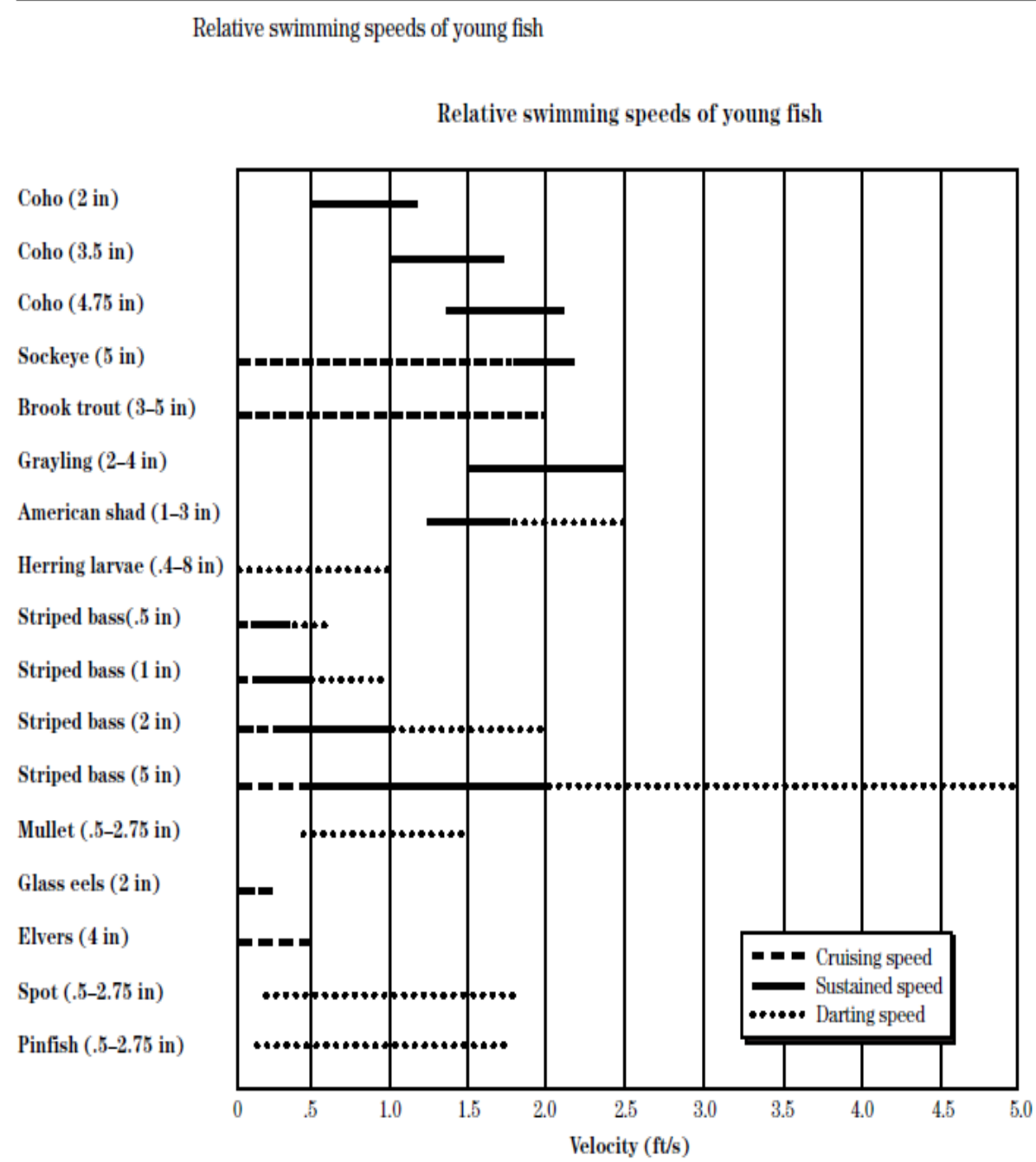


Table E-2: Relative Swimming speeds of adults (Richardson, 2004)

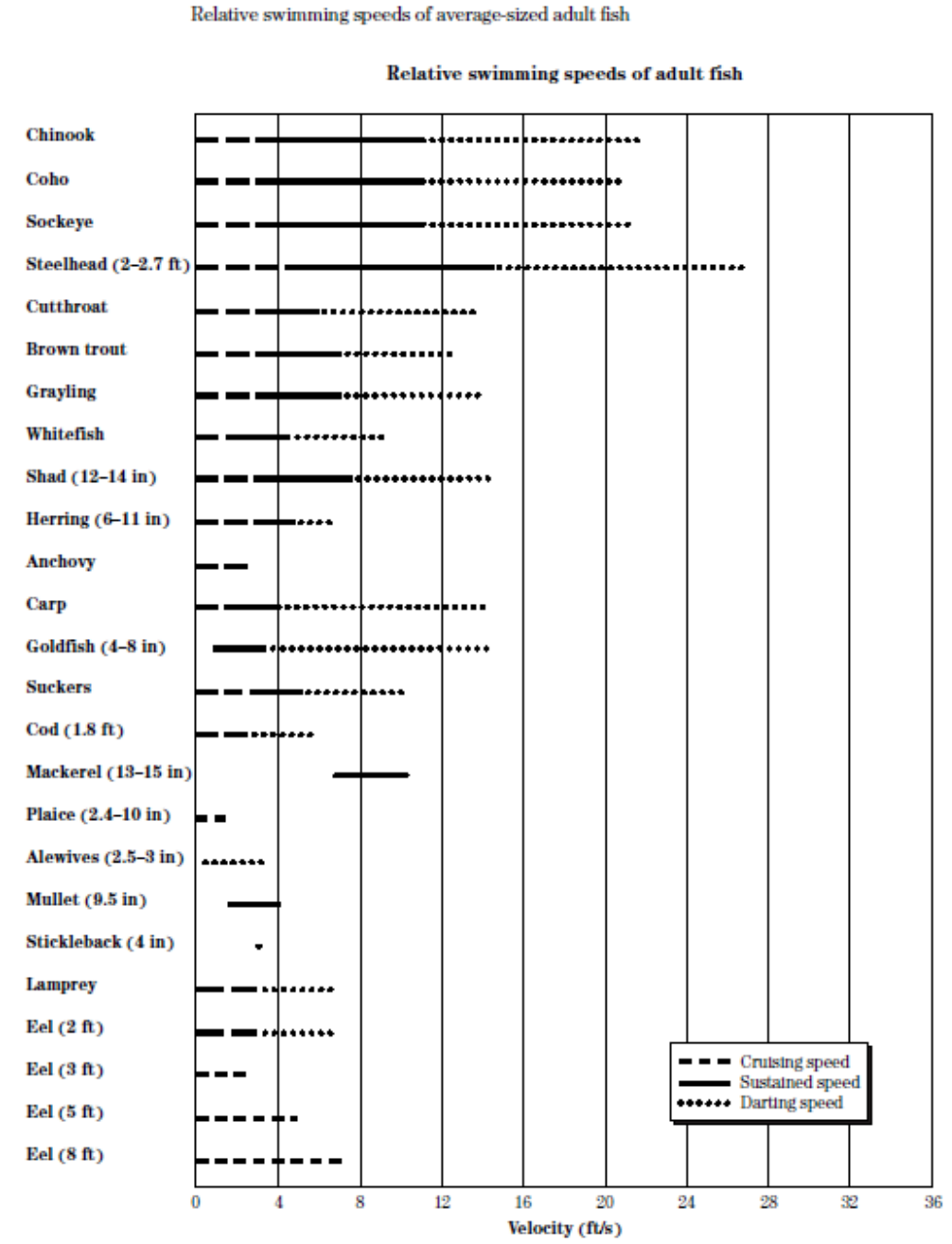


Table E-3: Relative Swimming speeds of various aquatic species

## Summary of Swimming Speeds for both Target and Surrogate Species

| Species                         | Common Name      | Life Stage <sup>a</sup> | Mean Length <sup>b</sup> (mm) | Water Temp (°C) | Time (s) | Swimming Mode | Swimming Speed (cm/s) | Reference                                    |
|---------------------------------|------------------|-------------------------|-------------------------------|-----------------|----------|---------------|-----------------------|--|
| <i>Anguilla rostrata</i>        | American eel     | Elver                   | 56 (TL)                       | 17-23           | 600      | Sustained     | 15                    | Barbin and Krueger 1994                      |
| <i>Anguilla rostrata</i>        | American eel     | Elver                   | 56 (TL)                       | 17-23           | 600      | Prolonged     | 25                    | Barbin and Krueger 1994                      |
| <i>Anguilla rostrata</i>        | American eel     | Elver                   | 56 (TL)                       | 17-23           | Unknown  | Burst         | 40                    | Barbin and Krueger 1994                      |
| <i>Anguilla australis</i>       | Short-finned eel | Glass eel               | 54 (TL)                       | 20-22           | 1800     | Sustained     | 29                    | Langdon and Collins 2000                     |
| <i>Anguilla australis</i>       | Short-finned eel | Glass eel               | 54 (TL)                       | 20-22           | 180      | Prolonged     | 35                    | Langdon and Collins 2000                     |
| <i>Anguilla australis</i>       | Short-finned eel | Glass eel               | 54 (TL)                       | 20-22           | 3        | Burst         | 79                    | Langdon and Collins 2000                     |
| <i>Anguilla reinhardtii</i>     | Long-finned eel  | Glass eel               | 51 (TL)                       | 21-23           | 1800     | Sustained     | 32                    | Langdon and Collins 2000                     |
| <i>Anguilla reinhardtii</i>     | Long-finned eel  | Glass eel               | 51 (TL)                       | 21-23           | 120      | Prolonged     | 42                    | Langdon and Collins 2000                     |
| <i>Anguilla reinhardtii</i>     | Long-finned eel  | Glass eel               | 51 (TL)                       | 21-23           | 5        | Burst         | 75                    | Langdon and Collins 2000                     |
| <i>Hypomesus transpacificus</i> | Delta smelt      | Adult                   | 35-74                         | 12-21           | 600      | $U_{crit}$    | 27.6                  | Swanson et al. 1998                          |
| <i>Osmerus mordax</i>           | Rainbow smelt    | Adult                   | 70-163                        | 10              | 3600     | Sustained     | 39-59                 | Griffiths 1979 in Katopodis and Gervais 1991 |
| <i>Alosa aestivalis</i>         | Blueback herring | Juvenile                | 85                            | 10              | Unknown  | $U_{crit}$    | 22.7                  | Terpin et al. 1997 in EPRI 2000              |
| <i>Alosa aestivalis</i>         | Blueback herring | Juvenile                | 89                            | 15              | Unknown  | $U_{crit}$    | 34.7                  | Terpin et al. 1997 in EPRI 2000              |
| <i>Alosa aestivalis</i>         | Blueback herring | Adult                   | 205                           | 15              | Unknown  | Burst         | 250 <sup>c</sup>      | Castro-Santos 2002                           |
| <i>Alosa pseudoharengus</i>     | Alewife          | Juvenile                | 136                           | 20              | Unknown  | $U_{crit}$    | 63.6                  | Wyllie et al. 1976 in EPRI 2000              |
| <i>Alosa pseudoharengus</i>     | Alewife          | Juvenile                | 137                           | 29              | Unknown  | $U_{crit}$    | 35.7                  | King 1971b in EPRI 2000                      |
| <i>Alosa pseudoharengus</i>     | Alewife          | Juvenile                | 46-150                        | 15              | 3600     | $U_{crit}$    | 42.6-53.5             | Griffiths 1979 in Katopodis and Gervais 1991 |
| <i>Alosa pseudoharengus</i>     | Alewife          | Adult                   | 225                           | 15              | Unknown  | Burst         | 275 <sup>c</sup>      | Castro-Santos 2002                           |

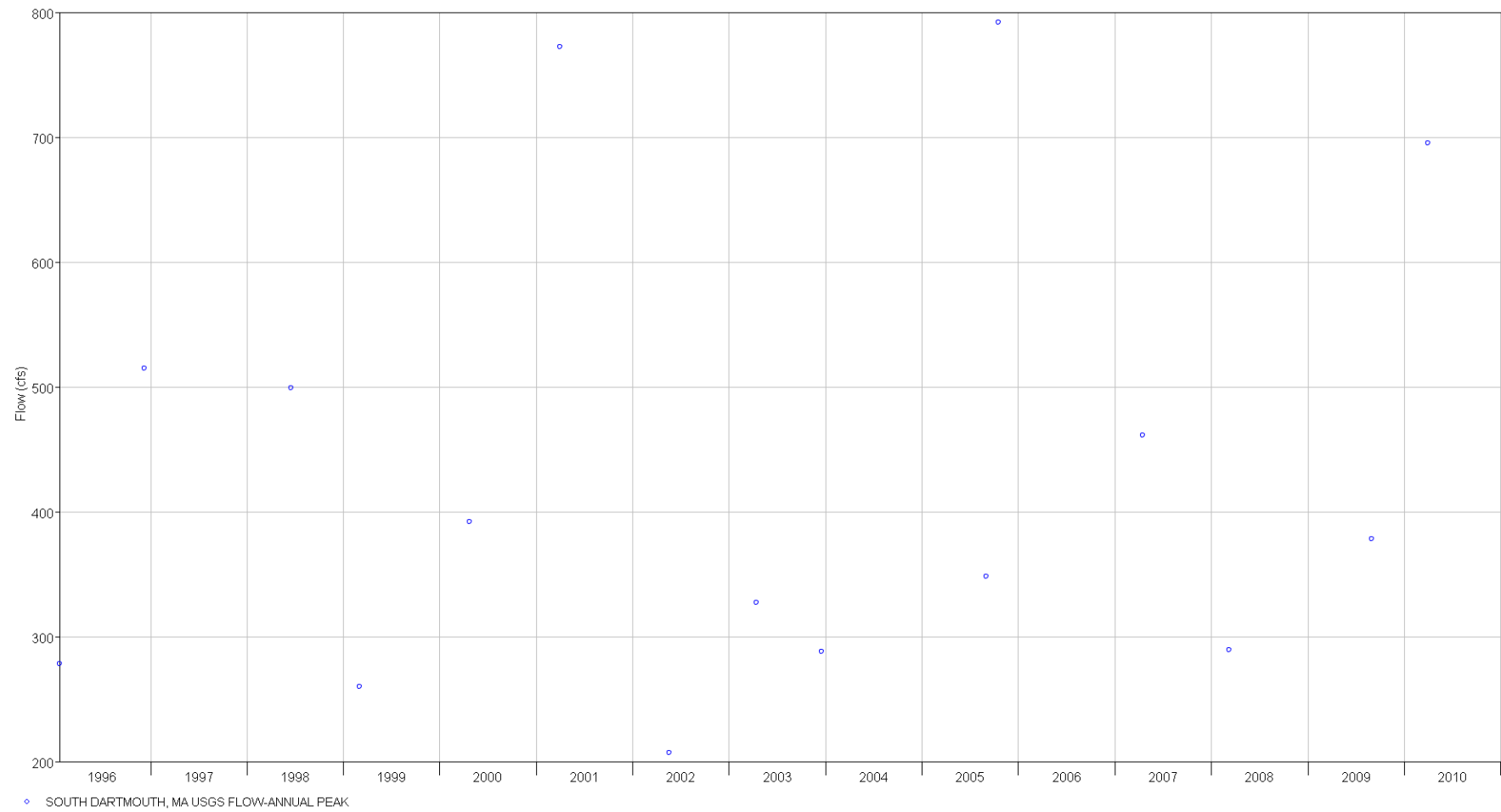
<sup>a</sup>Unless specified in the literature, life stage was assumed based on fish length.

<sup>b</sup>Mean length is fork length unless otherwise noted (TL = Total Length)

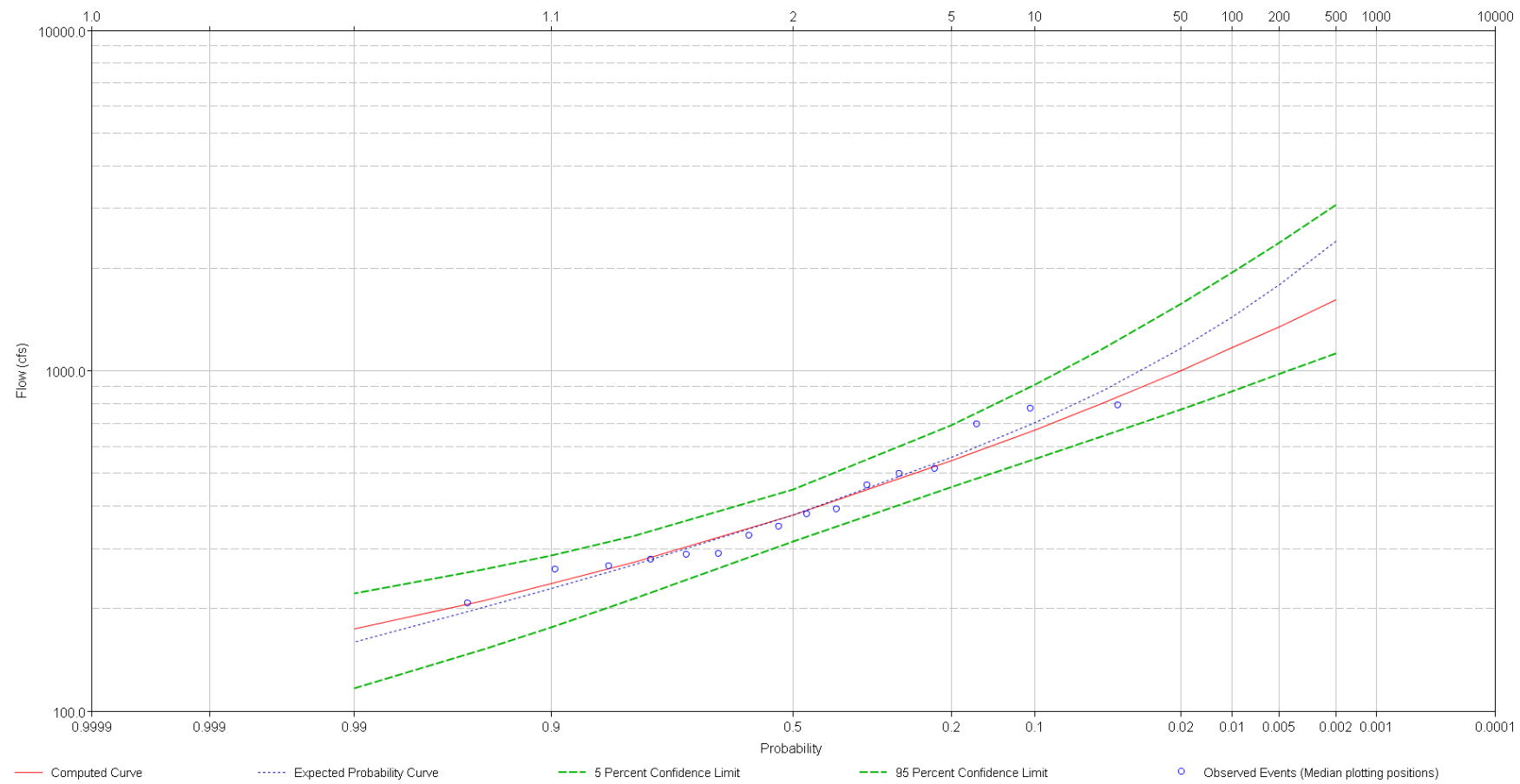
<sup>c</sup>Swimming speed based on volitional ascent in an open flume and indicates the water velocity at which 50% of the fish are able to ascend at least five meters.



## Appendix F: Paskamanset River Flow Frequency Data



Bulletin 17B Plot for Pask Flow Frequency  
Return Period



## Appendix 2: State River Herring Regulations

The following regulations affect the catch of river herring (alewives and bluebacks) in cities and towns without local control. These regulations establish catching days, daily catch limits, and gear restrictions and are being promulgated to establish consistent state management of river herring not under the local control of a city or town by operation of M. G. L. c. 130, s.94. These regulations are easily understood, readily enforceable, and will help assure adequate escapement of river herring for spawning.

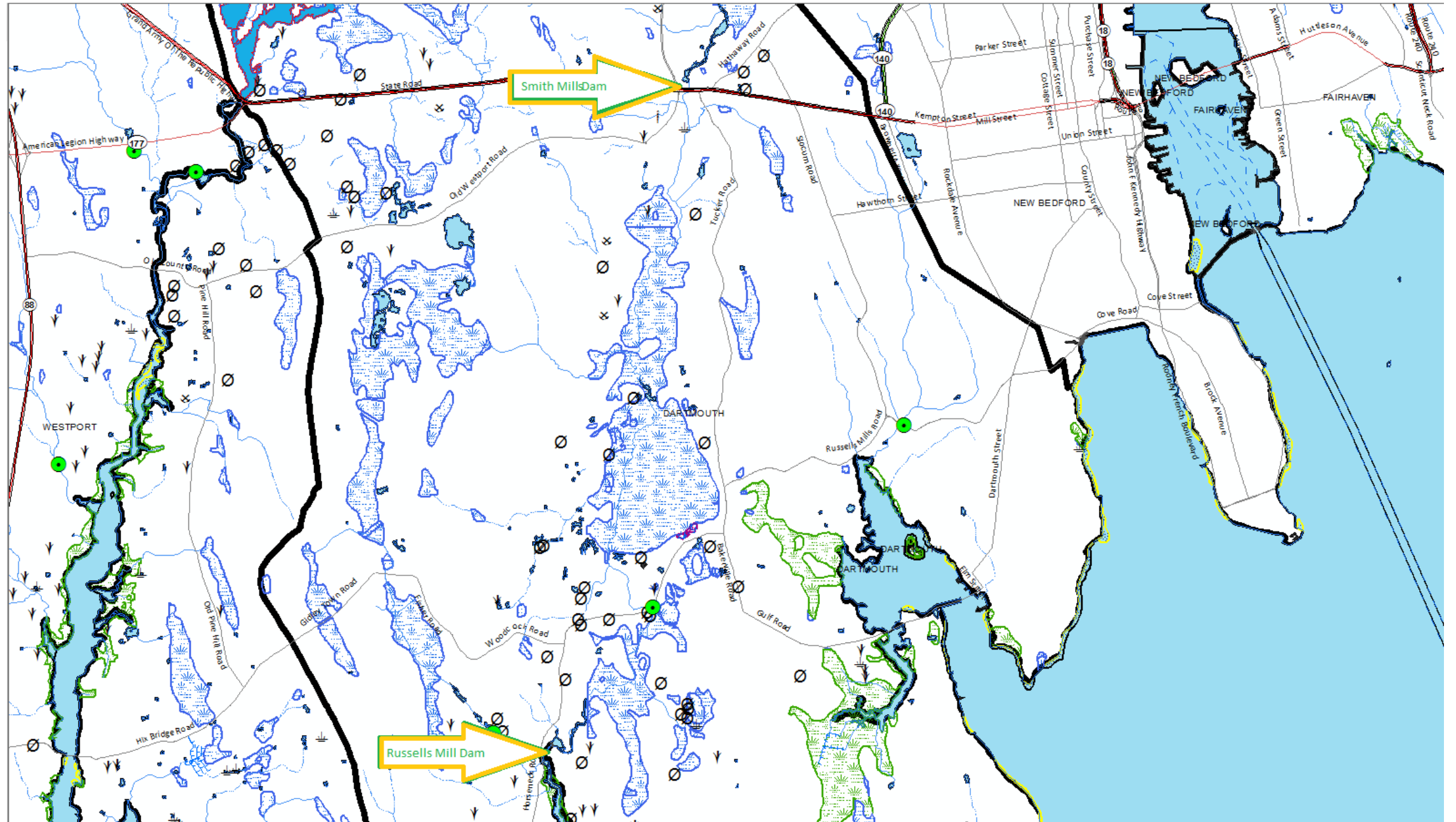
Below is section 6.17 of 322 CMR:

### 6.17 River Herring

- 1) Purpose. This regulation is promulgated to establish consistent state management of river herring fisheries not under local control of a city or town by operation of M. G. L. c. 130 s. 94.
- 2) Definition. For purpose of this regulation, the term River Herring means those species of fish known as alewives (*Alosa pseudoharengus*) and bluebacks (*Alosa aestivalis*).
- 3) Catching Days. It is prohibited and unlawful for any person to catch river herring on Tuesdays, Thursdays, and Sundays.
- 4) Daily Catch Limit. It is prohibited and unlawful for any person to catch more than 25 river herring per day.
- 5) Gear Restrictions. It is prohibited and unlawful to catch river herring with any net other than hand-held dip nets.
- 6) Exception. These regulations shall not apply to the catching of river herring in cities and towns which have acquired local control by operation of M. G. L. c. 130, section 94, or to the catching of herring authorized by the Director under 322 CMR 4.02 (1)(b) and (1)(c).

# Appendix H: Russells Mills Dam and Smith Mills Dam Locus Map

- USGS DATA COLLECTION STATIONS
- Soil Spot Features
- Point Features
  - Blowout
  - ✱ Bouldery Spot
  - ✱ Clay Spot
  - ✱ Dry Spot
  - ✱ Gravel pit
  - ✱ Gravelly spot
  - ⊖ Landfill
  - ⊖ Marsh or swamp
  - ⊖ Mine or quarry
  - ⊖ Rock outcrop
  - ⊖ Sandy spot
  - ⊖ Sinkhole
  - ⊖ Spoil area
  - ⊖ Stony spot
  - ⊖ Stripped land
  - ⊖ Very stony spot
  - ⊖ Wet spot
- Linear Features
  - || Levee
  - ~ Gully
  - Short, steep slope
  - Escarpments:
    - ▲ Bedrock
    - VA Other
- EOT-OTP Major Roads
  - Road Classification
  - Limited Access Highway
  - Multi-lane Hwy, not limited access
  - Other Numbered Highway
  - Major Road, Collector
- 1:25,000 USGS/MassDEP Hydrography
- Linear Features
- Water Bodies
  - ▭ Pond, Lake, Ocean
  - ▭ Reservoir
  - ▭ Wetland
  - ▭ Salt Wetland
  - ▭ Submerged Wetland
  - ▭ Cranberry Bog
  - ▭ Tidal Flat
  - ▭ Inundated Area
- TOWNSURVEY\_POLY



**Buzzards Bay Drainage Recommendations:**

1. Fish passage at the first two dams on the Acushnet River must be improved either by full or partial removal of the obstructions or by construction of efficient fishways.
2. An additional Denil baffle should be added to the entrance of the fishway on the Paskamanset River at Russells Mills in Dartmouth.
3. A short-term solution to the fish passage issue at Horseshoe Pond on the Weweantic River is to modify the existing millrace, possibly by inserting a section of aluminum steep pass. A long term answer, should funding become available, is to install a permanent Denil ladder.
4. Improvements should be made to the section of fishway under Route 6 on the Agawam River in Wareham in order to allow this system to reach its potential.
5. Cranberry bog owners on streams that have anadromous fish runs should be made aware of the impacts their operations have on these populations as well what measures can be taken to avoid them. Appropriate screening methods, flow regulation and mandatory fish kill reporting should be included in the conditions section of all state issued permits.

Appendix J: Russells Mills Dam Construction Agreement

Easement

Know all men by these presents that I, Mary L. Forsythe, widow, of Dartmouth, Bristol County, Massachusetts, grant to the Town of Dartmouth, a municipal corporation established by law and situated in said county and commonwealth, a perpetual easement and right for the purpose of laying, installing and maintaining the necessary sustaining walls and appurtenant fixtures to contain and direct the flow of water contained in the Paskamansett River situated in said Dartmouth in that area southerly of Rock O'Dundee Road, so-called and thence into Slocum River, so-called, as said Paskamansett River flows over across and through that strip of land in said Dartmouth bounded and described as follows:

Beginning at a point approximately 34 feet from the Westerly side line of Rock O'Dundee Road, said point of beginning being located at the end of a corrugated steel culvert located on the Northerly side line of the grantor's land; thence Westerly along side of the Northerly side line of the grantor's land a distance of approximately 45 feet to a point for a corner; thence Easterly parallel to and 10 feet from the second course described approximately 32 feet to a point for a corner; thence Northerly by the grantor's land a distance of 10 feet to the point of beginning.

The above described being part of lot #23 on Plat 58 on file with the Assessors office of the Town of Dartmouth and also on file with the Land Court Certificate # 10457, Document 30081 in the Bristol County Registry of Deeds (S.D.) in Plan Book 55 Page 77.

This easement shall include the right of the said Town of Dartmouth, as it shall determine from time to time, to enter upon said premises with men, tools, equipment and vehicles as necessity may require to construct, maintain, repair, replace and remove the said retaining walls, stones, and other material or any part thereof so constructed or maintained on said premises.

It hereby is understood that the said Town of Dartmouth will hold the grantor harmless from any liability incurred in the construction, maintenance, removal, repair, replacement or relocation of the said wall or other facilities located or to be located within the above granted land.

In witness whereof, I, the herein named grantor have hereunto set my hand and seal this twenty sixth day of March nineteen hundred and seventy four.

Mary L. Forsythe