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Fish Passage Design for the Center Falls Dam in Winchester MA

A Major Qualifying Project Report:

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WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Abstract

One of the main contributors to declining herring population in Massachusetts is the large number of dams along rivers. The focus of this project is fish passage design for the Center Falls Dam on the Aberjona River in downtown Winchester. Through the use of hydrologic, hydraulic, and structural analyses the dam was assessed. A fish passage was then designed for a denil passage along with alternative recommended designs for a steeppass fishway to provide a way for river herring to properly spawn upstream of the dam.

Authorship and Acknowledgements

The project was completed by two civil engineering students focusing in structural and environmental studies, Peter Eggleston and Anthony Guerra, respectively. The writing responsibilities were shared for the Introduction, Background, and Conclusion and Recommendations. For the Methodology and the Results sections of the report the work on hydrologic analysis, hydraulic analysis, and economic analysis was the responsibility of Anthony Guerra while the structural portions were the focus of Peter Eggleston. Any other additional writing not mentioned was completed collaboratively as a group effort.

The advisors of the project were Professors Leonard Albano and Paul Mathisen. Professor Mathisen provided guidance on hydrologic analysis and hydraulic modeling while Professor Albano focused on structural aspects of the project.

The team would also like to thank Brian Waz from the U.S. Fish and Wildlife Service, Doctor Brett Towler also from the U.S. Fish and Wildlife Service, and finally Nancy Dewall with Sheepscot Machine Works for providing valuable information regarding fish passage design.

Capstone Design

This project focuses on the design of a fish passage for the Town of Winchester in the Center Falls Dam on the Aberjona River. Two students authored the project; both majoring in civil engineering with focusses in structural engineering and environmental engineering. Through environmental and structural design analysis of existing conditions, a design for a denil passage along with recommendations for a steeppass fishway design that met the needs of the project was developed while meeting the Capstone Design requirements set by the American Society of Civil Engineers. By incorporating engineering standards and realistic constraints the following considerations were taken into account: environmental; health and safety; sustainability; manufacturability; social; economic; and ethical.

Environmental, sustainability, and manufacturability issues were considered with the design of the fish passage. The design needed to ensure that the herring would be able to successfully traverse the passage to restore some balance to the ecosystem upstream of the dam and allow for healthier spawning grounds to be reached. The designed passage also needed to meet the spatial restrictions imposed by the dam already in place and the separate floodgates used in its operation. There was also consideration of construction factors such as materials and standard dimensions.

Health and safety issues were addressed through the hydrologic analysis of the flow of the river and the structural analysis performed on the passage design and the dam from the new loadings which included the use of ACI and NDS standards to ensure a certain factor of safety and reliability in the design. A flow duration curve was created to study existing conditions and to predict the distribution of future flows over the dam. This allowed analysis of the effect of the proposed fish passage on the flows of the dam to ensure there wouldn't be any downtown flooding as a result of a fish passage being built on the dam. The flow analysis covers social aspects of the project as well since one of Winchester's historical attractions is the Center Falls Dam and the passage needed to be designed such that water was still flowing over the dam.

Economic issues were considered when the cost model of the final design and alternative designs were done. The models were based off similar products and quotes received from companies that design fish passages. This estimation addresses economic constraints by serving as a base that could be cut down to decrease cost or added to if there are to be adequate funds when the project comes to fruition.

The project also fulfilled ethical concerns by following the American Society of Civil Engineers code of ethics. Throughout the course of the project the team researched and worked to ensure that they were performing well within areas in which they felt they were competent. The end services provided to the Town of Winchester were done in an honest and impartial manner that attempted to enhance the environment around the dam for the benefit of the town.

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1.0 Introduction

With the growth and expansion of civilization, many manmade structures have been erected for varying purposes. One such type of structure is a dam which is used for retaining and collecting water for storage. While dams serve their purpose to humans for things such as reservoirs of drinking water and flood control, they also have a rather large environmental impact on the different ecosystems in which they are placed. Some of the negative impacts that dams have on the environment are the trapping of sediment that are critical to physical processes downstream of the dam; changes in temperature, chemical composition, and dissolved oxygen levels of the river or stream; and the blocking of fish migrations. New England, Massachusetts specifically, is home to a variety of different types of dams in various bodies of water across the state. Most of these dams serve as flood protection for communities that have risen around the rivers and streams throughout the state. Although the best solution to counter the negative environmental impacts of the dams would be removal of the dams this could lead to public safety issues, and so different methods have been taken to rectify the issues. One example of a riverway that is negatively impacted by dams in the state is the Aberjona River.

The Aberjona River is one of many rivers that lie in the Mystic River Watershed. It flows for over nine miles through the northwestern suburbs of Boston before it empties into the Mystic Lakes. As the areas around the river have become more settled, people have started to affect the river system and the wildlife within it more and more. With the advent of dams for flood control, the river's environmental habitat has been changing drastically. Two particular species affected by the changes are alewife and blueback herring, collectively known as river herring. Due to the dams built at various points on the Aberjona River, herring populations have declined because of these obstructions to their migration patterns. One dam on the riverway that impacts the migration of fish is the Center Falls Dam. The dam was recently upgraded, but it was not feasible to include a fish passage as part of this construction project. Many citizens and organizations still have a strong interest in incorporating a fish passage at this site. Through the installation of a fish passage, river herring can be provided an opportunity to reach more appropriate spawning grounds upstream.

The goal of this project was to design a fish passage to be implemented by the Town of Winchester in the Center Falls Dam on the Aberjona River, as seen in Figure 1, in order to accommodate the migration of aquatic life, in particular herring. The dam is a concrete arch structure used mainly as flood control. Typically before a big storm the impoundment is drained to allow for more storage as necessary to avoid flooding in the downtown area.

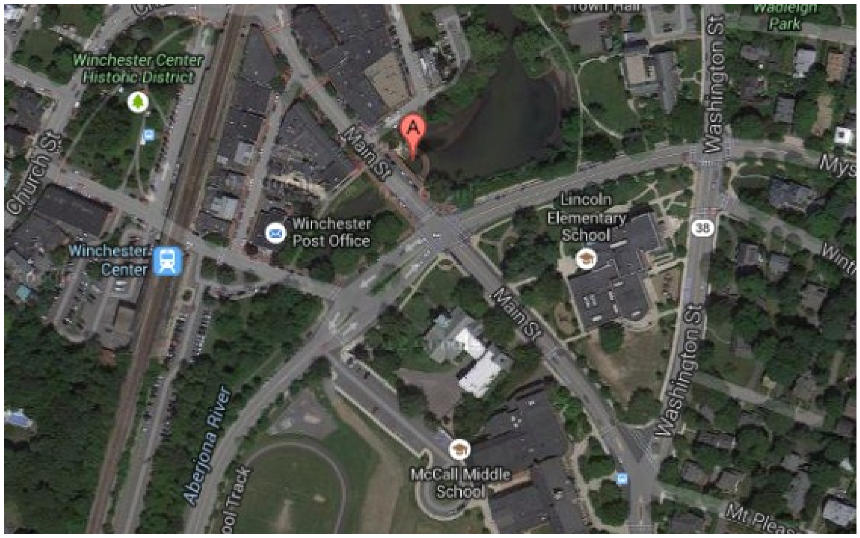


Figure 1: Map of downtown Winchester and the Aberjona River. Point A marks the Center Falls Dam (Google Maps, 2013)

For the Town of Winchester the concerns are mainly that the fish passage works aesthetically, fitting into the historical feel of the area, while also being affordable. In order to give the town a proper usable design a hydrologic and hydraulic analyses were performed on the dam. These analyses of existing conditions were followed by a design of a denil fish passage and recommendations for alternative designs of a steeppass fishway to ensure the best fit for the town. This also included a structural analysis for the designed fish passage. To finalize the design, a structural analysis was also performed on the dam to ensure the new loads from the passage wouldn't change the structural integrity of the dam. Using engineering standards and realistic constraints, all aspects of the design were completed in a manner that followed the requirements of capstone design as set forth by the American Society of Civil Engineers.

The remaining portions of the report walk through the background research needed to fully understand the project, the methodology and thought process behind the design of the passage, the results obtained with completion of the design, and the final conclusions and recommendations made at the end of the designing process. There are also various appendices that are referenced throughout the report that are attached at the end for any reader wanting more information on specific data as outlined in the report.

2.0 Background

The objective of the project was to design a fish passage for the Center Falls Dam in Winchester Massachusetts. In order to understand the scope of the project, background research was conducted. The more critical information needed to analyze the project was compiled into the following sections to provide information on herring, hydrologic and hydraulic analysis, and fish passages.

2.1 Herring

The Mystic River Watershed is home to a variety of aquatic life including river herring. Although there are two different types of river herring, they are generally categorized together due to the difficulties of distinguishing the two species. Both species of herring are considered to be anadromous, meaning that they are born in freshwater but then migrate to saltwater in the earlier stages of life. Some of the distinguishing characteristics of the two types of herring can be found in Table 1.

Table 1: Traits of Alewife and Blueback Herring

	Alewife	Blueback
Lifespans	Up to 10 years	Up to 8 years
Size	Lengths of 14 to 15 inches	Maximum size of 16 inches
Color Scheme	Bronze coloring in the dorsal region	Blue coloring in the dorsal region
Egg Production while Spawning	Females produce 60,000-300,000 eggs	Females produce 60,000-103,000 eggs

One important characteristic that the two types of river herring share though is swimming speeds. Herring, and other fish, have three basic swimming speeds: cruising, sustained, and darting. A cruising swim speed is one typically used for movement and migration that can be continuous for hours at a time. Sustained speeds are those that are maintained for minutes at a time, usually used to get through obstacles while migrating. Darting speed is a single effort used when feeding or sometimes for evasive purposes. The main ability for fish to navigate obstructions though can be based off of the species' sustained swimming speed but should be well under the darting speed of the fish (Bell, 1990). Fish passages can be considered as an obstacle that a sustained swimming speed throughout is acceptable for aquatic life migration. For blueback and alewife herring, the sustained speed is about 1.5 m/s or 4.9 ft/s. (Bell, 1990)

A rather unfortunate piece of data about river herring is the decline of the species. In a study by Peter Marteka (2004), he showed that from 1985 to 2003 there was a drastic drop in herring counts in the Connecticut River from approximately 600,000 herring to only 1300 respectively. These declining trends have also been observed in various states throughout New England including Massachusetts and the Mystic River Watershed. Today, both alewife and blueback herring are considered species of concern meaning that the NOAA National Marine Fisheries Service has inadequate information to place the species under the Endangered Species Act but there is concern for the viability of the species. Some factors behind the decline of the herring are habitat degradation, fishing, and loss of habitat from dam construction. (NOAA)

One way the decline of herring from dam construction is fought is through the installation of fish passages. These fishways provide a way for the fish to migrate upstream of dams to spawn in more suitable waters.

2.2 Fish Passages

The ideal solution for allowing fish to swim up an obstructed stream is to remove the obstruction. In the case that the obstruction is necessary, such as a dam for flood control, removal may not be a viable option as it may cause problems in the area. A fish passage is solution that can be applied in such a case. A fish passage is a structure that provides an alternate pathway that allows fish to navigate around a major obstacle. Implementing a passage for fish to swim around the obstruction will allow fish to migrate upstream relatively uninhibited while allowing the dam or other obstruction to remain in place. The United States National Oceanic and Atmospheric Administration (NOAA) and the United Nations Fisheries and Aquaculture Department (FAD) provide information on what should be considered when implementing a fish passage.

The FAD(2002) and NOAA(2013) state that the flow passing through a fish passage should be high enough for fish to migrate upstream while not being so high that the fish become fatigued. NOAA suggests that the flow within the fish passage be controlled within a range between a minimum flow and a maximum flow. The minimum flow is the lowest flow for which the species of concern is expected to be capable of traversing while the maximum flow is the highest flow in which the species is expected to traverse. The flow within the passage should exceed the minimum flow 95% of the time and exceed the maximum flow 5% of the time during the spawning season of the fish to be considered a successful passage. If the distance of the passage can tire fish, it is recommended to include rest areas of little to no flow where fish can stop while traveling up the passage.

The placement and orientation of the fish passage entrance should be considered carefully. Both NOAA(2013) and the FAD(2002) state that the entrance should be as far downstream from the obstacle as possible, but should also be placed in an area that the fish will notice the flow emitting from the entrance, known as the attraction flow. If there are high or turbulent flows near the obstacle, the fish may not sense the attraction flow and may miss the entrance. It may be better to place the entrance downstream of the obstacle where the water flow is calmer. The FAD suggests that the ideal orientation of the entrance is parallel with the river flow. This orientation will allow fish to enter without having to change direction too much. According to

NOAA, the direction the entrance is oriented depends on the attraction flow conditions. An entrance with a flow velocity higher than that of the surrounding river should be oriented 0 to 45 degrees from the direction of river flow while an entrance with flow lower velocity than that of the surrounding river should be oriented 45 to 90 degrees from the direction of river flow. If a flow high enough to attract fish cannot be achieved without exceeding the flow limits in the passage, NOAA suggests that additional flow be routed from elsewhere to increase the attraction flow near the entrance of the passage without increasing the flow within the passage.

The placement of the exit of the passage also needs to be considered upstream of the obstruction. Both NOAA(2013) and the FAD(2002) stress the importance of choosing a safe, calm location for the exit. Too much turbulence or a large change in velocity may make it difficult for fish to re-enter the stream and continue upstream. The exit should also be far enough upstream from the obstruction so that the fish do not get caught near the obstruction. For example, the high water velocities near the top of a dam may sweep fish entering the river back downstream.

Additional features may be included to increase the functionality of the passage. NOAA(2013) and the FAD(2002) both suggest features like a floating “trash boom” to block floating debris from entering the passage or providing a means to perform maintenance; this may include a gate at the exit to cut off flow through the passage. The FAD suggests placing a layer of substrate similar to that of the river bed along the bottom of the passage to create a more natural environment and to allow smaller migratory organisms to more easily navigate upstream. NOAA suggests implementing a hydraulic drop at the exit to increase the attraction flow into the river. NOAA also suggests placing an angled trash rack at the upstream exit to provide a method of filtering out debris that is easy to maintain.

2.2.1 Types of fish passages

Both the United States National Oceanic and Atmospheric Administration’s “Diadromous Fish Passage: A Primer on Technology, Planning, and Design for the Atlantic and Gulf Coasts” (US NOAA, 2013) and the United Nations Fisheries and Aquaculture Department’s “FISH PASSES Design, Dimensions and Monitoring” (UN FAD, 2002) present similar options for various aquatic passage designs. The three main types of fish passage design mentioned by the documents include Pool and Weir Fishways, Vertical Slot Fishways, and Baffled Chute Fishways.

2.2.2 Pool and Weir Fishways

Pool and Weir fishways, as seen in Figure 2, consist of consecutive chambers each with a weir located at the top of the downstream wall allowing water to flow into the next chamber. The fish swimming through this type of passage are able to swim over the weirs or if the fish is capable they potentially may jump from pool to pool under certain flow conditions. Additionally if they are present the fish may swim through orifices located near the bed of the passages. Orifices are only added when there is enough water; otherwise, the passage may be dewatered. These fishways function well with low flows; however, they require well-controlled head water levels. Variations in headwater will cause inconsistent flow within the passage. (UN FAD 2002, US NOAA 2013)

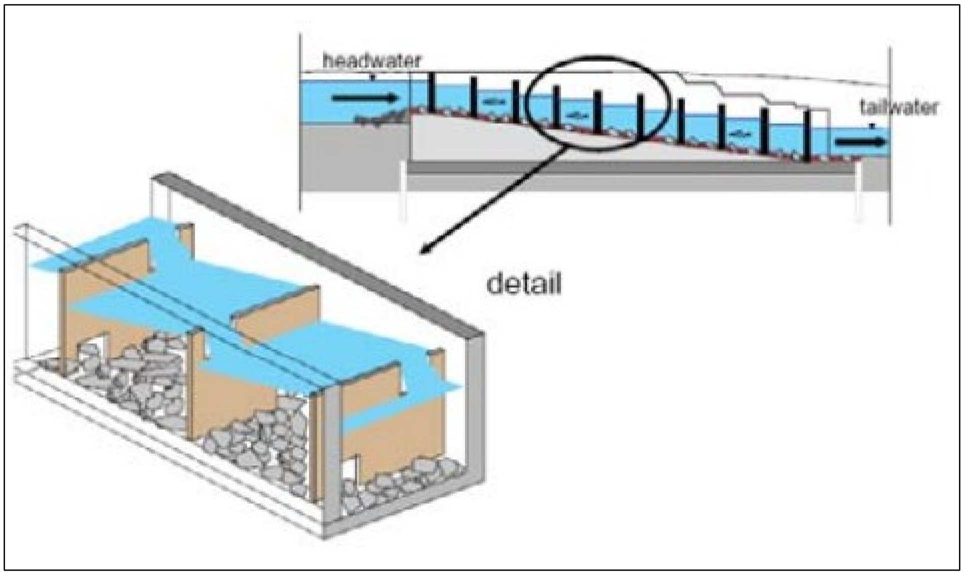


Figure 2: A diagram of a pool and Weir Fish Passage. (US NOAA 2013)

2.2.3 Vertical Slot Fishways

Vertical Slot fishways are more common along the Atlantic Coast of the U.S than the pool and weir passages and are effective in a wide range of flow conditions. This style of passage, seen in Figure 3, is both versatile and yields positive results for many Atlantic coast species including American shad, river herring, and striped bass. These fishways consist of consecutive walls with one or two vertical openings in each wall. Baffle plates are usually included to reduce turbulence and dissipate energy. The benefit of the vertical openings is that as the water level changes, the percentage of the wall that the water can flow through remains the same. The pools between the vertical slot walls also provide an area for fish to rest while traveling up the passage. One of the problems that can arise with this type of passage is that narrow slots may cause the descaling and death of some fish. (US NOAA 2013)

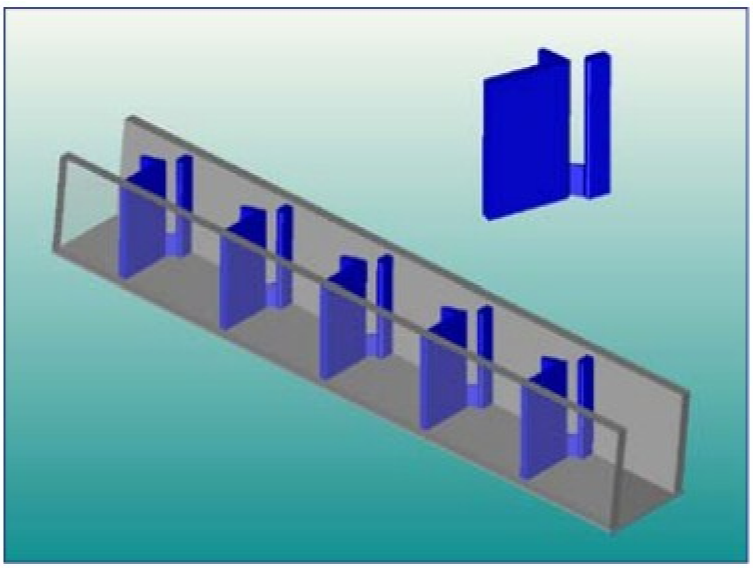


Figure 3: A diagram of a Vertical Slot Fish Passage. (US NOAA 2013)

2.2.4 Baffled Chute Fishways

Baffled Chute Fishways incrementally reduce hydraulic head through the use of baffles. The baffles allow for a controlled hydraulic step and the dissipation of energy. There are two main types of a Baffled Chute Fishway, the Denil Fishway and the Steeppass, both seen in Figure 4. Standard Denil Fishways tend to be easier to build than Steeppasses but standard Denil passages usually have a lower incline. The United Nations document Fish Passes: Design, Dimensions and Monitoring(UN FAD, 2002) provides many recommended guide values for Denil Passage design as seen in Table 2(also refer to Figure 5 for use with Table 2).

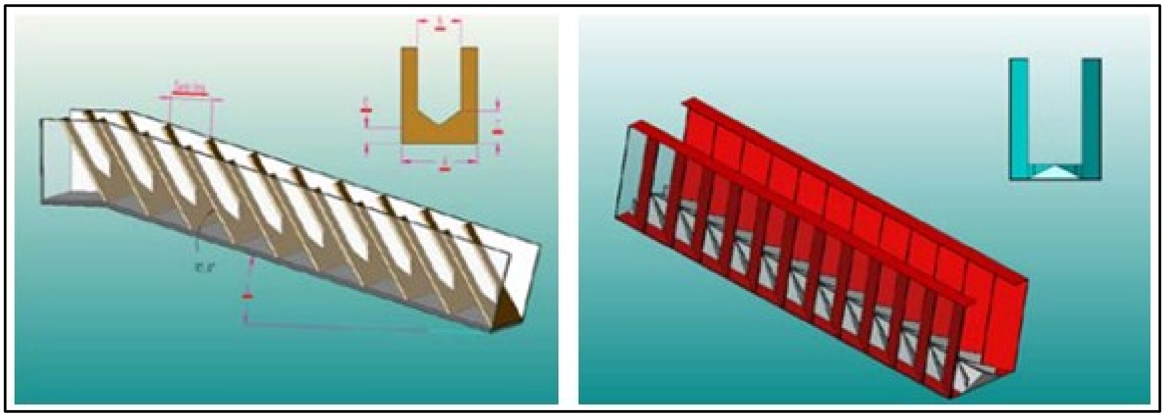


Figure 4: Diagrams of Baffled Chute Fish Passages. A Standard Denil Pass is shown on the left, and a Steep Pass is shown on the right. (US NOAA 2013)

Table 2: Recommended Guide Values(UN FAD, 2002)

	Tolerance Range	Recommended Guide Values
Baffle Width (b_a/b)	0.5-0.6	0.58
Baffle Spacing (a/b)	0.5-0.9	0.66
Distance between the lowest point of the cutout and the bottom(c_1/b)	0.23-0.32	0.25
Depth of the triangular section (c_2c_1)	2	2

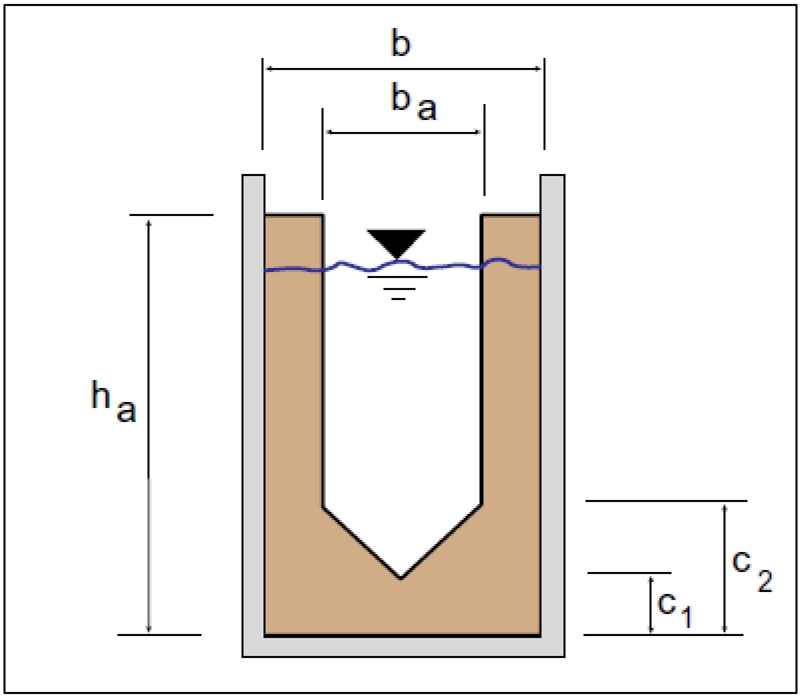


Figure 5: Baffle Dimensions

Steeppasses are more complex and more effective at dissipating energy than the Denil passage which allows Steeppasses to be built with greater inclines. (US NOAA 2013) This is useful for areas that require a large change in elevation in a short distance.

Both types of Baffled Chute Fishways can be built from a variety of materials and can be built for a relatively low cost compared to other fishways, such as pool and weir passages. Baffled Chute Fishways also have a few downsides to their use. If not properly maintained, the passage may become clogged. These fishways require a larger minimum flow than other passage styles. This flow needs to be met for the passage to function. During low flow conditions, the larger demand for water may increase the possibility of dewatering upstream. The high flow in this system may also cause problems for weaker fish. As with Vertical Slot Fishways, the baffles in the Baffled Chute Fishways may cause injury to the fish. (UN FAD 2002, US NOAA 2013)

2.2.5 Fishways Summary

Summarized in the Table 3 are some pros and cons for the fish passages considered for the project.

Table 3: Fish Passage Pros and Cons (Personal Communication, Towler, 2013)

Fish Passage Type	Pros	Cons
Pool and Weir	Relatively easy to engineer; used extensively in the past so they are familiar to many people	Not applicable where head water and tail water fluctuates significantly; many times used with jumping species or faster swimmers; can be difficult for young and older fish to pass
Denil	Relatively low cost due to prefabrication of some components; steep slope results in small footprint; suited for low to medium head dams	Turbulent flow field in the chute; susceptible to debris clogging; slower moving fish can struggle to pass through
Steeppass	Designed to be low cost and portable (mostly prefabricated); used for small watersheds or coastal streams	Low capacity for fish passing in the passage; not necessarily very aesthetically appealing as it sits out of the water
Vertical Slot	Naturally provides resting areas for fish in the passage; applicable to medium head dams	Mostly used in large scale on the west coast so scalability to the east coast can be a problem

Of the fish passages mentioned the two not considered for the project were the pool and weir and vertical slot style passages. It was determined that herring are not a jumping species of fish and their lack of jumping ability makes It difficult to use pool and weird passages under low flow conditions. The fact that tail water fluctuations are an issue also impacted the final decision to not include a pool and weir design for the project. The vertical slot passage was ruled out because of its lack of scalability to the smaller needs of the Winchester project.

2.3 Hydrology

Hydrology is a multidisciplinary subject dealing with topics ranging from fluid mechanics and hydrodynamics to the storage, circulation, and distribution of surface and ground water. In short, though, it can be said that hydrology is simply the study of the movement, distribution, and quality of water. One of the applications of hydrology is statistical hydrology where properties of hydrologic records such as river flow are used to estimate future flows. (Bedient, Huber, and Vieux, 2013)

A flow duration curve is one of the tools used in hydrologic analysis. The curve is based off a river's flow data typically taken over the course of yearly timespans, obtained from gauge data many times recorded in the USGS database. The curve is a cumulative frequency curve that shows the amount of time a specified discharge value is equaled or exceeded over a given period of time. The curve disregards sequence of flows and allows for interpretation of the flow characteristics of the stream in question. Using a flow duration curve can allow for future predictions of flows in a stream and can be used to predict expected flows in fish passage design. (Searcy, 1959)

2.4 Hydraulic Engineering

Hydraulic systems, such as dams and fish passages, are designed to transport, store, or regulate water. Although an understanding of hydrology, soil mechanics, structural analysis, and environmental engineering is needed to understand these systems an application of fundamental fluid mechanics is required for all hydraulic systems. Each hydraulic project tends to have its own constraints to which it must adapt. Most systems are designed with topography, geography, ecology, social concerns and material availability in mind. (Houghtalen, 2010)

The flow of the water going through or over a hydraulic system, in this case the dam, can change if another hydraulic system, the fish passage, is added to the overall system. Hydraulic analysis is used for the project to model the flow of water over the dam for existing conditions and to develop an understanding for the impact a fishway could have on the dam. The analysis also allows for a judgment to be made on the placement of the entrance and exit to the proposed passages. Flow over the dam in the situation of the arched Center Falls Dam can be modeled as a curved broad crested weir. Khosrojerdi and Kavianpour (2002) provides the following equation for analysis of a curved broad crested weir:

Equation 1

$$Q = C_d * B * h^{1.5}$$

Where:

Q = the flow passing over the dam

B = the arc length of the dam (as seen in Figure 6)

h = the depth of water over the dam

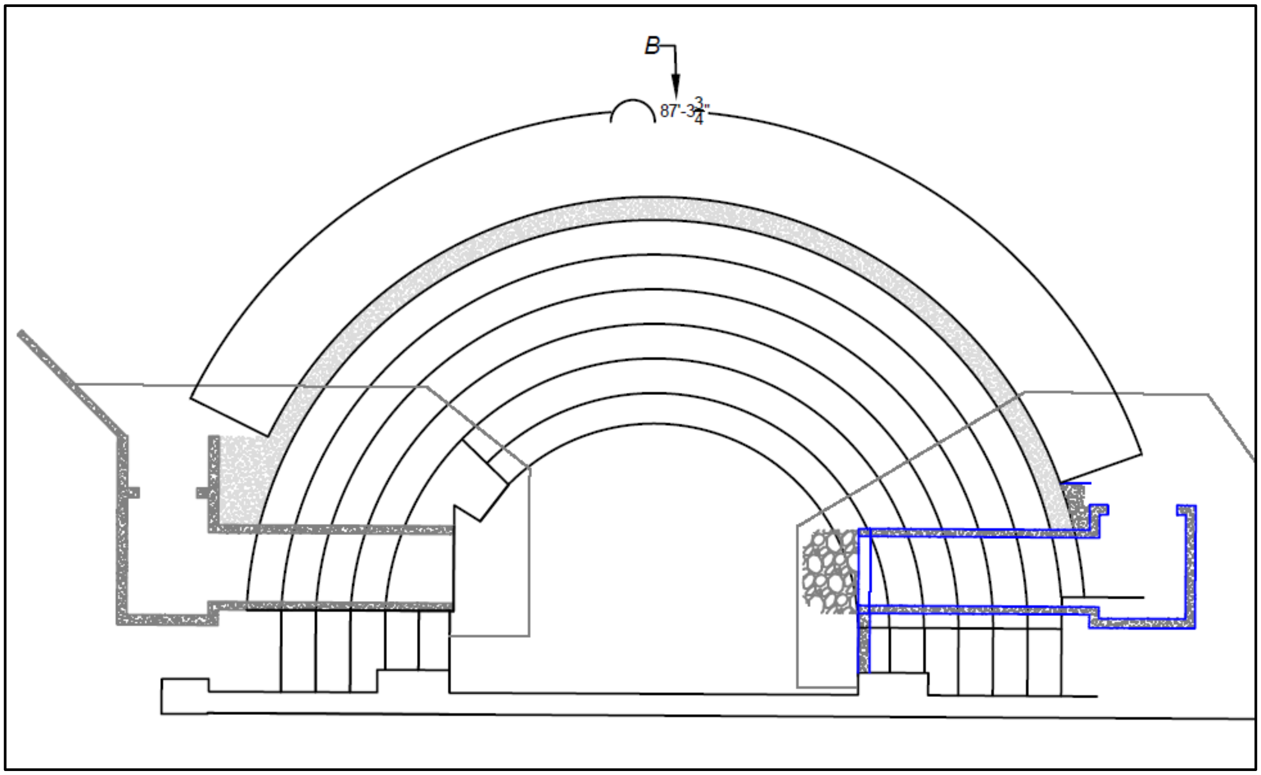


Figure 6: Overview of the Center Falls Dam from blueprints in Appendix C

Length = *B*

C_d is a constant determined by the equation:

Equation 2

$$C_d = \left(0.5 + 0.33 * \frac{h}{P} + \frac{h}{L}\right)^{0.6}$$

Where, as seen in Figure 7:

$L =$ the thickness of dam

$P =$ the height of the dam

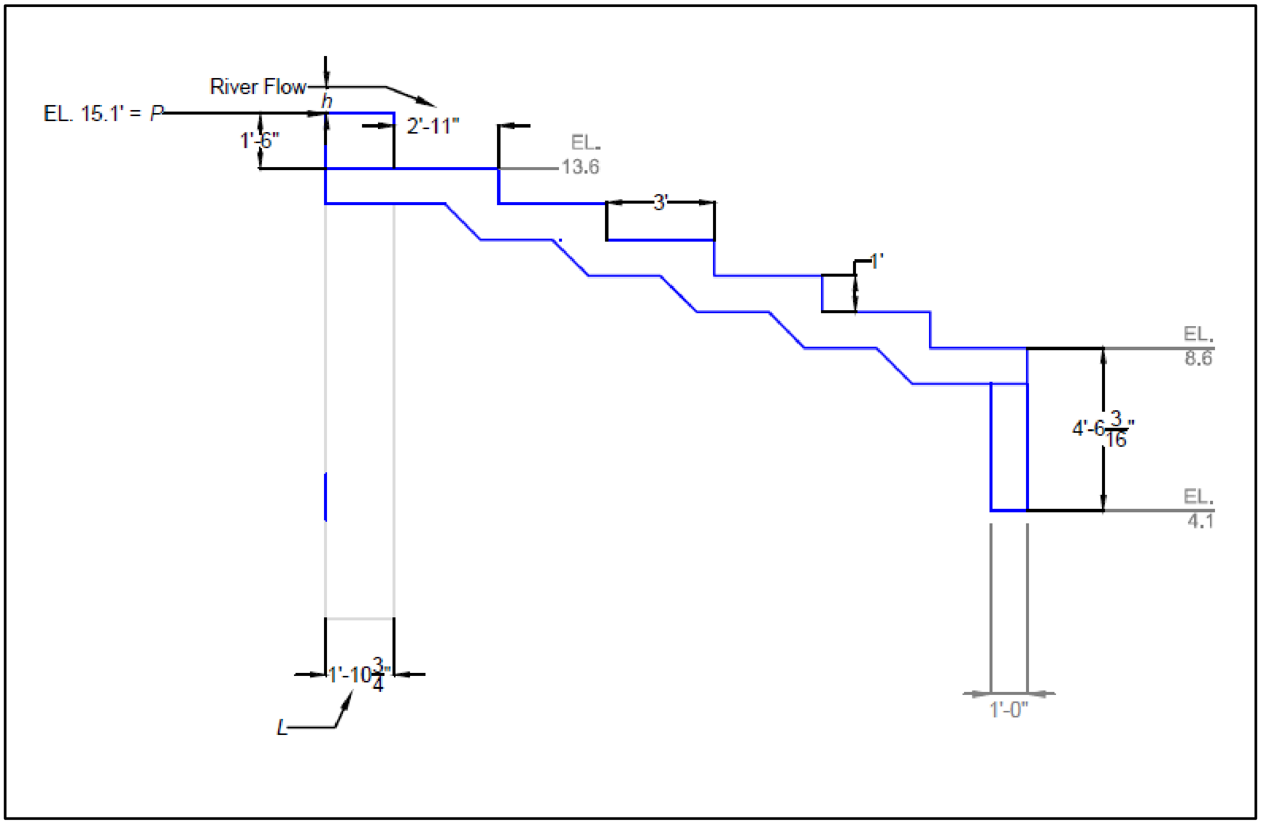


Figure 7: Section of the Center Falls Dam from blueprints in Appendix C

The downstream flow of the river is also an important characteristic that can be modeled using Manning's equation as provided by Houghtalen (2010):

Equation 3

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

Where:

$Q = the\ flow\ of\ the\ river$

$n = Manning's\ roughness\ coefficient$ - Value to be looked up: in the case of the Aberjona River downstream of the Center Falls Dam it can be taken to be 0.035 as based off of charts in (Houghtalen 2010)

$A = cross\ sectional\ area$

$R = hydraulic\ radius$

$S = stream\ grade$

and:

$$A = by$$

$$R = \frac{by}{b + 2y}$$

Where:

$b = the\ width\ of\ the\ river$

$y = depth\ of\ the\ river$

2.5 Structural Analysis

The structural analysis for the project mainly focused on the fish passages. It started with designing the thickness for the baffles, channel reinforcement, and then was completed with an analysis of the new loadings on the dam from the proposed passages.

2.5.1 Baffle Design

In order to determine the thickness for the baffles of a fish passage the amount of force that they would have to withstand must be calculated. To determine the force applied to the baffles due to water impact, the following equation referenced from Houghtalen (2010) can be applied:

Equation 4

$$F = \rho * Q_p * (V_2 - V_1)$$

Where:

F = Force applied by water on the baffle

$\rho = density\ of\ water = 1.94 - slug/ft^3$

Q_p = Flow through the passage

$V_2 = 0$ = The assumed final velocity of water after impact

V_1 = The initial velocity of water before impact

When the force due to water impact is determined, the force can then be divided by the projected area of the baffle to determine a distributed load.

Equation 5

$$P_{impact} = \frac{F}{A}$$

Where:

P_{impact} = distributed Load

A = Area of baffle

The loading due to water pressure must also be considered and can be calculated using the following equation:

Equation 6

$$P_{pressure} = \gamma * h^*$$

Where:

$\gamma = specific\ weight\ of\ water = 62.3 - lb/ft^3$

This is not the only force of concern for the baffles though. The baffles must be able to resist the bending and shear stresses created by the combined impact and pressure forces. The thickness of the baffle is established based on the more critical stress condition, bending or shear.

2.5.2 Reinforcement

Concrete is a material which has high compression force resistant but limited tension capacity. Tensile reinforcement is then needed to counter this point of failure. ASTM and ACI have developed standards when reinforcing concrete with re-bar detailing specific bar sizes, grades, and required amount of coating. These standards were followed during the design of the passage channel.

When adding reinforcement, a minimum thickness of concrete cover is needed to protect the steel reinforcement. ACI has developed standards for the minimum coverage thickness needed in different situations. The applicable situations for the project include a minimum coverage of 2.5 inches for concrete exposed to water and 3 inches for concrete in contact with the ground as stated in ACI 350 (ACI vol. 4 2010).

2.5.3 Loadings on the Dam

Installation of the fish passage will involve removing a small section of the dam and placing the upstream end of the fish passage on the dam. Removing a section will weaken the dam and the passage will also add to the loads that the dam experiences. The dam was analyzed under the conditions of the added fish passage to determine if additional reinforcement is necessary in order for the dam to remain structurally stable.

2.6 Center Falls Dam

The Center Falls Dam, seen in Figure 8, in Winchester Massachusetts is an arched dam that water flows over and down arched steps. This dam is located in the path of herring migration. Juvenile herring have been observed by the project team near the base of the dam. It was also observed the herring are most likely to spawn near or under a bridge that is located just downstream of the dam (B. Chase, October 2013). Adult herring most likely mate in this location because they cannot travel further upstream due to the dam. The dam may be considered a curved, broad-crested weir to calculate characteristics of flow passing over the top. (Refer to Appendix C for blueprints of the physical structure of the dam)

Figure 8: The Center Falls Dam, Winchester MA

At the time of this project the Center Falls Dam was under construction. The construction began with the replacement of a gate valve and was extended when it was discovered that a portion of the dam's cascading steps had collapsed and needed to be repaired. During construction, water flowing from the Aberjona River was diverted through a butterfly valve normally used for low flow conditions. The dam currently does not have a fish passage.

2.7 Summary of Background

The Center Falls Dam needs a fish passage to allow for the herring population in the area to thrive. Although there are various types of passages for different situations, two options were explored for the project that the team determined would best fit the constraints of the project scope. The denil passage was fully designed while the steeppass was considered as an alternative design. A design was not developed for the steeppass fishway because this passage is typically prefabricated with pre-determined sizing. The next chapter details the methods used to determine the design of the fish passage. It encompasses data collection, a literature review, a hydrologic and hydraulic analysis, and a structural analysis for both the passage and the dam.

3.0 Methods

The goal of this project was to develop a design that would accommodate fish passage for the Center Falls Dam on the Aberjona River in Winchester, MA. The main tasks done to achieve this design are outlined in this chapter and are as follows:

- data collection
- literature review
- hydrologic analysis
- hydraulic analysis
- design of the passages
- structural analysis
- economic analysis

3.1 Data Collection

The collection of data was the start of the research for the project. During a site visit on September 18, 2013, general observations of the dam were made. Blueprints of the dam were also obtained from Brian Waz, a Hydraulic Engineer from the US Fish and Wildlife Service, who explained details of the dam including the necessary determined location for the fish passage. Historical flow data of the Aberjona River was obtained from the United States Geological Survey (USGS) website. The data obtained includes the average flow for each day during the spawning months for the herring (April through June over the past thirty years) as recommended by Brett Towler and Brian Waz, hydraulic engineers from the US Fish and Wildlife Service.

The site was visited a second time on November 30, 2013. A survey was done to identify the slope grades around the dam for input to the hydraulic analysis and to determine the spine of the river upstream of the dam. This provided useful information on placement of the fish passage in relation to where the main flow of the river occurs.

3.2 Literature Review

Background information used during the project was gathered from various sources such as textbooks, journal articles, and meetings with engineers from the US Fish and Wildlife Services and biologist from the Massachusetts Division of Marine Fisheries. The range of subjects of information included biology, hydrology, fluid mechanics, structural analysis, and fish passage design.

Different styles of fish passages were researched. Both the United Nations Fisheries and Aquaculture Department and the United States National Oceanic and Atmospheric Administration have produced documents presenting fish passage styles and designs. Using these documents, multiple styles of fish passages were examined to gain an understanding of the benefits and problems produced by each style. This research allowed the team to narrow down the number of passages worth pursuing for the project. The overall knowledge obtained from these resources also allowed for a base to which the passage could be designed.

3.3 Hydrologic Analysis

Before designing the passage it was necessary to determine maximum, minimum, and average daily flows for the river. In order to determine these values the data obtained from the USGS flow gauge in the river was analyzed. Using basic Microsoft Excel functions, the average daily flow was calculated. Because the velocity of the flow within the passage should exceed the minimum velocity 95% of the time (i.e. the minimum velocity that herring are expected to be present) and exceed the maximum velocity 5% of the time (i.e. the maximum velocity that herring are expected to be present) during the spawning season, a flow duration curve was needed to determine expected greatest and lowest 5% river flows.

Using the historical flow data of the Aberjona River gathered from the USGS a flow duration curve was created in order to determine the 95% minimum flow (i.e. flow that is exceeded by 95% of the flows) and 5% maximum (i.e. Flow that is exceeded by 5% of the flows) along with the ability to make predictions on future flows for the river. Using Microsoft Excel, the discharge data from the past 30 years, a value recommended by Dr. Brett Towler (personal communication,2013) to get a good representation of the river, was ranked. The following formula was then applied to calculate the probability of exceedance:

Equation 7

$$P = \frac{M}{n+1}$$

Where:

$P = probability\ that\ a\ given\ flow\ will\ be\ equaled\ or\ exceeded$

$M = the\ ranked\ position\ on\ the\ listing$

$n = the\ number\ of\ events\ for\ the\ period\ of\ record$

Once the probabilities were obtained, they were graphed against the discharges to allow for prediction of the percent of time certain flows could be expected to be equaled or exceeded.

3.4 Hydraulic Analysis

The hydraulic analyses included modeling of the flow over the dam, downstream of the dam, and through the fish passage. The amount of flow is influenced by the flow available to pass through the fish passage, while the velocity of the flow and turbulence affects the ability of the fish to enter the stream from the passage. Using the equations from Khosrojerdi and Kavianpour(2002), excel was used to graph a relationship between the flow over the dam (Q) and interval values for the depth of water over the dam (h). The graph was then used to generate an equation based off of a best fit curve of the data points in order to solve for h from given values of Q. The equation generated is as follows:

Equation 8

$$h = 0.0529 * Q^{0.6588}$$

Values for *h* were then determined from the daily flows retrieved from the USGS database; however, focus was placed on the overall average flow and the low flow expected to be exceeded 95% of the time along with the high flow expected to be exceeded only 5% of the time as determined from the flow duration curve.

The downstream values for the river were modeled using Manning's equation. Using the flows calculated for the 95% minimum, 5% maximum, and average flow of the river as a base, the depth of the river was calculated for each of those points. The known values for the equation were entered and the equation was set to zero and graphed. This provided a way to determine *y*, the only unknown variable. Once the values for *y* were obtained the velocity of the river was determined for each of the design flows.

3.5 Design of the Passage

Two styles of fish passage were chosen that best fit both spatial and flow restrictions of the project. The styles chosen had to be capable of carrying adequate flow for the migrating fish while remaining small enough to fit in the allotted area. Due to spatial restraints, the styles available to be implemented were restricted. Different building materials were also considered. The final designed passages were meant to be as inexpensive as possible while providing adequate structural integrity. The material and style of the passages were also designed with aesthetics in mind since the project is in a heavily populated downtown area.

Certain aspects of the passages by nature are the same, such as the entrance and exit locations. Using the results of the hydraulic analysis of the dam and through meetings with experts in the field, the best location for the entrance and the exit of the passages were chosen. Bradford Chase, a marine biologist of the Massachusetts Division of Marine fisheries confirmed that the fish passage entrance should be at the base of the dam. The fish can be expected to search along the base of the dam until they hit the attraction flow produced by the passage. The exit of the passages was determined with the help of Brian Waz with the U.S. Fish and Wildlife services. During low flows, it is expected that the flow should still be higher at the spine even if there are dry spots elsewhere on the river. The spine will also produce consistent flows that will provide the fish with a sense of direction for upstream travel to ensure the fish don't inadvertently swim downstream and over the dam.

3.5.1 Denil Passage

Using Fish Passes: Design, Dimensions and Monitoring(UN FAD, 2002) as a guide, the pass was designed with an assumed channel width (b) of 2.5 feet due to the spatial restrictions of the site and the steepness of the desired chosen slope of 1 on 5. This slope was chosen so as to limit the length of the passage as much as possible to keep costs lower. The passage design also took into consideration the many recommended values for baffle traits, as seen in Table 2 in the background, and used the guide values to calculate the dimensions for the baffles inside the passage.

3.5.1.1 Determining the Height of the Water in the Passage

Another parameter used in the passage design was the expected perpendicular height of the water in the passage, here on referred to as $h*$ as seen in Figure 9. According to the design manual $h*$ should never be less than 1.15 ft and can be calculated by rearranging Kruger's equation:

Equation 9

$$h^{*} = b_a{}^{1.584}\sqrt{\frac{Q_p}{1.35 b_a^{2.5}\sqrt{gI}}}$$

Where:

$h^{*} = perpendicular\ height\ of\ the\ water\ in\ the\ passage$

$b_a = inner\ baffle\ width$

$Q_p = flow\ of\ the\ passage$

$g = acceleration\ due\ to\ gravity\ (32.2\ ft/s^2$

$I = slope\ of\ the\ channel$

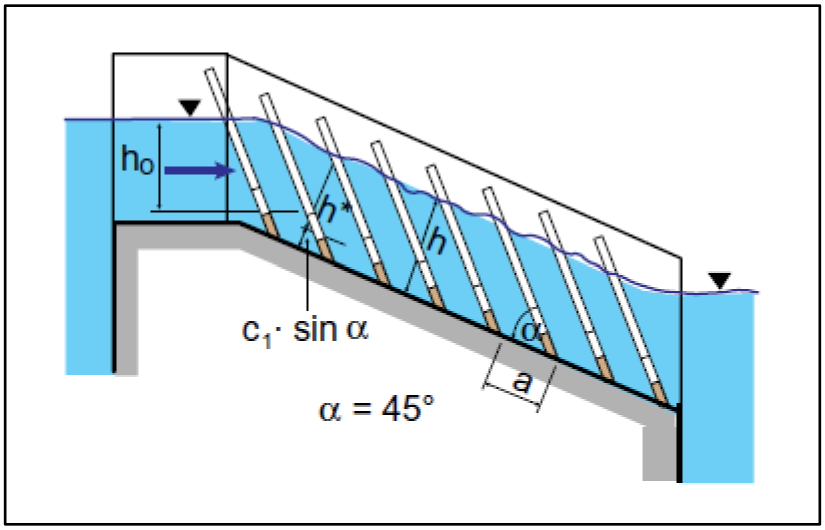


Figure 9: Side profile of a denil passage from Fish Passes: Design, Dimensions, and Monitoring (UN FAD, 2002)

Another necessary parameter was the level of the lower edge of the first baffle section, also referred to as h_o, which could be found using h* with a graph provided by United Nations text (UNFAD, 2002), see Figure 9 for a visual representation of h_o. Eight points were graphed from the provided graph in Microsoft Excel in order to create a best fit curve so that an equation could be derived for h_o as seen in Figure 10.

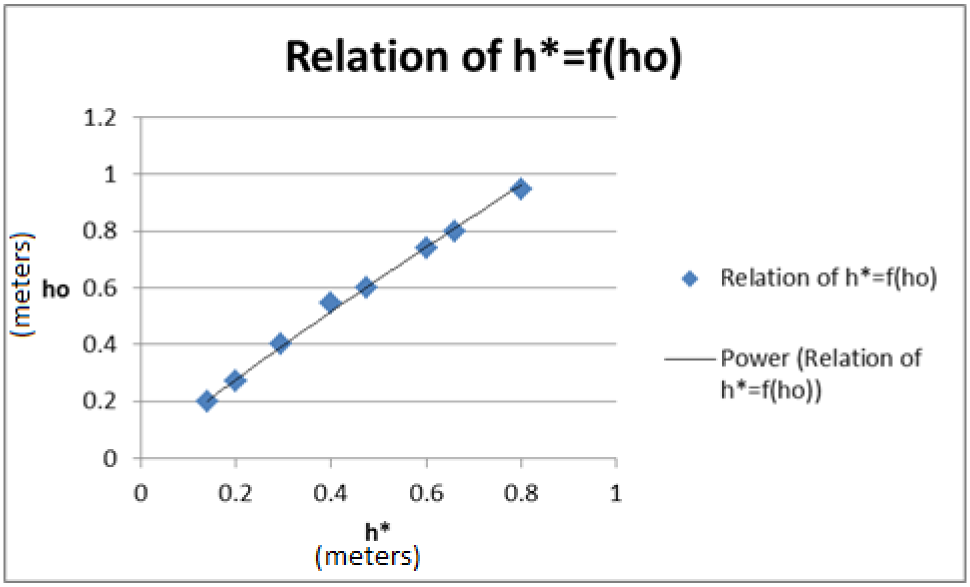


Figure 10: Relation of h to ho from Fish Passes: Design, Dimensions, and Monitoring (UN FAD, 2002)*

3.5.1.2 Flow Conditions

The next aspect analyzed was the flow going through the fish passage and determining how far of an offset the fish passage needed to be from the dam. Once the equations for h*were obtained values for Q_p were determined ranging from 2.5 to 52.5 cubic feet per second with intervals of 2.5 cubic feet per second. According to the guide document Fish Passes: Design, Dimensions, and Monitoring (UN FAD 2002), the ratio of h^*/b_a should range from 1.5 to 1.8. These values for h* determined the optimum desired flow going through the passage. After that, values for h_o were calculated from the h* values. Using these numbers a value was set for the distance from the bottom of the fish passage to the top of the dam starting from zero and going up to two feet in 0.05 ft intervals. Since the flows through the passage and over the dam combine to make up the total flow of the river, these intervals were used to calculate the flow of the river using the following formulas:

Equation 10

$$Q_r = Q_d + Q_p$$

Equation 11

$$Q_d = \left(\frac{h_o - x}{0.0528}\right)^{\frac{1}{0.6588}}$$

and so it can be deduced that:

Equation 12

$$Q_r = \left(\frac{h_o - x}{0.0528}\right)^{\frac{1}{0.6588}} + Q_p$$

Where:

$Q_r = the\ flow\ of\ the\ river$

$Q_d = the\ flow\ over\ the\ dam$

$Q_p = the\ flow\ of\ the\ pass$

$x = the\ distance\ from\ the\ bottom\ of\ the\ fish\ passage\ to\ the\ top\ of\ the\ dam$

$h_o = the\ level\ of\ the\ lower\ edge\ of\ the\ first\ baffle\ section$

See Appendix D for the data obtained in calculations.

Once the values for the flow of the river were calculated they were compared to the data from the flow duration curve. Values were chosen for x based on the percent of time the height of the water through the passage was in the ideal range where h^*/b_a remained 1.5-1.8 for the majority of the time.

3.5.1.3 Verification of the Flow Height Upstream

Once x was established the difference in height of the upstream flow and h_o needed to be verified to ensure the value for x could be used. In order to verify that the upstream height of water above the bottom of the fish passage and the value obtained for h_o were essentially the same, the following energy conservation equation provided by Professor Mathisen of Worcester Polytechnic Institute was applied:

$$h_1 = h_o + \frac{Q^2}{2gb^2h_o^2}$$

Where:

h_1= the upstream height of water above the fish passage bottom

g= acceleration due to gravity

3.5.1.4 Resting Pool Design

A resting pool was designed for the denil passage using the following design equation from *Fish Passes: Design, Dimensions, and Monitoring* (UN FAD, 2002):

Equation 13

$$E = \frac{\frac{\rho}{2}Qv^2}{b_m h_m l_b} < 25\ to\ 50\frac{w}{m^3}$$

Where:

E= the volumetric power dissipation

Q= maximum flow through the passage

ρ = density

b_m= width of the resting pool

h_m= water depth of the resting pool

l_b= length of the resting pool

$v = \frac{Q}{h^* b_a}$ = velocity

Values for b_m and l_b were assumed to be 2ft each to have a square pool that would be the width of the passage for each of construction. From this h_m was calculated.

3.5.2 Steeppass Passage

The width of the Steeppass to be designed was assumed to be 3ft based off of spatial restrictions to the site. The rest of the calculations were based off of this specified width for the passage.

3.5.2.1 Determining the Height of the Water in the Passage

The *Canadian Journal of Engineering* (Katopodis, 1991) provides the following equation relating flow through a steep pass to characteristics of the passage.

Equation 14

$$\frac{Q_p}{\sqrt{g * S_o * b^5}} = 0.97 * (\frac{y_o}{b})^{1.55}$$

Where:

Q_p = Flow through the steep pass

g = acceleration due to gravity = $32.2\, {}^{ft}/_{s^2}$

S_o = Slope of the steep pass

b = width of the steep pass

y_o = depth of water within the steep pass

From the equation, y_o (as seen in Figure 11) was determined in the following expression:

Equation 15

$$y_o = \sqrt[1.55]{\frac{Q_p}{0.97 * \sqrt{g * S_o * b^5}}} * b$$

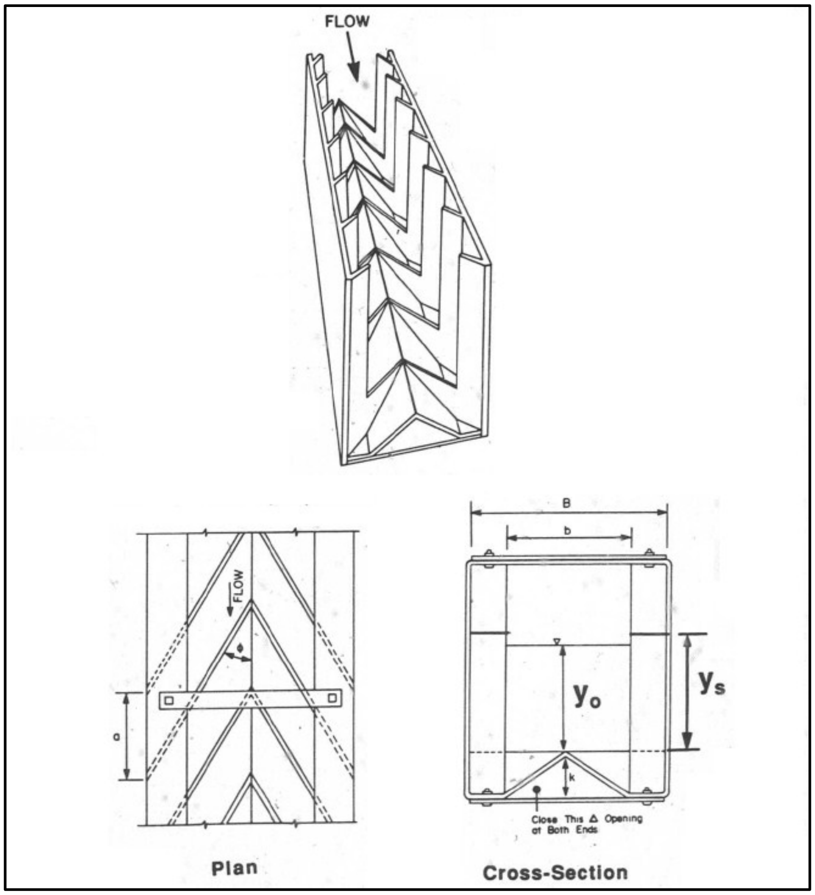


Figure 11: Details of the steeppass fishway from Hydraulics of Steeppass Fishways

In order to ensure that the fish passage contains an adequate minimum flow even during low river flow, it is possible to place the exit of the fish passage lower than the top of the dam. Since the water level of the river will be the same flowing over the dam and through the fish passage, the difference in depth of the water through the passage and over the dam is equal to the height offset of the passage from the dam, refer to Figure 11 for details of the steeppass fish passage. The following equation was determined to relate the water depth through the steep pass and over the dam:

Equation 16

$$y_o = h + x$$

and

$$h = y_o - x$$

Where:

$h =$ depth of water over the dam

$h = 0.0528 * \, Q_d{}^{0.6588}$ (as determined in Section 3.4)

x = vertical distance from the bottom of the fish passage to the top of the dam

Substituting "y_o" and "h" with their given equations yields the following:

Equation 17

$$0.0528 * Q_d^{0.6588} = \sqrt[1.55]{\frac{Q_p}{0.97 * \sqrt{g * S_o * b^5}}} * b - x$$

3.5.2.2 Flow Conditions

The flow over the dam, Q_d, was solved for resulting in:

Equation 18

$$Q_d = \sqrt[0.6588]{\left(\frac{\sqrt[1.55]{\frac{Q_p}{0.97 * \sqrt{g * S_o * b^5}}} * b - x}{0.0528} \right)}$$

Since again the flows through the passage and over the dam combine to make up the total flow of the river, the river flow "Q_r" may be expressed the same as in equation 6.

Substituting for "Q_d" in equation 6 yields:

Equation 19

$$Q_r = Q_p + \sqrt[0.6588]{\left(\frac{\sqrt[1.55]{\frac{Q_p}{0.97 * \sqrt{g * S_o * b^5}}} * b - x}{0.0528} \right)}$$

The equation above expresses the flow of the river in terms of the variable flow through the steep pass. The values of the passage/dam height offset (x), the slope (S_o), passage width (b), and gravitational acceleration (g) all remain constant. In order to estimate an ideal value for x, a spreadsheet chart was formed to calculate the river flow from given values of x and Q_p. The remaining variables were assigned the following values:

$b = 2.5$ – ft

$S_o = \frac{11}{45}$ – ft/ft (based off of the height change and allotted channel length of the dam)

$g = 32.2\ ^{ft}/_{s^2}$

Multiple values for Q_p were used, ranging from 2.5 to 52.5ft^3/s with an interval of 2.5. Multiple values for x were also used, from 0 to 2 feet with an interval of 0.05 ranging. The required river flow was calculated for each combination of Q_p and x values.

In order to determine the ideal flow through the fish passage, the water velocity was calculated for multiple passage flows. The following equation was used:

Equation 20

$$V = \frac{Q_p}{A}$$

Where:

V = velocity in $ft/_s$

Q_p = passage flow in $ft^3/_s$

A = area in ft^2 = $b * y_o$

b = 2.5 ft

y_o = water height in ft = $\sqrt[1.55]{\frac{Q_p}{0.97*\sqrt{g*S_o*b^5}}} * b$, from Equation 10

The water velocity was calculated for passage flows ranging from 2.5 to 50 ft^3/s using intervals of 2.5 ft^3/s.

3.6 Structural Analysis

A structural analysis was conducted for the design of the denil fish passage and for the dam with the new loadings on it from the designed fish passage. The following sections outline the various design loadings that were considered for the different parts of each structure.

3.6.1 Denil Passage: Baffle Design

The first portion of the Denil structural analysis was determining the necessary thickness of the baffles. The loading applied to the baffles was considered for a worst case scenario situation. In this situation, a baffle is completely clogged and the passage is completely filled causing a maximum impact load. The portion of the fish passage downstream of the clogged baffle is also assumed to be empty causing a maximum pressure loading on the baffle.

3.6.1.1 Forces

The forces applied to the baffle were determined using the equations explained in section 2.5.1 Baffle Design. The final water velocity (V_2 in equation 4) after coming in contact with the baffle was assumed to be zero for a worst case scenario.

Since the passage was assumed to be filled, the water level (h* - as seen in Figure 9) was assumed to be equal to the height of the baffles (2.9-in). From section 3.5.1, the values for h* were calculated for values of Q_p and placed in a chart. From this chart, the value for Q_p was determined for when h* = 2.9-in.

From the determined value for Q_p, V_1 was calculated as the velocity of water through the passage using the following equation from *Fish Passes: Design, Dimensions, and Monitoring* (UN FAD, 2002).

Equation 21

$$V_1 = Q_p/(h^* * b_a)$$

Where:

b_a= width of baffle opening

Once the distributed load (P_{impact} in equation 5) and the loading due to water pressure were determined, the total loading on the baffle was calculated by combining the loadings from both the water impact and pressure in order to assume the largest possible load. A load factor of 1.6 was also added for a measure of safety.

3.6.1.2 Bending Strength

The cross section of the baffle was divided into separate portions, as seen in Figure 12, for which the bending and shear stresses were then calculated independently. Doing this made the stress calculations for the baffle easier and assumed a larger stress on the baffle segments, so the thickness calculated with this method would be more than adequate for the expected conditions in the passage. The portion of the baffle that requires the largest thickness determined the thickness for the entire baffle.

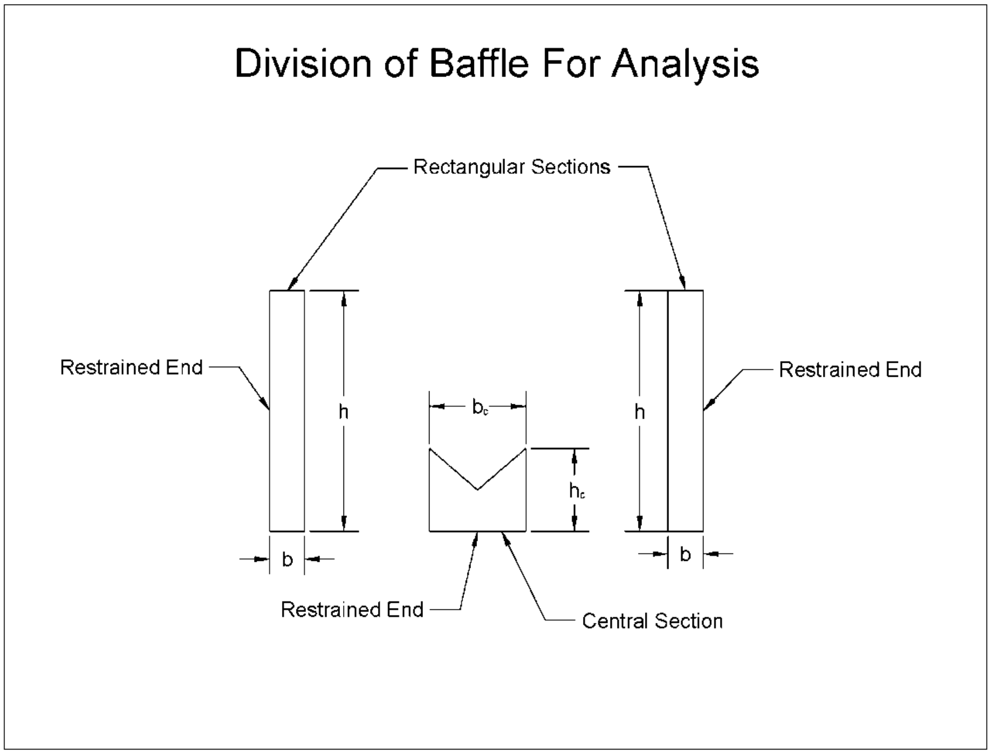


Figure 12: Division of Baffles

First, the rectangular section was analyzed. The section was treated as a cantilever beam with a width equal to the height of the fish passage and a length equal to the width of the rectangular cross section(shown as dimension b in Figure 12). The maximum distributed load was calculated at the base where water was the strongest so to determine a worst case scenario. As a conservative calculation, the maximum load was considered to be applied across the entire cantilever. The resulting conservative applied load w was expressed by the following equation:

Equation 22

$$w_{applied} = 1.6 * [P_{impact} * h + (\gamma * h) * h]$$

Where:

$w_{applied}$ = applied load (in plf)

h = height of the rectangular cross section

*(*Note: The equation above assumes a uniform distributed load due to water pressure when in fact, water creates a triangular distributed load. This was done because the cantilever in this case is oriented so that*

the water load is distributed along the width of the cantilever instead of the length. Assuming the maximum water pressure along the entire width allowed the entire section to be design to withstand the maximum loadings expected to be seen in on portion of the cantilever.)

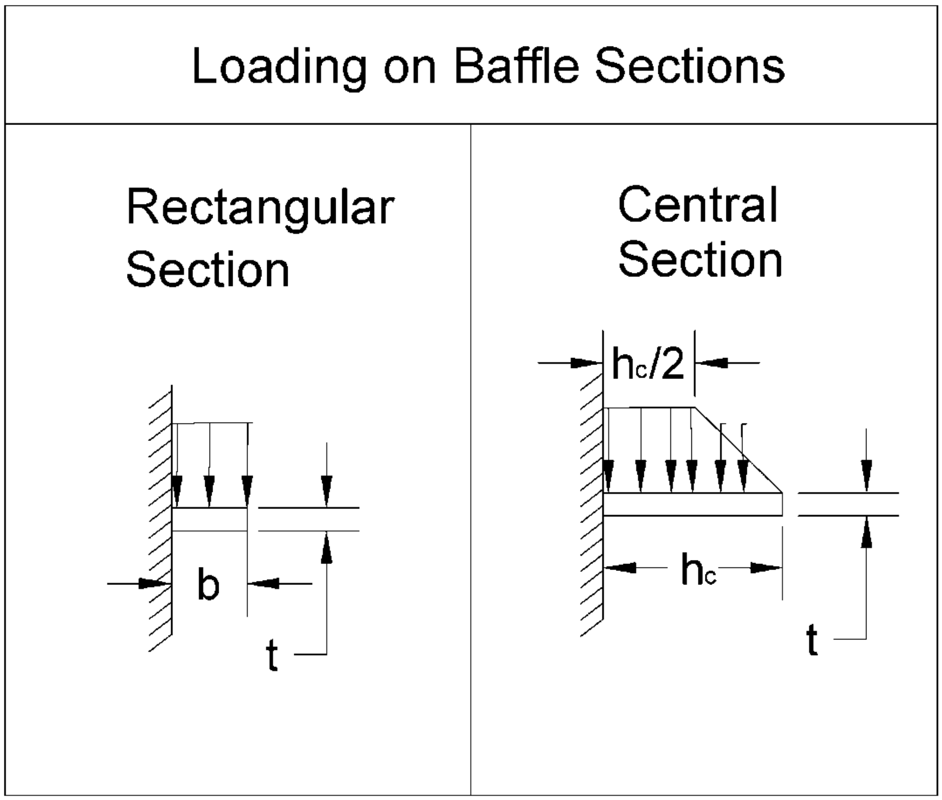


Figure 13: Baffle Section Loadings

With the distributed load determined seen in Figure 13, the moment was then calculated. As a linear distribution, the moment was calculated with the following equation:

Equation 23

$$M = \frac{w_{applied} * b^2}{2}$$

Where:

M = moment due to applied load (in ft*lbs)

b = length of the cantilever (width of rectangular cross section)

Next, the central section was analyzed. Again, the section was treated as a cantilever beam with a bottom width equal to the passage channel width and length equal to the section height. The loading for this section was calculated in a similar manner as the rectangular section, however, being a shorter, odd shaped section, the equation resulted as follows:

Equation 24

$$w_{applied} = 1.6 * [P_{impact} * b_c + (\gamma * h_c) * b_c]$$

Where:

b_c = width of the central section

h_c = width of the central section

This section does not have a constant width and at half its height, the width reduces linearly until it reaches “0” at the full height. The resulting distributed load is constant as long as the width is constant but then diminishes when the width shrinks. This in turn meant that the linear portion of the applied load may be expressed using the equation above, however, past half the height of the section, the load would be expected to decrease from the calculated value to zero along the remaining length of the section.

The moment for the central section was then calculated. Due to the varying load, the equation used varied slightly from the one used for the rectangular section.

Equation 25

$$M = \frac{w_{applied} * {h_c}^2}{8} + \frac{w_{applied} * {h_c}^2}{6}$$

In order to solve for the required thickness, the applied stress was calculated for each section in terms of the thickness and compared to the strength of the material used (wood and aluminum). To do this, first the moment of inertia and the distance from the neutral axis were calculated in terms of thickness using the following equations.

Equation 26

$$I = \frac{b_c * t^3}{12}$$

$$c = \frac{t}{2}$$

Where:

I = moment of inertia

b = width of cantilever cross-section (= height of rectangular section)

c = distance to neutral axis

t = unknown thickness

Stress was calculated in terms of thickness using the following equation:

Equation 27

$$\sigma_b = \frac{M * c}{I}$$

So:

$$\sigma_b = \frac{M * \frac{t}{2}}{\frac{b_c * t^3}{12}}$$

Where:

σ_b = bending stress

The stress was then set equivalent to the material bending strength and the required thickness for each section was determined. The greater of the two required thicknesses was chosen as the thickness of the entire baffle.

3.6.1.3 Shear Strength

The required baffle thickness to with stand shear stresses was determined for both baffle sections. Since both sections have rectangular cross sections, shear stress was calculated in terms of thickness with the following equation:

Equation 28

$$\frac{3 * V}{2 * b * t}$$

Where:

V = Factored Shear Force = $\left[1.6 * \left(P_{impact} + P_{pressure}\right)\right]$

b = Thickness

The above equation is derived for rectangular cross sections from the shear equation: ($\frac{VQ}{Ib}$)

The equation for shear stress was then compared to the shear strength of each material and the required thickness was determined. The thickness determined was compared to the required thickness due to shear stress and the larger of the two was chosen for the thickness of the entire baffle.

3.6.2 Common Calculation Methods for Concrete Sections

The following sections explains the process used to calculate different characteristics of concrete cross-sections.

3.6.2.1 Bending Strength and Reinforcement of Concrete Cross Section

Since concrete is strong in compression but weak in tension, tensile reinforcement is needed whenever concrete is expected to experience a tensile load. It was desirable to ensure the concrete remained tension controlled in failure; therefor, the steel must reach a strain of at least 0.005 when the concrete reaches a strain of 0.003. For this to happen, the distance from the top of the concrete to the neutral axis must be less than or equal to 0.375* d where d is the distance from the center of the reinforcing steel to the compressive surface of the concrete section. Refer to the figure below for a visual representation.

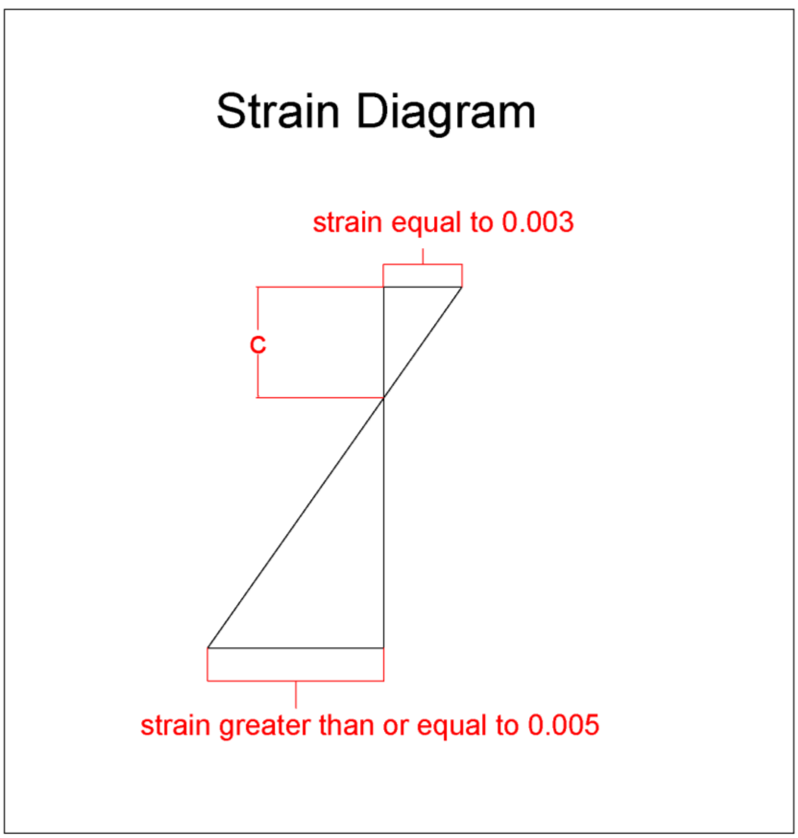


Figure 14: Strain Diagram

The minimum values for d for different concrete sections were calculated to determine both the needed thickness on the beam and the placement of the reinforcing steel. To do this, basic equilibrium equations were used and variables in the equations were solved for in terms of d.

Equation 29

$$0.85 * f'_c * a * b = A_s * f_y$$

Where:

b = width of the concrete section

a =depth of concrete stress block = $\beta_1 * c$

β_1 is a coefficient dependent on the concrete strength

c is the distance from the compression surface to the neutral axis

$$c \geq 0.375 * d$$

A_s = area of reinforcing steel

f_y = yield strength of reinforcing steel

With the equation above, A_s was determined in terms of d.

The concrete section must be able to withstand the moment caused by the applied loadings. The capable moment of the reinforced system must be greater than the calculated applied moment as shown in the following equation.

Equation 30

$$M_u = \phi * A_s * f_y * (d - \frac{a}{2})$$

Where:

M_u = moment due to applied load

ϕ = strength reduction factor (= 0.9 for tension controlled sections)

Since A_s and a were solved for in terms of d and all other variables in the equation are known, the minimum value for d was calculated.

At this point, the concrete cover protects the reinforcing steel was referenced to determine the total thickness of the beam. The total thickness of the beam is equal to d plus the radius of the re-bar plus the depth of concrete cover needed. If the value for d minus the radius of the re-bar was than the required depth of coverage, then d(and the thickness) was increased until the re-bar was sufficiently covered.

$$\boldsymbol{if}: d \geq \frac{Dia_s}{2} + t_c \qquad \boldsymbol{Then}: t_b = d + \frac{Dia_s}{2} + t_c$$

$$\textbf{\textit{if}}: d \leq \frac{Dia_s}{2} + t_c \qquad \textbf{\textit{Then}}: d = \frac{Dia_s}{2} + t_c \ \textbf{\textit{and}} \ \ t_b = 2 * (\frac{Dia_s}{2} + t_c)$$

Where:

t_b = thickness concrete section

t_c = Thickness of needed cover over reinforcement steel

Dia_s = diameter of reinforcement steel rods

(See 3.6.3.4 Channel and Resting Pool Wall Design: Minimum Coverage for coverage details)

Once a value for d was determined, the area of steel was calculated. A size for reinforcing bar and rebar spacing was chosen so that the total steel area was less than the calculated area of steel, so that the spacing did not exceed 2 times the section thickness, and so that the spacing was no less than 1-in between the outer surfaces of the rebar. The reason the total steel area was chosen to be less than the calculated steel area was to keep the section in a tension controlled failure. The moment capacity was again calculated and compared to the applied moment to verify the structural integrity.

Equation 31

$$M_u = \phi * A_s * f_y * (d - \frac{a}{2})$$

If the applied moment exceeded the strength capacity of the section, d was increased to increase the section strength.

3.6.2.2 Shear Strength

The minimum thickness of concrete needed to withstand shear forces was calculated by solving for both the shear strength of the concrete wall in terms of thickness, setting it equal to the applied shear load, and solving for the thickness. The following equation was used:

Equation 32

$$\phi * V_n = V$$

Where:

V = applied shear force

ϕ = strength reduction factor = **0.75**

V_n = nominal strength of the concrete section

V_n was calculated with the following equation:

Equation 33

$$V_n = 2 * \lambda * \sqrt{f'_c} * b_w * t$$

Where:

λ = 1 for normal weight concrete

f'_c = compressive strength of the concrete

b_w = width of concrete section

t = thickness of concrete section

Substituting the above equation for V_n and solving for t yields the following equation:

Equation 34

$$t = \frac{V}{\phi * 2 * \lambda * \sqrt{f'_c} * b_w}$$

3.6.2.3 Freeze/Thaw Reinforcement for Concrete Section

To account for freeze thaw cycles that commonly occur in the New England area, additional reinforcement is needed perpendicular to bending reinforcement. The minimum area of reinforcement can be determined using the following equation:

Equation 35

$$A_{sf} = C_{ft} * b * t$$

Where:

A_{sf} = minimum area of steel reinforcement needed for freeze thaw cycles

b = width of concrete cross section

t = thickness of concrete cross section

C_{ft} = Coefficient dependent on the length of beam/wall ranging from 0.003 to 0.006 (ACI 349-06: 7.12.2.1)

A rebar size was chosen to allow for spacing less than the maximum of 12-in. The number of bars needed was rounded up to ensure adequate space. The bar size chosen was also at minimum a #4 bar, the minimum size allowed for Freeze/Thaw reinforcement (ACI 349-06: 7.12.2.2).

3.6.2.4 Minimum Concrete Coverage

ACI regulations were consulted to determine the minimum coverage needed to protect reinforcing steel (2.5in for sections exposed to water and 3in for sections in contact with the ground as stated in ACI 350) (ACI vol. 4 2010). If any sections were not an adequate thickness to protect the steel properly, the section thickness was increased to provide the minimum required cover the section was analyzed again to ensure that it remained structurally sound.

3.6.3 Denil Passage: Channel Wall and Resting Pool Wall Design

The passage walls were designed to withstand the applied loading due to the water flow and so that they could withstand exposure to water and freeze thaw cycles. When calculating loads, the passage was assumed to be completely filled with water at each point to account for a worst case scenario. The loadings applied to the walls can be seen in Figure 15.

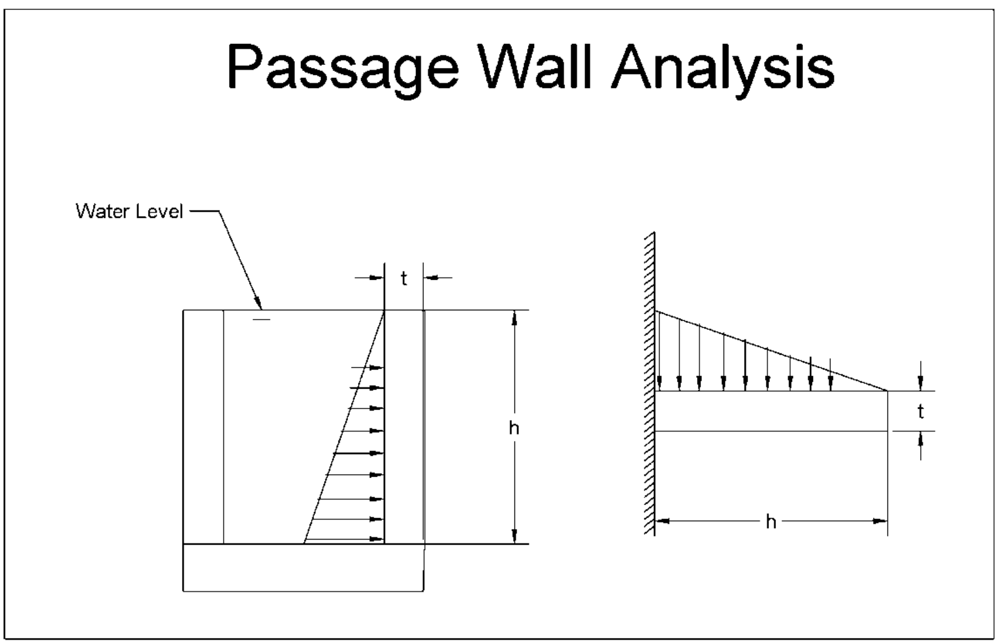


Figure 15: Passage Wall Analysis

3.6.3.1 Channel and Resting Pool Wall Design: Bending Strength

The walls of the passage were considered as cantilever beams. The loading on the walls was from the water pressure. The applied load can be expressed with the following equation:

Equation 36

$$w_L = \gamma * h * b$$

Where:

w_L =Factored Live load due to water pressure (plf)

h = height of the wall (as seen in Figure 15)

b = length of the wall

γ = specific weight of water

From the applied load, the bending moment was calculated using the following equation:

Equation 37

$$M_b = \frac{w_L * h^2}{6}$$

Where:

M_b = bending moment

The bending moment was then used to determine the required section thickness and steel reinforcement through the process shown in section *3.6.2.1 Bending Strength and Reinforcement of Concrete Cross Section*. Where $M_u$in section 3.6.2.1 is equal to M_b.

Equation 38

.

3.6.2.2 Channel and Resting Pool Wall Design: Shear Strength

The total shear force due to water loads was determined as follows:

$$V = \frac{\gamma * b * h^2}{2}$$

The methods for determining the minimum thickness to withstand shear forces can be found in section 3.6.2.2 Shear Strength.

3.6.3.3 Channel and Resting Pool Wall Design: Freeze/Thaw Reinforcement

The methods for determining the minimum required freeze/thaw reinforcement can be found in section 3.6.2.3 Freeze/Thaw Reinforcement for Concrete Section.

3.6.3.4 Channel and Resting Pool Wall Design: Minimum Coverage

The methods for determining the minimum concrete coverage for steel reinforcement can be found in section 3.6.2.4 Minimum Concrete Coverage.

3.6.4 Denil Passage: Channel Bottom Design

The channel bottom was designed to withstand the loadings associated with the water live load and the dead load of both the channel wall weight and the self-weight of the channel bottom. In these calculations, the passage was assumed to be simply supported and the span of the passage was assumed to be the maximum expected distance between supports. The maximum thickness for the bottom channel was used in all scenarios. The location and loading applied to the passage bottom can be seen in Figure 16.

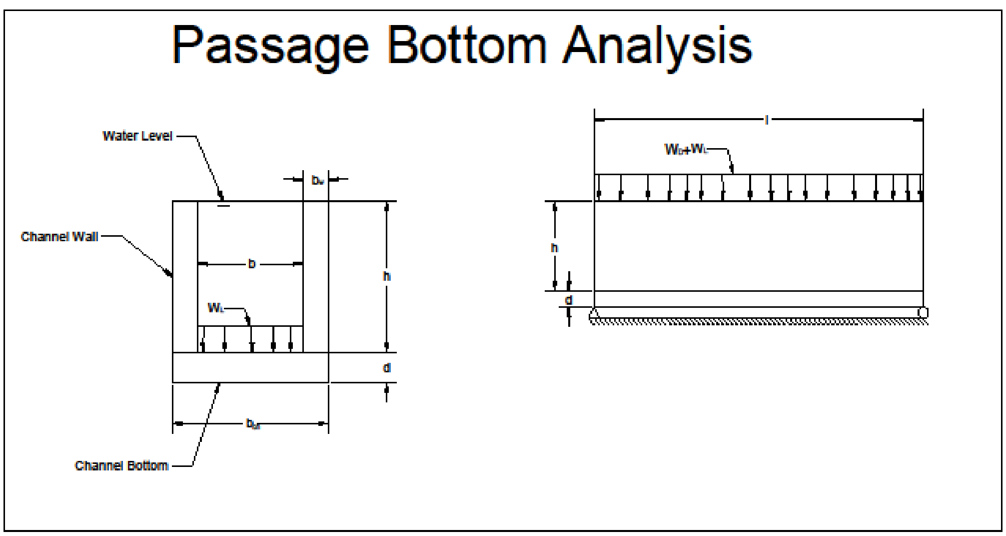


Figure 16: Passage Bottom Analysis

3.6.4.1 Channel Bottom Design: Bending Strength and reinforcement

The distributed load due to water was calculated assuming that the passage was filled with water. This load can be expressed with the following equation:

Equation 39

$$w_L = \gamma_w * h * b$$

Where:

w_L = Live load due to water (as seen in Figure 16)

h = channel wall height (as seen in Figure 16)

b = channel width (as seen in Figure 16)

γ_w = specific weight of water

The distributed live load due to concrete weight was then calculated. A thickness was assumed for the channel bottom so to get a better estimate.

Equation 40

$$w_D = 2 * (\gamma_c * h * b_w) + \gamma_c * d * b_{ch}$$

Where:

w_D = Dead load due to Concrete

h = channel wall height

b_w = channel wall width

d = estimated channel floor thickness

b_{ch} = channel width $+ 2 * b_w$

γ_c = specific weight of concrete

The total distributed load was determined by combining the dead and live loads with appropriate factors.

Equation 41

$$w_{total} = w_D + w_L$$

The moment caused by the applied load was then calculated using the following equation:

Equation 42

$$M_{app} = \frac{w_{total} * l^2}{8}$$

Where:

M_{app} = applied moment

l = span of the passage

To withstand the bending stresses due to the applied loads, the fish passage walls and floor were considered as one unit. It was also assumed that any needed tensile reinforcement would be placed in the passage floor.

To determine the needed floor thickness to withstand bending stresses, the placement of steel reinforcement was determined. As explained in section 3.6.2.1 Bending Strength and Reinforcement of Concrete Cross Section, the steel reinforcement should be designed so that failure of the structure is tensioned controlled and that the cross-section can withstand the applied moment.

For definitions of undefined variables used in this section, please refer to section 3.6.2.1.

Since the walls and bottom of the passage are considered to act as one unit in bending the value for d for reinforcement is dependent on both the height of the passage walls and the location of the reinforcement in the channel bottom. Initially, a value for d was estimated so that the reinforcement would have adequate concrete covering.

Equation 43

$$0.85 * f'_c * a * b = A_s * f_y$$

$$a = \beta_1 * c$$

$$c \geq 0.375 * d$$

Where:

b = width of the passage cross section

Using the equation above and the known variables, a value for A_s was calculated. A re-bar size was chosen that would allow spacing less than the maximum of 2 times the section's thickness. The number of bars used was rounded down to the nearest number so to not exceed the calculated steel area. Exceeding the calculated area would mean the section was no longer tension controlled.

The strength of the section was then verified against the applied moment to ensure the structural integrity of the section.

Equation 44

$$M_u = \phi * A_s * f_y * (d - \frac{a}{2})$$

Where:

$$M_u = M_{app}$$

If $M_u > \phi * A_s * f_y * (d - \frac{a}{2})$ then d would be increased, and the thickness of the floor would be increased until the section was structurally adequate.

3.6.4.2 Channel Bottom Design: Shear Strength

When considering shear strength of the passage floor, it was assumed that the floor would carry the full weight of the water and concrete load to ensure an adequate thickness.

To calculate the applied shear force, the following equation was used:

Equation 45

$$V_u = \frac{w_{total} * l}{2}$$

The applied shear force was then used to determine the minimum thickness for the channel bottom to withstand shear loadings.

The methods for determining the minimum thickness to withstand shear forces can be found in section 3.6.2.2 Shear Strength.

3.6.4.3 Freeze/Thaw Reinforcement

The methods for determining the minimum required freeze/thaw reinforcement can be found in section 3.6.2.3 Freeze/Thaw Reinforcement for Concrete Section.

3.6.4.4 Minimum Coverage

The methods for determining the minimum concrete coverage for steel reinforcement can be found in section 3.6.2.4 Minimum Concrete Coverage.

3.6.5 Denil Passage: Resting Pool Bottom Design

The floor of the resting pool was considered to be a simply supported beam. The only loads applied to the floor are both the load due to water and the load due to the self-weight of the concrete. The required concrete thickness was determined for bending stresses, shear stress, and minimum coverage for concrete. The largest value for concrete thickness governed as the thickness of the section. The location and loading applied to the resting pool bottom can be seen in Figure 17.

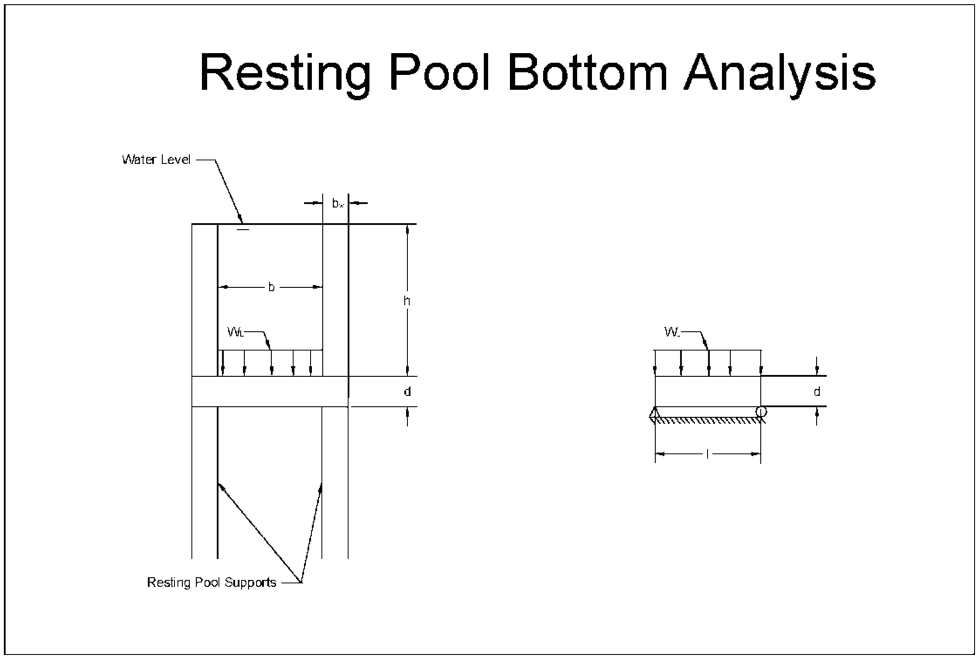


Figure 17: Resting Pool Bottom Analysis

3.6.5.1 Resting Pool Bottom Design: Bending Strength and Reinforcement

An initial thickness for the pool bottom was estimated to account for the additional concrete weight.

The loads applied can be expressed by the following equations:

Equation 46

$$w_L = \gamma_w * h * b$$

Where:

w_L = applied live load due to water (as seen in Figure 17)

h = resting pool wall heights (as seen in Figure 17)

b = width of the resting pool (as seen in Figure 17)

γ_w = specific weight of water

Equation 47

$$w_D = \gamma_c * d * b$$

Where:

w_D = applied dead load due to concrete

d = estimated thickness of Pool bottom

The total applied load was calculated as a combination of the live and dead loads:

Equation 48

$$w_{total} = w_L + w_D$$

As a simply supported beam, the applied moment can be expressed through the following equation:

Equation 49

$$M_b = \frac{w_{total} * l^2}{8}$$

Where:

l = length of the pool bottom

M_b = bending moment

The bending moment was then used to determine the required section thickness and steel reinforcement through the process shown in section *3.6.2.1 Bending Strength and Reinforcement of Concrete Cross Section*. Where $M_u$in section 3.6.2.1 is equal to M_b.

3.6.5.2 Resting Pool Bottom Design: Shear Strength

The applied shear load V was determined through the following equation:

Equation 50

$$V = \frac{w_{total} * l}{2}$$

The methods for determining the minimum thickness to withstand shear forces can be found in section 3.6.2.2 Shear Strength.

3.6.5.3 Resting Pool Bottom Design: Freeze/Thaw Reinforcement

To determine the minimum needed reinforcement for freeze thaw cycles, the same method was used as in section **Error! Reference source not found.**. (Please refer to section **Error! Reference source not found.** for more details)

3.6.5.4 Resting Pool Bottom Design: Minimum Coverage

The methods for determining the minimum concrete coverage for steel reinforcement can be found in section 3.6.2.4 Minimum Concrete Coverage.

3.6.6 Denil Passage: Resting Pool Supports Design

The supports of the resting pool were considered as 4 members carrying both an axial and a bending load. The largest loading on one member was used to determine the thickness of all 4 members. The supports were designed to withstand loadings from both the fish passage and resting pool. The supports were also planned to have symmetrical bending reinforcement so that the supports can withstand being loaded from either of two directions. The location, orientation, and loading applied to the Resting Pool Supports can be seen in Figure 18.

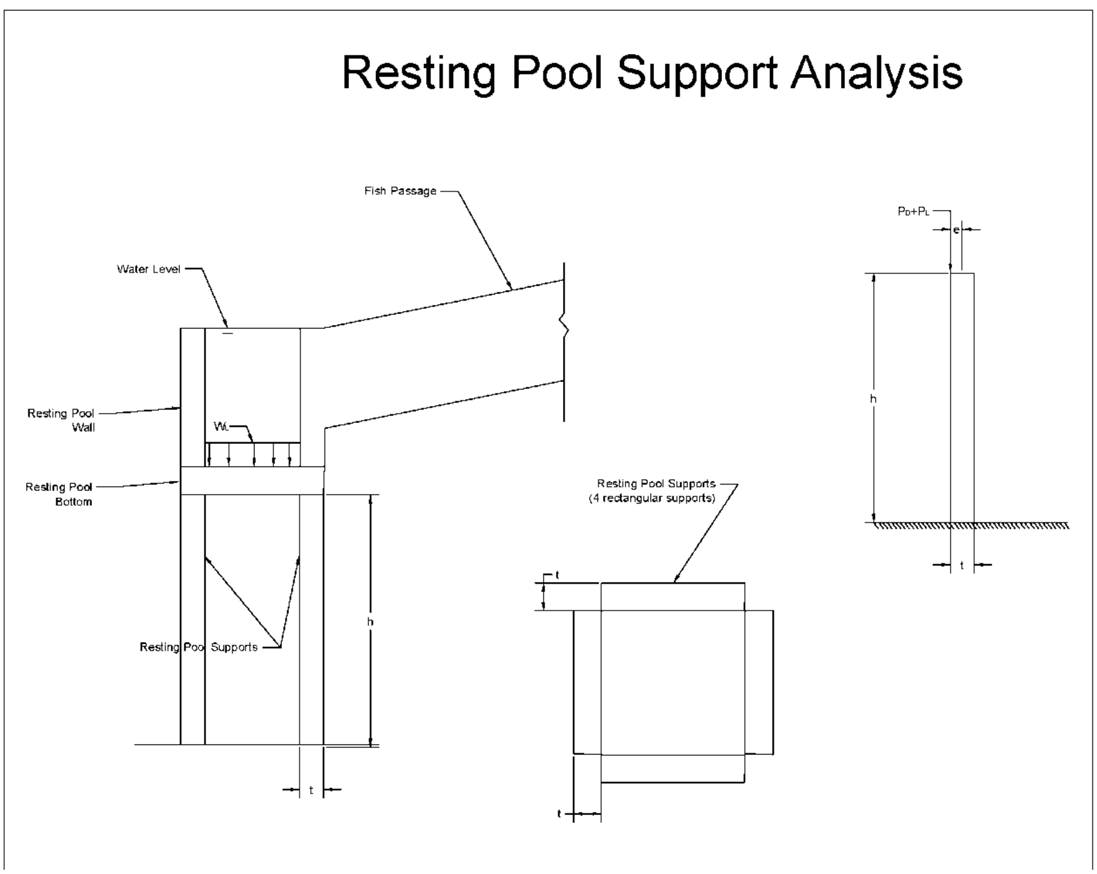


Figure 18: Resting Pool Support Analysis

3.6.6.1 Resting Pool Supports Design: Combined Bending and Compressive Strength

The maximum load for one member to carry was predicted as half of the load due to one span of passage and half of the load due to the resting pool.

The total applied dead load can be expressed in the following equation:

Equation 51

$$P_D = \frac{\gamma_w * ((A_{cp} * l) + V_{crp})}{2}$$

Where:

P_D = Dead Load (as seen in Figure 18)

γ_w = specific weight of water

A_{cp} = cross-sectional area of concrete of previously designed passage (combined cross sections of channel walls and channel bottom)

V_{crp} = total volume of concrete from the previously designed resting pool

l = largest section length of the passage

The total applied live load can be expressed in the following equation:

Equation 52

$$P_L = \frac{\gamma_w * b_{ch} * h_{ch} * l}{2}$$

Where:

γ_w = Specific weight of water

b_{ch}= width of Passage channel

h_{ch} = height of passage walls

The total combined load was determined with the following equation:

Equation 53

$$P_{total} = P_D + P_L$$

Once the maximum load was determined, the maximum applied stress was determined in terms of the thickness of the member.

First, the bending moment was calculated as:

Equation 54

$$M_b = P_{total} * e$$

Where:

e = maximum eccentricity = $\frac{t}{2}$ (t = thickness of member)

The bending moment was then used to estimate the required section thickness and steel reinforcement through the process shown in section *3.6.2.1 Bending Strength and Reinforcement of Concrete Cross Section*. Where M_u in section 3.6.2.1 is equal to M_b.

The minimum section thickness to withstand axial loading was then calculated using the following equation:

Equation 55

$$P_{total} = 0.80 * \left[0.85 * f'_c * (b * t)\right]$$

Where:

$A_s and\ f_y$ are values from the reinforcement calculations

3.6.6.2 Resting Pool Bottom Design: Freeze/Thaw Reinforcement

The methods for determining the minimum required freeze/thaw reinforcement can be found in section 3.6.2.3 Freeze/Thaw Reinforcement for Concrete Section.

3.6.6.3 Resting Pool Bottom Design: Minimum Coverage

The methods for determining the minimum concrete coverage for steel reinforcement can be found in section 3.6.2.4 Minimum Concrete Coverage.

3.6.7 Denil Passage: Impact to Existing Dam

The installment of the fish passage will cause additional loadings to the existing dam. The additional applied stresses were calculated to determine if the dam would require additional reinforcement to withstand the additional passage loads.

The height at which the passage would be installed was determined in section 3.5.1.1 as a height below the curved dam. So the height above the base of the dam section where the passage would be installed is equal to the total height of the section, minus the total height of the dam, minus the height below the dam that the passage will be placed.

The calculations in this section are similar to those found in section **Error! Reference source not found.**(please refer to section **Error! Reference source not found.** for definitions of undefined variables).

The location of the loading applied to the section of the dam can be seen in Figure 19.

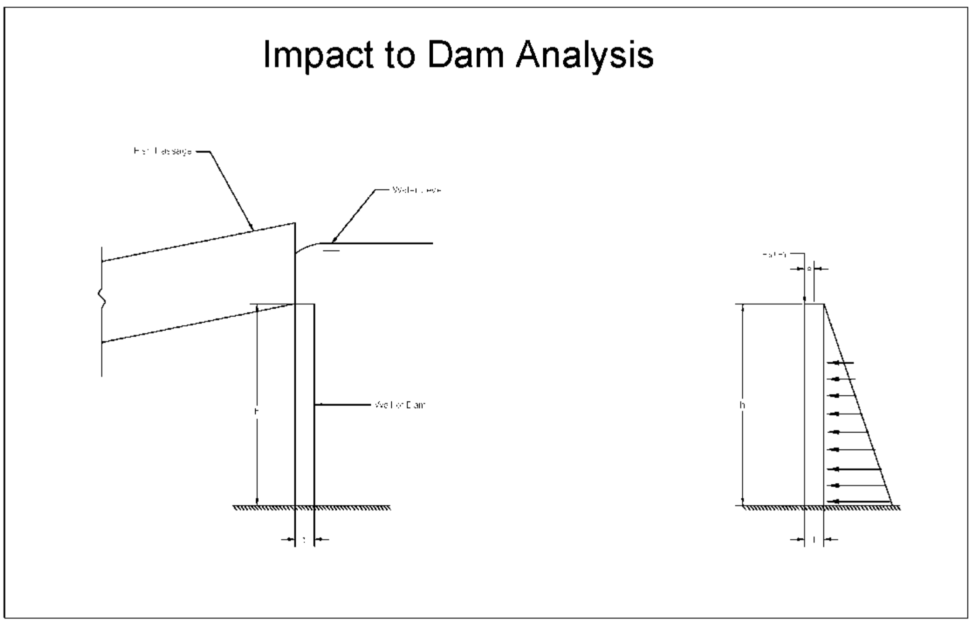


Figure 19: Impact to Dam Analysis

3.6.7.1 Impact to Existing Dam: Combined Bending and Compressive Strength

The total vertical load was calculated as half of the fish passage load.

The dead load can be expressed as

Equation 56

$$P_D = \frac{\gamma_c * (A_{cp} * l)}{2}$$

Where:

P_D = Dead Load

γ_c = specific weight of concrete

A_{cp} = cross-sectional area of concrete of previously designed passage

l = largest section length of the passage

The total applied live load can be expressed in the following equation:

Equation 57

$$P_L = \frac{\gamma_c * b_{ch} * h_{ch} * l}{2}$$

Where:

γ_c = Specific weight of water

b_{ch}= width of Passage channel

h_{ch} = height of passage walls

The total combined load was determined with the following equation:

Equation 58

$$P_{total} = P_D + P_L$$

Once the maximum load was determined, the maximum applied stress was determined.

First, the bending moment was calculated as:

Equation 59

$$M = P_{total} * e$$

Where:

e = maximum eccentricity = $\frac{t}{2}$ (t = thickness of the dam)

The bending stress due to the vertical load was then calculated

Equation 60

$$\sigma_{bv} = \frac{M * c}{I}$$

Where:

σ_{bv} = Bending stress due to the vertical load

c = half the thickness of the dam

$I = \frac{b*t^3}{12}$, (b = total passage width)

Bending stress due to water pressure was calculated as well.

Equation 61

$$w_L = \gamma * h * b$$

Where:

w_L = Live load due to water pressure (plf)

h = height of the section of the dam

b = width of the section of the dam

With the applied load, the section of dam was considered as a cantilever beam and the maximum applied moment was calculated.

Equation 62

$$M_{bw} = \frac{w_L * h^2}{6}$$

Where:

M_{bw} = bending moment due to water pressure

The stress due to water pressure was then calculated.

Equation 63

$$\sigma_{bw} = \frac{M * c}{I}$$

Where:

σ_{bw} = Bending stress due to water pressure

The stress due to an axial compressive load was then calculated. The stress can be expressed in the following equation:

Equation 64

$$\sigma_{axial} = \frac{P_{total}}{b * t}$$

The total applied stress was the determined by combining all forms of stress.

Equation 65

$$\sigma_{total} = \sigma_{axial} + \sigma_{bv} + \sigma_{bw}$$

The total stress was then compared to common concrete strengths to determine if reinforcement is need before installing the passage.

3.7 Economic Analysis

An economic analysis was conducted on each of the passages thought to be a possibility for the project. Brian Waz, having worked on many fish passages in the past, was contacted as an expert for this evaluation. He provided a document with pricing per foot rise for passages of similar size for both steeppass and denil passages, refer to Appendix G for full data. This data was used to provide feasible level range costs for each type of fishway proposed. The data was from 2007 so the compound inflation rate from 2007 to 2013, 12.6% (U.S. Bureau of Labor Statistics, 2013), was used to determine what the cost of the passages would be in present dollars using the following equation:

Equation 66

$$cost\ in\ 2013 = \frac{(cost\ in\ 2007) * (inflation\ rate)}{100\%}$$

and so

$$price\ of\ passage = (cost\ in\ 2013\ per\ foot\ rise) * (foot\ rise\ of\ the\ passage)$$

It was also determined that since steeppass fishways are prefabricated, another way to get an accurate cost estimate for the project would be to obtain a quote from a company that produces the passages. There are few manufacturers of fish passages in the northeast but one company that does is Sheepscot Machine Works. Nancy DeWall, a sales engineer for the company, was contacted, and she provided a budgetary quotation for the project based off of typical costs for projects they do.

3.8 Summary of Methods

The methodology presented the approach for the project. It outlines all of the design equations needed to analyze the different aspects of the project while also establishing an order in which to work logically. The hydrologic analysis was completed first to establish the flows of the river followed by hydraulic analysis of the flow over the dam and in the passages. This determined design flows so that a proper structural analysis could be done with the expected flows of the river. The final analysis was the economic analysis, performed to determine which passage would be most cost effective. The results of these methods are presented in the following chapter.

4.0 Results

The results of the project follow the approach presented in the Methodology chapter and are presented in this chapter. These results include a hydrologic analysis of the river, a hydraulic analysis of the water flowing over the dam, downstream of the dam, and in the fish passages, a structural analysis of the denil passage and the dam, and an economic analysis of the designed fish passage and alternative design passage. All structural designs follow the code set by the American Concrete Institute.

4.1 Parameter Establishment

The project had many parameters that were established based on recommendations from experts or based off of restrictions from the fish or the allotted space for the passage. One of the chief design parameters was the sustained speed of the herring which was set to be 4.9 ft/s. The next established parameter was the width of the passages. Using CAD drawings of the dam provided by the town, it was determined that the width of the channel of the passage could not exceed 3ft. From this constraint, it was determined that the width of the channel for the denil passage would be 2ft to allow for reasonable flows with the desired 1:5 slope.

4.2 Hydrologic Analysis

To analyze the flow data retrieved from the USGS gauge in the river, Microsoft Excel was used. Using basic commands the average flow for the data was determined to be 48 cfs. A flow duration curve was also created from the data. The flow duration curve is presented in terms of the exceedence probability in Figure 20. The curve was used to determine the 95% minimum and 5% maximum flows of 8 cfs and 132 cfs, respectively, for the river as design parameters to be used in the fish passage designs.

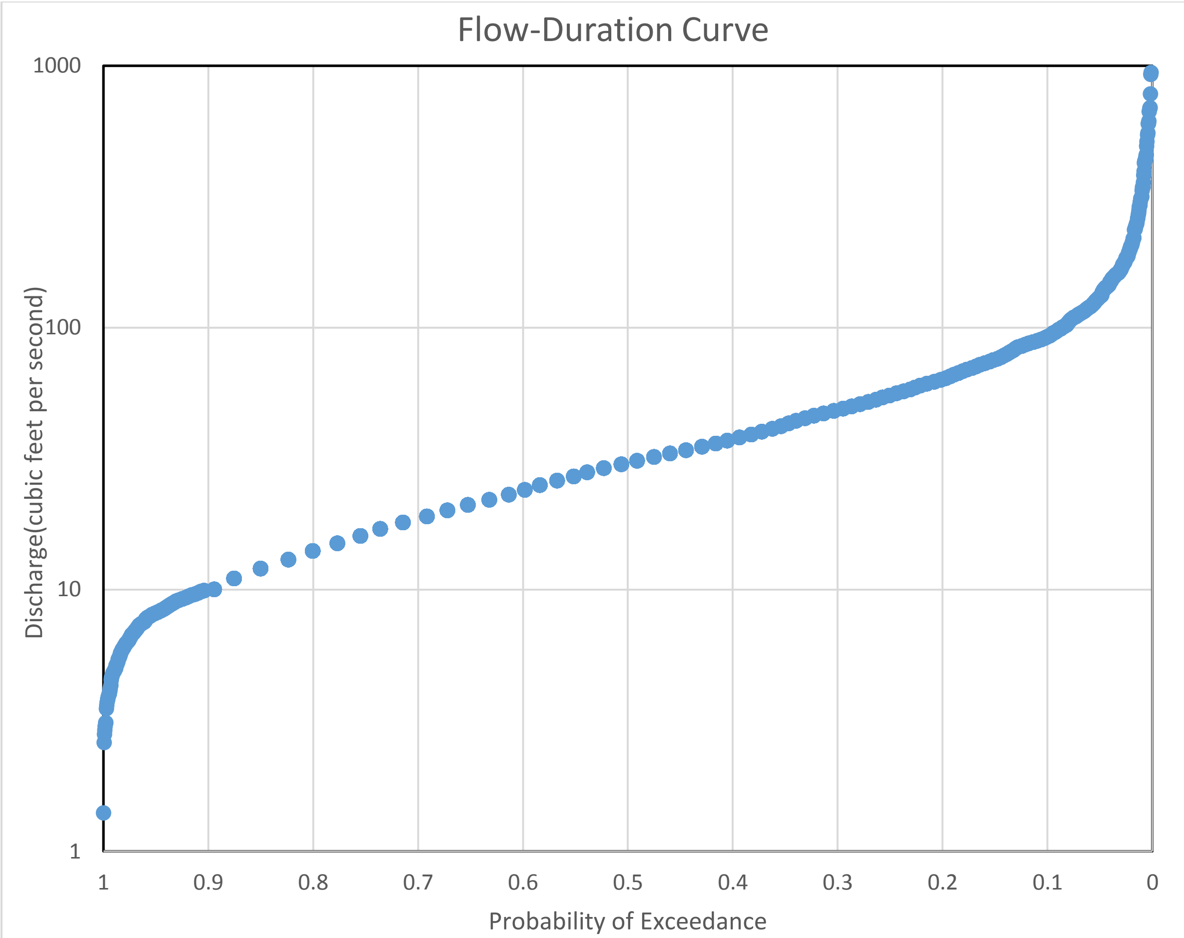


Figure 20: Flow Duration Curve (Frequency Distribution)

4.3 Hydraulic Analysis

Using the design equations established in sections 2.4 and 3.4 of the background and methodology, a graph was produced showing the relationship between the flow over the dam and interval values for the depth of the water over the dam, as seen in Figure 21.

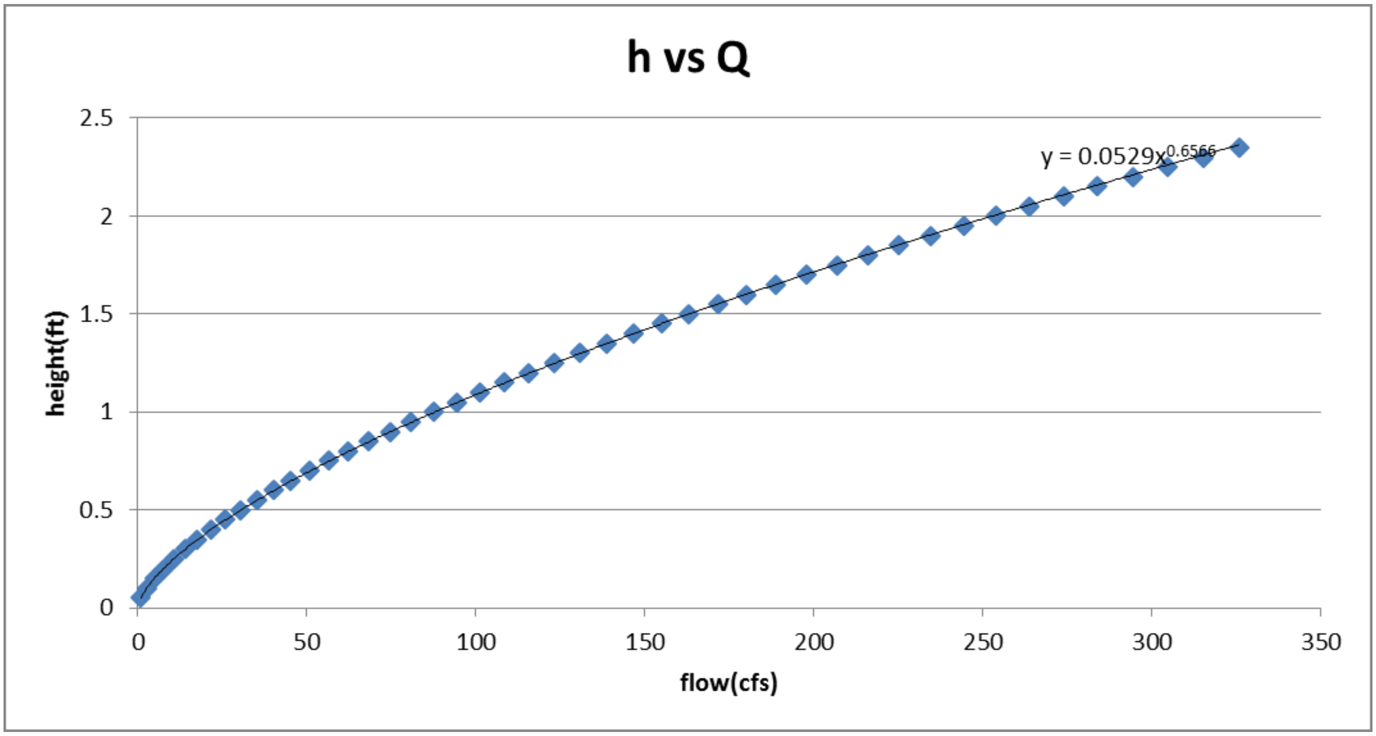


Figure 21: Height vs Flow Relationship

The velocity of the flow downstream of the dam was determined using Manning's equation and the grade of the river determined from elevations measured while surveying the site. The flow data are presented in the table below.

Table 4: Flow Data Obtained from Manning's Equation

Flow of the River	Assumed River Width	Expected River Height	Expected Velocity Downstream of the Dam
Average:48 cfs	26 ft	0.80 ft	2.32 ft/s
95% Minimum: 8.1 cfs	26 ft	0.27 ft	1.16 ft/s
5% Maximum: 132 cfs	26 ft	1.48 ft	3.42 ft/s

4.4 Design of the Passage

This section provides the final results of hydraulic calculations and the required dimensions determined through the hydraulic analysis of the Steep passage and the Denil passage.

4.4.1 Denil Passage Flow Conditions

Following the guide recommendations in *Fish Passes: Design, Dimensions, and Monitoring* (UN FAD, 2002) the optimum values for the expected perpendicular height of the water in the passage were determined to be found when the flow going through the passage was between

12.5 cfs and 17.5 cfs based on the design equations. Values for h_o were then calculated for the values of h* based on the best fit curve of the relation of h* and h_o as shown in Figure 22. The equation was used as follows:

Equation 67

$$h_o = 1.1765h^{*0.898}$$

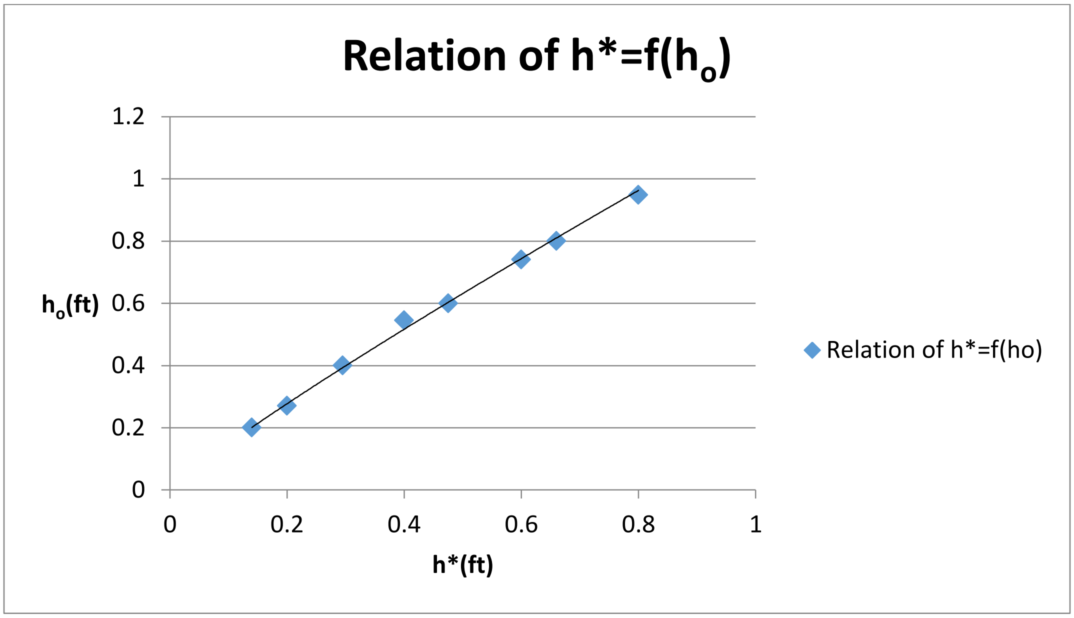


Figure 22: Relation of h=f(h_o)*

With both of these values the flow of the river was determined for varying values of the distance from the bottom of the fish passage to the top of the dam. These data were then analyzed to determine what the best value for that distance would be so that the flow going over the dam could be maximized while still having the appropriate flow in the passage. As highlighted in Figure 23, a value of 1.9 ft was chosen.

height difference (feet)						Flow of River for Given Flow Through Fishpassage and Value for Dam and Passage Height Difference (CFS)															
						Flow through Passage (CFS)															
x	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5
0	31.10262	78.57581	135.3681	199.2624	269.0434	343.921	423.3315	506.8483	594.135	684.9183	778.9704	876.0984	976.1362	1078.939	1184.379	1292.342	1402.727	1515.443	1630.405	1747.538	1866.771
0.05	26.71279	72.43629	127.9208	190.729	259.5633	333.5919	412.2269	495.0259	581.6417	671.793	765.2464	861.8043	961.2968	1063.576	1168.513	1275.991	1385.906	1498.167	1612.687	1729.391	1848.207
0.1	22.57938	66.48187	120.6274	182.331	250.2057	323.3759	401.2279	483.303	569.2429	658.758	751.6089	847.5934	946.538	1048.292	1152.723	1259.713	1369.157	1480.961	1595.038	1711.311	1829.707
0.15	18.71816	60.71807	113.4911	174.0703	240.9722	313.2741	390.3354	471.6805	556.9392	645.8138	738.0586	833.4663	931.86	1033.086	1137.008	1243.509	1352.479	1463.825	1577.457	1693.297	1811.273
0.2	15.14832	55.15095	106.5151	165.9492	231.8643	303.2876	379.5505	460.1592	544.7315	632.9611	724.5958	819.4235	917.2633	1017.958	1121.37	1227.379	1335.874	1446.759	1559.945	1675.351	1792.905
0.25	11.89398	49.78721	99.70287	157.9699	222.8836	293.4179	368.874	448.7398	532.6204	620.2004	711.2211	805.4654	902.7483	1002.91	1105.809	1211.323	1319.341	1429.764	1542.501	1657.472	1774.602
0.3	8.98672	44.63429	93.05827	150.1348	214.0319	283.6661	358.3072	437.4233	520.6066	607.5324	697.9352	791.5925	888.3154	987.9404	1090.325	1195.342	1302.881	1412.839	1525.127	1639.661	1756.366
0.35	6.470558	39.70055	86.58528	142.4464	205.3109	274.0336	347.8509	426.2105	508.6908	594.9577	684.7384	777.8053	873.9651	973.0511	1074.918	1179.437	1286.494	1395.986	1507.822	1621.918	1738.196
0.4	4.413488	34.99547	80.28825	134.9074	196.7224	264.5218	337.5064	415.1024	496.8739	582.477	671.6315	764.1043	859.6979	958.2419	1059.588	1163.606	1270.18	1379.205	1490.587	1604.242	1720.092
0.45	2.944855	30.52991	74.17188	127.5205	188.2685	255.1322	327.2748	404.0998	485.1566	570.0908	658.6149	750.49	845.5141	943.5134	1044.337	1147.852	1253.939	1362.495	1473.422	1586.635	1702.056
0.5	2.5	26.31646	68.24128	120.2888	179.9511	245.8662	317.1571	393.2036	473.5397	557.8	645.6893	736.9629	831.4142	928.8659	1029.164	1132.173	1237.773	1345.857	1456.327	1569.097	1684.086
0.55	2.5	22.37007	62.50204	113.2154	171.7723	236.7254	307.1548	382.415	462.024	545.6052	632.8553	723.5236	817.3987	914.2998	1014.07	1116.571	1221.681	1329.291	1439.303	1551.627	1666.184
0.6	2.5	18.70875	56.9603	106.3037	163.7344	227.7114	297.2689	371.7349	450.6103	533.507	620.1134	710.1725	803.4681	899.8156	999.0549	1101.046	1205.663	1312.798	1422.349	1534.227	1648.349
0.65	2.5	15.3549	51.62282	99.55724	155.8396	218.8259	287.5008	361.1643	439.2995	521.5063	607.4644	696.9102	789.6229	885.4138	984.1195	1085.597	1189.721	1296.378	1405.466	1516.895	1630.582
0.7	2.5	12.33743	46.49718	92.97994	148.0906	210.0706	277.8518	350.7043	428.0925	509.6038	594.9087	683.7374	775.8635	871.0946	969.2641	1070.227	1173.854	1280.031	1388.655	1499.634	1612.883
0.75	2.5	9.695797	41.59185	86.57594	140.4898	201.4474	268.3233	340.3559	416.9901	497.8001	582.4472	670.6545	762.1905	856.8586	954.4891	1054.934	1158.062	1263.757	1371.915	1482.442	1595.252
0.8	2.5	7.488626	36.91647	80.34971	133.04	192.9583	258.9168	330.1204	405.9934	486.0962	570.0804	657.6621	748.6044	842.7063	939.7949	1039.719	1142.346	1247.557	1355.247	1465.32	1577.69
0.85	2.5	5.818418	32.48209	74.30611	125.7441	184.6051	249.6337	319.9989	395.1032	474.4928	557.8091	644.7608	735.1056	828.6381	925.1818	1024.583	1126.706	1231.432	1338.652	1448.269	1560.196
0.9	2.5	5	28.30159	68.45042	118.6052	176.3899	240.4755	309.9926	384.3206	462.9906	545.6339	631.9513	721.6947	814.6545	910.6504	1009.526	1111.143	1215.381	1322.128	1431.288	1542.772
0.95	2.5	5	24.39022	62.78845	111.6266	168.3151	231.444	300.1027	373.6465	451.5907	533.5555	619.2341	708.3724	800.7559	896.2011	994.5482	1095.657	1199.404	1305.678	1414.379	1525.416
1	2.5	5	20.76649	57.32656	104.8117	160.3828	222.5407	290.3306	363.082	440.2937	521.5747	606.6098	695.139	786.9429	881.8342	979.6502	1080.249	1183.503	1289.3	1397.54	1508.13
1.05	2.5	5	17.45347	52.07183	98.16435	152.5956	213.7674	280.6776	352.6281	429.1007	509.6922	594.0792	681.9951	773.2159	867.5503	964.8325	1064.917	1167.677	1272.996	1380.773	1490.914
1.1	2.5	5	14.48114	47.03217	91.68855	144.9559	205.126	271.145	342.286	418.0124	497.9088	581.6429	668.9414	759.5755	853.3497	950.0952	1049.664	1151.927	1256.766	1364.078	1473.768
1.15	2.5	5	11.89072	42.21647	85.38864	137.4665	196.6182	261.7343	332.0568	407.0299	486.2253	569.3015	655.9785	746.0221	839.233	935.439	1034.49	1136.253	1240.61	1347.455	1456.692
1.2	2.5	5	9.744446	37.6349	79.26931	130.1302	188.2462	252.4469	321.9416	396.154	474.6424	557.0557	643.1068	732.5563	825.2006	920.8641	1019.394	1120.655	1224.528	1330.904	1439.687
1.25	2.5	5	8.154578	33.29918	73.33567	122.9501	180.012	243.2845	311.9417	385.3859	463.161	544.9062	630.3271	719.1786	811.2529	906.3711	1004.377	1105.134	1208.52	1314.426	1422.753
1.3	2.5	5	7.5	29.22304	67.59329	115.9294	171.9177	234.2487	302.0584	374.7264	451.782	532.8537	617.6399	705.8896	797.3906	891.9603	989.4402	1089.691	1192.588	1298.02	1405.889
1.35	2.5	5	7.5	25.42289	62.0483	109.0715	163.9657	225.341	292.2928	364.1766	440.5061	520.8991	605.0459	692.6898	783.6139	877.6323	974.5831	1074.324	1176.73	1281.688	1389.097
1.4	2.5	5	7.5	21.91885	56.70746	102.3801	156.1583	216.5633	282.6464	353.7377	429.3343	509.0429	592.5457	679.5798	769.9236	863.3873	959.8063	1059.036	1160.949	1265.43	1372.377
1.45	2.5	5	7.5	18.73637	51.57833	95.8592	148.4982	207.9173	273.1205	343.4106	418.2675	497.2861	580.14	666.5601	756.32	849.226	945.1104	1043.826	1145.243	1249.245	1355.729
1.5	2.5	5	7.5	15.90915	46.66936	89.51302	140.9879	199.405	263.7166	333.1966	407.3066	485.6293	567.8294	653.6314	742.8036	835.1487	930.4956	1028.695	1129.614	1233.135	1339.153
1.55	2.5	5	7.5	13.48505	41.99018	83.34616	133.6304	191.0283	254.4362	323.0967	396.4526	474.0734	555.6147	640.7942	729.3751	821.1559	915.9624	1013.642	1114.061	1217.099	1322.649
1.6	2.5	5	7.5	11.5403	37.55181	77.36362	126.4286	182.7894	245.2807	313.1124	385.7065	462.6191	543.4965	628.0491	716.035	807.2482	901.5113	998.6692	1098.585	1201.138	1306.219
1.65	2.5	5	7.5	10.23229	33.36709	71.57083	119.3857	174.6903	236.2519	303.2447	375.0693	451.2675	531.4756	615.3969	702.7837	793.4259	887.1426	983.776	1083.187	1185.252	1289.861
1.7	2.5	5	7.5	10	29.45123	65.97378	112.5052	166.7334	227.3514	293.495	364.542	440.0193	519.5527	602.838	689.6219	779.6897	872.8569	968.9629	1067.866	1169.442	1273.577
1.75	2.5	5	7.5	10	25.82268	60.57906	105.7907	158.9211	218.5809	283.8646	354.1257	428.8754	507.7286	590.3733	676.5501	766.0399	858.6545	954.2304	1052.624	1153.707	1257.367
1.8	2.5	5	7.5	10	22.50442	55.39398	99.24613	151.2559	209.9423	274.355	343.8216	417.8367	496.004	578.0032	663.5689	752.4771	844.536	939.579	1037.46	1138.049	1241.231
1.85	2.5	5	7.5	10	19.52629	50.42677	92.87564	143.7405	201.4375	264.9675	333.6307	406.9042	484.3798	565.7286	650.6789	739.0018	830.5018	925.0089	1022.375	1122.467	1225.169
1.9	2.5	5	7.5	10	16.92928	45.68672	86.68383	136.3778	193.0684	255.7037	323.5543	396.0788	472.8567	553.5501	637.8807	725.6147	816.5523	910.5207	1007.369	1106.962	1209.182
1.95	2.5	5	7.5	10	14.77514	41.18444	80.67561	129.1706	184.8371	246.5651	313.5936	385.3616	461.4356	541.4684	625.1749	712.3161	802.6881	896.1148	992.4421	1091.534	1193.269
2	2.5	5	7.5	10	13.1748	36.93227	74.85638	122.1223	176.7458	237.5534	303.7498	374.7536	450.1173	529.4842	612.5621	699.1066	788.9096	881.7916	977.5958	1076.184	1177.433
2.05	2.5	5	7.5	10	12.5	32.94473	69.23202	115.2363	168.7969	228.6701	294.0243	364.2558	438.9027	517.5983	600.0431	685.9869	775.2174	867.5516	962.8298	1060.912	1161.672
2.1	2.5	5	7.5	10	12.5	29.23931	63.80904	108.516	160.9927	219.9172	284.4184	353.8693	427.7927	505.8115	587.6184	672.9575	761.6119	853.3952	948.1447	1045.718	1145.987
2.15	2.5	5	7.5	10	12.5	25.83766	58.59465	101.9656	153.3357	211.2964	274.9335	343.5952	416.7883	494.1246	575.2887	660.0189	748.0937	839.3228	933.5409	1030.602	1130.378
2.2	2.5	5	7.5	10	12.5	22.76751	53.59695	95.58913	145.8287	202.8096	265.5711	333.4347	405.8904	482.5382	563.0547	647.1718	734.6633	825.3351	919.0187	1015.566	1114.847
2.25	2.5	5	7.5	10	12.5	20.06634	48.82504	89.39116	138.4745	194.4588	256.3327	323.389	395.0999	471.0533	550.9172	634.4169	721.3212	811.4323	904.5786	1000.609	1099.392
2.3	2.5	5	7.5	10	12.5	17.78899	44.28936	83.37662	131.276	186.2462	247.2198	313.4593	384.4179	459.6708	538.8767	621.7546	708.068	797.6151	890.221	985.7326	1084.015
2.35	2.5	5	7.5	10	12.5	16.02817	40.00197	77.55088	124.2366	178.1738	238.2341	303.6469	373.8454	448.3913	526.9341	609.1856	694.9043	783.8839	875.9465	970.9361	1068.715

Figure 23: Denil Flow and Offset Data

By comparing these values with the values from the flow duration curve, it was determined that these values would allow for there to be flow over the dam approximately 85% of the time. Further analysis with the flow duration curve allowed the team to deduce that the flow would remain in the optimum range about 63% of the time.

It was also determined that the difference between the height of the water upstream of the fish passage and h_o was negligible and so the values determined for x were acceptable. See Table 5 for a summary of the flows expected to be seen through the passage and over the dam during expected high and low flows of the river.

Table 5: Expected Flows

Expected Flows When Implementing Denil Passage With a 1.9-ft offset			
	Flow Through Passage (cfs)	Flow Over Dam (cfs)	Flow of River (cfs)
Expected High Flow	18.75	113.25	132
Expected Average Flow	15.2	32.8	48
Expected Low Flow	8.1	0	8.1

4.4.2 Denil Passage Resting Pool

The denil passage resting pool was determined to be a 2ft by 2ft pool with a depth of 3.5ft using the design equation. This allowed for the volumetric power dissipation value to be low enough that it would not affect the fish and their ability to traverse the passage. The resting pool will be located at the corner of the fish passage. The passage channel will enter the resting pool on one side and exit on an adjacent side to the entrance.

4.4.3 Steeppass Flow Conditions

Figure 24 was used to determine an ideal value for the vertical distance from the bottom of the fish passage to the top of the dam, x. The value for x chosen needed to allow the flow through the passage to remain within a range adequate for herring. A flow too large may exceed the maximum velocity that herring can swim and a flow too low may make it impossible for the herring to swim upstream through the passage.

									Qr values												
					Qp																
X (ft)	2.5	5	7.5	**8.1**	10	12.5	15	17.5	20	22.5	25	27.5	**30**	32.5	**35**	37.5	40	42.5	45	47.5	50	52.5
0	36.58984078	72.2083	107.4698	115.8955	142.5015	177.3636	212.0909	246.7068	281.2275	315.6652	350.0294	384.3276	418.5658	452.7494	486.8824	520.9687	555.0114	589.0133	622.9768	656.9041	690.7972	724.6578
0.05	31.91455847	66.26097	100.6347	108.8783	134.9614	169.2288	203.4369	237.5888	271.688	305.7381	339.7426	373.7044	407.6263	441.5105	475.3593	509.1746	542.9581	576.7114	610.436	644.133	677.8038	711.4494
0.1	27.48028261	60.50448	93.96671	102.0239	127.5734	161.2357	194.9165	228.5978	262.2702	295.9284	329.5693	363.1914	396.7938	430.3761	463.9382	497.4803	531.0026	564.5055	597.9893	631.4545	664.9015	698.3307
0.15	23.29988896	54.9449	87.46975	95.33624	120.3406	153.3865	186.5315	219.7357	252.9758	286.2373	319.5107	352.7896	386.0694	419.3469	452.6199	485.8865	519.1456	552.3962	585.6376	618.8693	652.091	685.3024
0.2	19.38863939	49.58897	81.14812	88.8191	113.266	145.6838	178.2842	211.0042	243.8062	276.6662	309.5679	342.5	375.454	408.424	441.4053	474.3941	507.3878	540.3842	573.3813	606.3779	639.3728	672.3649
0.25	15.76503202	44.44416	75.00648	82.47678	106.3531	138.1302	170.1766	202.405	234.763	267.2165	299.7423	332.3238	364.9489	397.6084	430.2953	463.004	495.7302	528.4703	561.2214	593.9811	626.7475	659.519
0.3	12.4521502	39.51887	69.04988	76.31388	99.60549	130.7285	162.211	193.9403	225.848	257.8898	290.0351	322.2623	354.555	386.901	419.2908	451.717	484.1734	516.6552	549.1583	581.6795	614.2159	646.7651
0.35	9.479967907	34.82262	63.28384	70.33541	93.02696	123.4816	154.3899	185.6118	217.0627	248.6874	280.4478	312.3166	344.2734	376.3028	408.3928	440.5339	472.7183	504.9397	537.193	569.4738	601.7785	634.1039
0.4	6.889722458	30.36632	57.7144	64.54682	86.62168	116.3928	146.7157	177.4219	208.4092	239.6111	270.9817	302.488	334.1053	365.815	397.6023	429.4557	461.3657	493.3247	525.3261	557.3648	589.436	621.5361
0.45	4.743651383	26.16266	52.34825	58.9541	80.39415	109.4653	139.1912	169.3726	199.8892	230.6624	261.6383	292.7778	324.052	355.4386	386.9203	418.4834	450.1166	481.8108	513.5584	545.353	577.1892	609.0623
0.5	3.154056616	22.22667	47.19284	53.56386	74.3492	102.7027	**131.8191**	161.4663	191.5047	221.8432	252.4191	283.1875	314.1145	345.1747	376.3478	407.6178	438.9718	470.3991	501.8907	533.4394	565.0386	596.6831
0.55	2.5	18.57651	42.25651	48.38344	68.49214	96.10885	124.6025	153.7055	183.2578	213.1551	243.3258	273.7183	304.2943	335.0245	365.8858	396.86	427.9322	459.0902	490.3238	521.6246	552.9851	584.3994
0.6	2.5	15.23477	37.54872	43.42108	62.82874	89.68788	117.5444	146.0928	175.1506	204.6	234.3598	264.3718	294.5926	324.9892	355.5355	386.211	416.9988	447.8851	478.8585	509.9094	541.0294	572.2116
0.65	2.5	12.23068	33.0803	38.68608	57.36538	83.44425	110.6484	138.6308	167.1855	196.1799	225.523	255.1495	285.0108	315.07	345.2981	375.6718	406.1725	436.7847	467.4957	498.2946	529.1722	560.1206
0.7	2.5	9.604202	28.86386	34.18912	52.10912	77.38275	103.9181	131.3224	159.3649	187.8969	216.8171	246.0529	275.5503	305.2683	335.1745	365.2435	395.4543	425.79	456.2362	486.781	517.4142	548.1271
0.75	2.5	7.415001	24.91427	29.94254	47.06787	71.50864	97.35724	124.1708	151.6912	179.7531	208.244	237.0837	266.2126	295.5853	325.1662	354.9272	384.8453	414.9018	445.0809	475.3695	505.7563	536.2318
0.8	2.5	5.768321	21.24952	25.96095	42.25052	65.82765	90.97011	117.1793	144.1671	171.7507	199.8057	228.2437	256.9992	286.0223	315.2743	344.7241	374.3466	404.1212	434.0308	464.0609	494.1993	524.4355
0.85	2.5	5	17.89195	22.2619	37.66721	60.34611	84.76121	110.3511	136.7955	163.8921	191.5041	219.5345	247.9116	276.581	305.5001	334.6353	363.9591	393.4491	423.0867	452.8561	482.744	512.7389
0.9	2.5	5	14.87038	18.86714	33.32966	55.07101	78.73542	103.6902	129.5794	156.1798	183.3414	210.958	238.9515	267.2626	295.845	324.662	353.684	382.8867	412.2496	441.756	471.3912	501.1429
0.95	2.5	5	12.2241	15.80459	29.25158	50.01016	72.89808	97.20056	122.5219	148.6164	175.3198	202.5162	230.1207	258.0687	286.3103	314.8056	343.5225	372.4349	401.5206	430.7615	460.1418	489.6483
1	2.5	5	10.01143	13.11198	25.44937	45.17237	67.25503	90.8864	115.6264	141.2047	167.4417	194.2112	221.4209	249.001	276.8974	305.0672	333.4758	362.0948	390.9007	419.8736	448.9968	478.2558
1.05	2.5	5	8.334046	10.84468	21.94311	40.56767	61.81273	84.75243	108.8966	133.9477	159.7095	186.0449	212.8539	240.061	267.6079	295.4484	323.5451	351.8677	380.3908	409.0933	437.9569	466.9665
1.1	2.5	5	7.5	9.096733	18.75818	36.20759	56.5783	78.80372	102.3363	126.8485	152.126	178.0198	204.4218	231.2506	258.4433	285.9504	313.7317	341.7547	369.9922	398.4215	427.0233	455.7811
1.15	2.5	5	7.5	8.11088	15.92825	32.10566	51.55974	73.04581	95.94975	119.9104	144.6937	170.138	196.1265	222.5714	249.4052	276.5747	304.0369	331.7569	359.7058	387.8593	416.1968	444.7006
1.2	2.5	5	7.5	8.1	13.501	28.278	46.76607	67.48478	89.74143	113.137	137.4157	162.4022	187.9702	214.0254	240.4953	267.3228	294.4621	321.8757	349.533	377.4078	405.4784	433.7259
1.25	2.5	5	7.5	8.1	11.55238	24.7443	42.20758	62.12733	83.71624	106.532	130.295	154.8148	179.9552	205.6146	231.7153	258.1963	285.0086	312.1124	339.4747	367.0681	394.8691	422.858
1.3	2.5	5	7.5	8.1	10.23864	21.52939	37.89615	56.98095	77.87952	100.0997	123.335	147.3787	172.0837	197.3409	223.067	249.1968	275.678	302.4682	329.5324	356.8412	384.3701	412.0978
1.35	2.5	5	7.5	8.1	10	18.66601	33.84576	52.05402	72.23711	93.84441	116.5392	140.0968	164.3583	189.2066	214.5524	240.326	266.4718	292.9446	319.7072	346.7285	373.9823	401.4463
1.4	2.5	5	7.5	8.1	10	16.2002	30.07311	47.35606	66.79546	87.77093	109.9114	132.9722	156.7816	181.2139	206.1733	231.5856	257.3915	283.5429	310.0004	336.7311	363.707	390.9047
1.45	2.5	5	7.5	8.1	10	14.20432	26.59875	42.89796	61.56172	81.88447	103.4556	126.0081	149.3564	173.3651	197.9319	222.9776	248.4388	274.2648	300.4135	326.8502	353.5453	380.4739
1.5	2.5	5	7.5	8.1	10	12.82187	23.44876	38.69241	56.54388	76.19075	97.17615	119.2081	142.0855	165.6628	189.8304	214.5037	239.6155	265.1117	290.9479	317.0871	343.4983	370.1551
1.55	2.5	5	7.5	8.1	10	12.5	20.65789	34.7544	51.75095	70.69605	91.07789	112.576	134.9721	158.1096	181.871	206.1661	230.9233	256.0853	281.6049	307.4432	333.5674	359.9494
1.6	2.5	5	7.5	8.1	10	12.5	18.27586	31.10208	47.19324	65.40731	85.16594	106.1158	128.0196	150.7083	174.0562	197.9667	222.3641	247.1872	272.3862	297.9199	323.7537	349.8581
1.65	2.5	5	7.5	8.1	10	12.5	16.38318	27.75799	42.88263	60.33228	79.44592	99.83188	121.2314	143.4619	166.3884	189.908	213.9398	238.4191	263.2933	288.5186	314.0586	339.8822
1.7	2.5	5	7.5	8.1	10	12.5	15.15377	24.75131	38.8331	55.47971	73.92402	93.72901	114.6114	136.3735	158.8704	181.992	205.6524	229.783	254.3278	279.2408	304.4835	330.0232
1.75	2.5	5	7.5	8.1	10	12.5	15	22.12189	35.06139	50.85953	68.60712	87.8123	108.1636	129.4464	151.5049	174.2214	197.5042	221.2806	245.4915	270.088	295.0297	320.2822
1.8	2.5	5	7.5	8.1	10	12.5	15	19.9292	31.58803	46.48318	63.50284	82.08738	101.8924	122.6843	144.295	166.5986	189.4974	212.9141	236.7861	261.0619	285.6989	310.6607
1.85	2.5	5	7.5	8.1	10	12.5	15	18.27794	28.43914	42.36402	58.61977	76.56042	95.80253	116.0909	137.2439	159.1264	181.6343	204.6854	228.2134	252.1642	276.4924	301.16
1.9	2.5	5	7.5	8.1	10	12.5	15	17.5	25.6495	38.51799	53.96767	71.23827	89.89925	109.6704	130.355	151.8077	173.9174	196.5968	219.7756	243.3965	267.4118	291.7816
1.95	2.5	5	7.5	8.1	10	12.5	15	17.5	23.2689	34.9645	49.55775	66.12854	84.18818	103.4273	123.6319	144.6455	166.3494	188.6505	211.4745	234.7607	258.4589	282.5269
2	2.5	5	7.5	8.1	10	12.5	15	17.5	21.37799	31.72799	45.4031	61.23979	78.67554	97.36629	117.0784	137.6431	158.9329	180.849	203.3123	226.2587	249.6352	273.3976

Figure 24: Steeppass Flow and Offset Data

In Figure 24, when the flow of the river is equal to the flow of the passage, all of water flow is passing through the passage and no water is passing over the dam. Since aesthetics is an important aspect to this design, the value chosen for x needed to ensure that water flowed over the dam most of the time if possible.

The water velocity was calculated for passage flows ranging from 2.5 ft^3/s to 50 ft^3/s in 2.5 ft^3/s intervals. The results are presented in the following table:

Table 6: Steeppass Water Velocities for the Passage

Qp (cfs)	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50
V (ft/s)	1.852135	2.36859	2.735104	3.029053	3.278645	3.497767	3.69442	3.873683	4.03901	4.192871	4.337097	4.473094	4.601961	4.724581	4.841673	4.95383	5.061551	5.165258	5.265311	5.362021

Since the maximum sustained speed for herring is 4.9 ft/s, a flow capable of generating this velocity should only be exceeded 5% of the time. The flow capable of generating this velocity is about 39-cfs. Figure 24 was referenced and different values for x were compared. Ultimately a value of 1.5-ft was chosen. This value will keep the flow within the passage between about 8.1-cfs and 30-cfs 90% of the time. This will keep the water velocity between 2.81-ft/s and 4.47-ft/s, so the maximum speed for herring should not be exceeded often. This value will also ensure that water is flowing over the dam at least 85% of the time so not to take away from the existing appearance. The round value of 1.5-ft should also make construction easier than some other options.

See Table 7 for a summary the flows expected to be seen through the passage and over the dam during expected high and low flows of the river.

Table 7: Flow Summary

Expected Flows When Implementing a Steeppass With a 1.5-ft offset			
	Flow Through Passage (cfs)	Flow Over Dam (cfs)	Flow of River (cfs)
Expected High Flow	28.9	103.1	132
Expected Average Flow	18.8	19.2	48
Expected Low Flow	8.1	0	8.1

4.5 Final Concrete Design

This section contains layout plans for the final layout of the designed concrete denil fish passage.

4.5.1 Placement of Passage Next to Dam

Figure 25 shows the placement of the denil passage in green. The passage will run along the existing dam and will be attached to the portion of the dam next to the existing low flow gate.

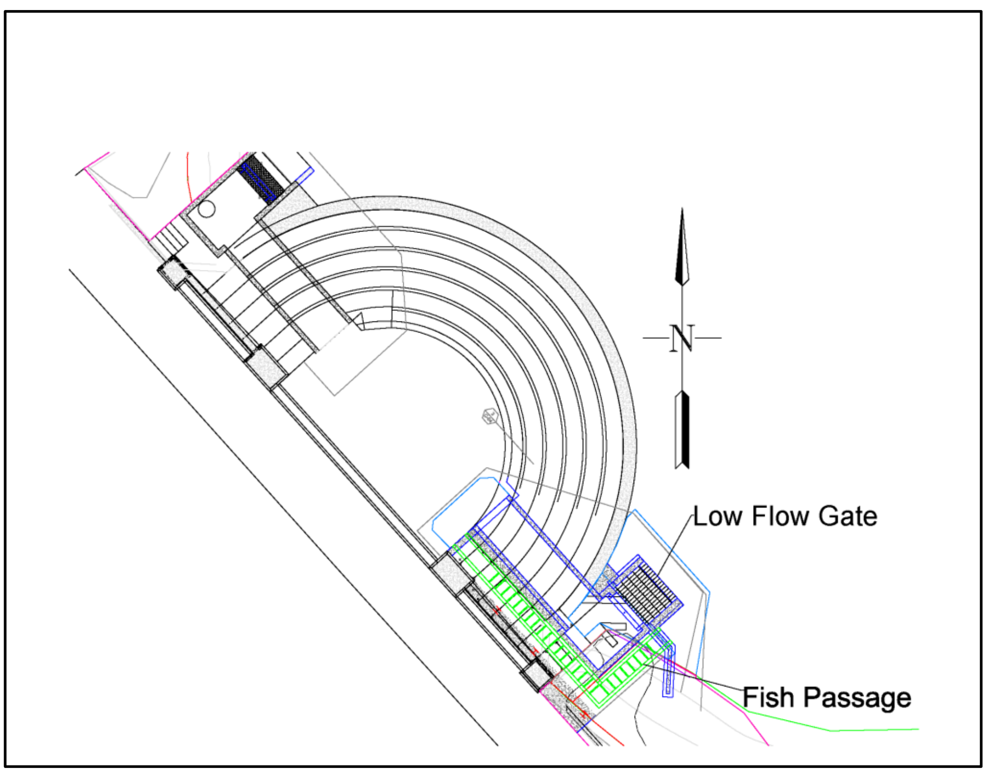


Figure 25: Top View of the Dam and the Fish Passage

4.5.2 Detailed Overview of Passage

The figure below shows the overview layout of the denil passage. As shown, the passage has a 15-ft and a 32-ft section. The 32-ft section slopes for a horizontal distance of 25-ft and spans 8-ft flat against the ground. The flat section contains no baffles. The two sections are joined together by the resting pool.

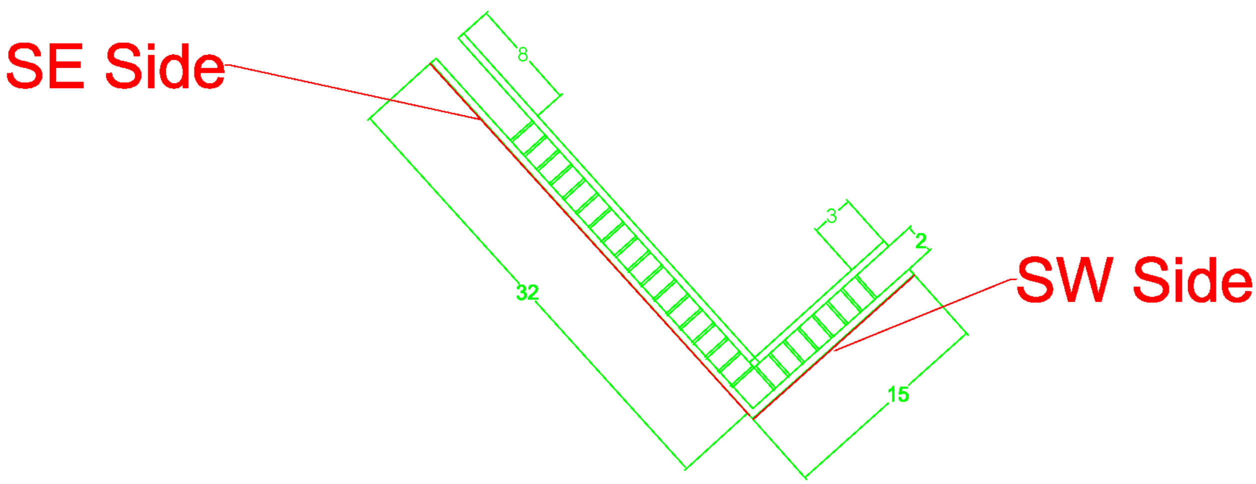


Figure 26: Top View of the Passage

4.5.3 Side View of Passage

The two sections of the passage can each be seen in the 2 side views shown below. Both sections are oriented at a 1:5 slope.

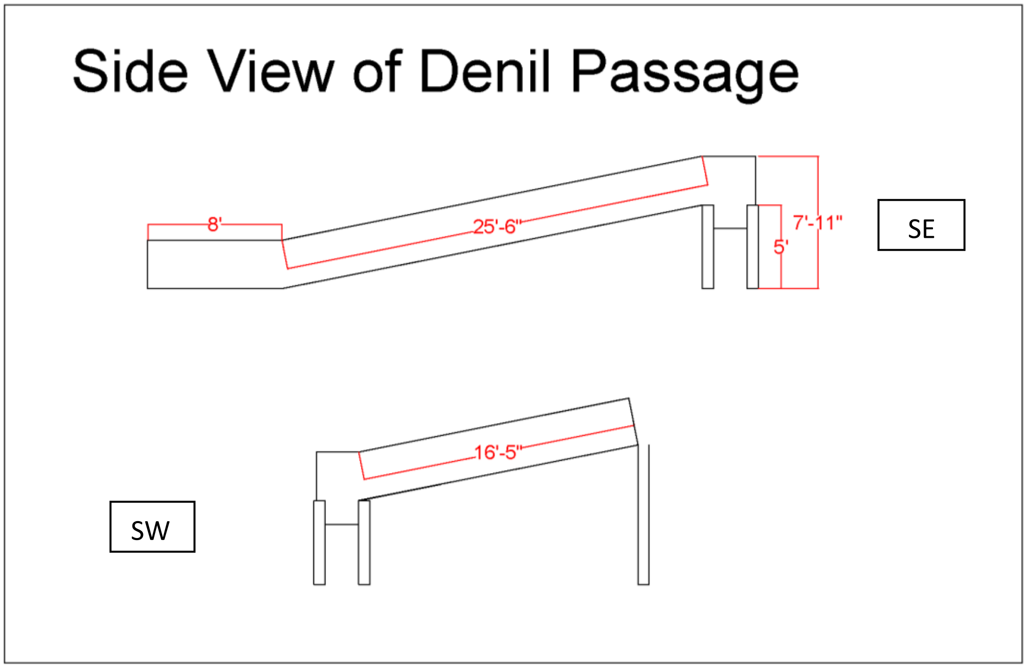


Figure 27: Side View of Denil Passage

4.6 Structural Analysis

The results for the structural analysis of the baffle design, reinforcement for the channel structure, and analysis of the new loadings on the dam are outline in the following section.

4.6.1 Denil Passage Baffle Design

Using the design equations and recommended values outlined in previous chapters (see section 3.6.1), the dimensions for the baffles were calculated. Figure 28 shows the dimensions for the final baffle.

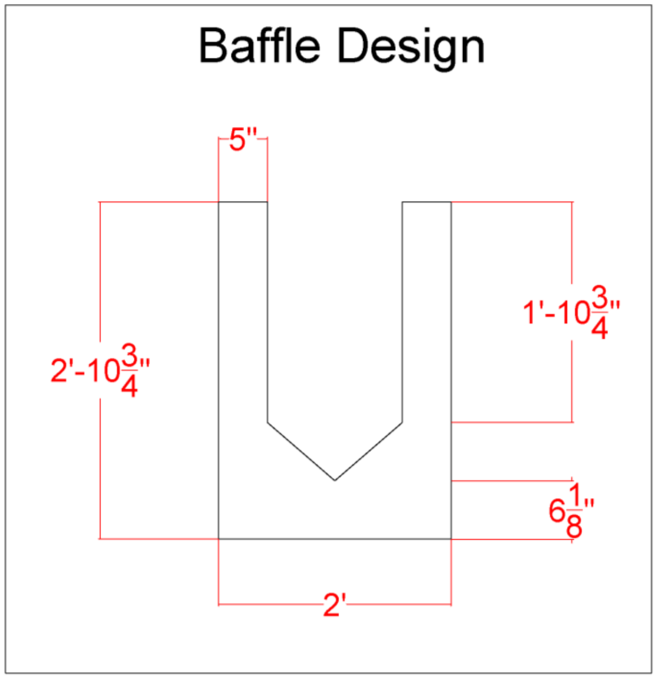


Figure 28: Baffle Design

The baffles were designed assuming to be made out of white oak as recommended for use by Brian Waz of the U.S. Fish and Wildlife Service. The thickness of the baffles was determined to be 1.7 inches thick, governed by the bending stress of the central section of the baffles. Larger baffle thicknesses such as 1.75-in or 2-in may be more common sizes to find and may be used instead of 1.7-in. See Appendix F for full calculations.

4.6.2 Denil Channel and Pool Wall Design

The driving factor for determining the thickness of the walls was the coverage needed for the re-bar due to ACI standards while the height of the walls were governed by the height of the baffles. The channel wall design is as seen in Figure 29. See Appendix F for full calculations.

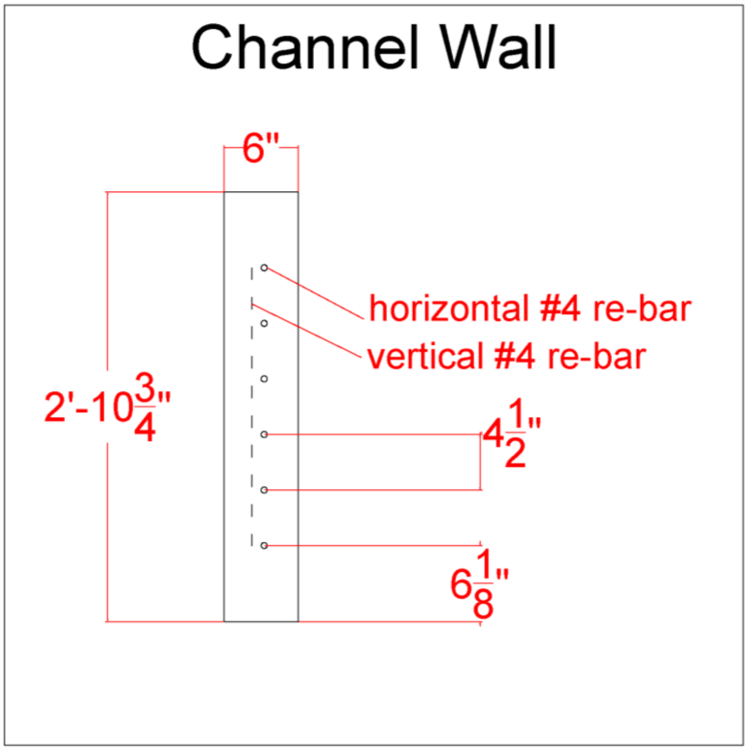


Figure 29: Channel Wall Design

The resting pool walls were determined using the same design equations as the channel walls as seen in section 3.6.3. The driving factor in determining the thickness of the walls was again the coverage needed for the re-bar while the height of the walls was determined by the desired depth of the pool calculated from the design equation provided by Fish Passes: Design, Dimensions and Monitoring. Refer to Figure 30 for a visual of the resting pool walls.

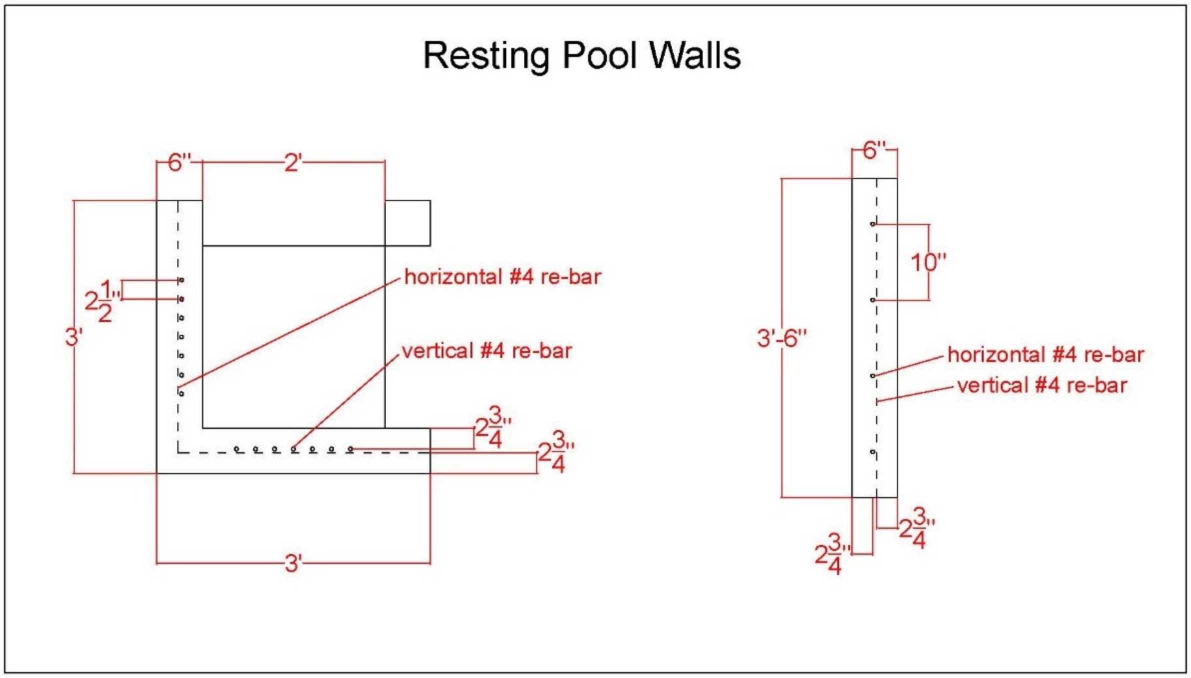


Figure 30: Resting Pool Wall Designs

4.6.3 Denil Channel Bottom Design

Figure 31 provides a visual representation of the bottom of the channel with dimensions and including reinforcing bar. The thickness of the bottom of the channel was governed by the shear forces on the channel. This is because it is simply supported and half the weight of the channel (filled with water) is supported by the bottom. The width was simply determined from the added width of the baffles and designed for the passage with the designed channel walls. Refer to Appendix F for full calculations.

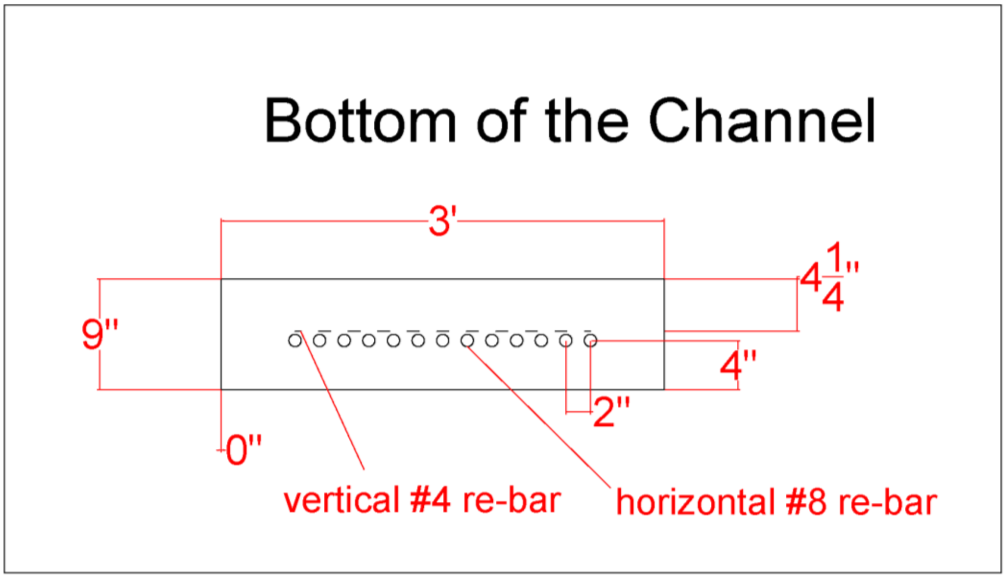


Figure 31: Bottom of the Channel

4.6.4 Denil Resting Pool Bottom

Figure 32 shows the final design for the resting pool base. The thickness for the pool was governed by the covering needs of the re-bar. The width was based off of the dimensions determined for the fish passage as seen in section 4.4.2. See Appendix F for full calculations.

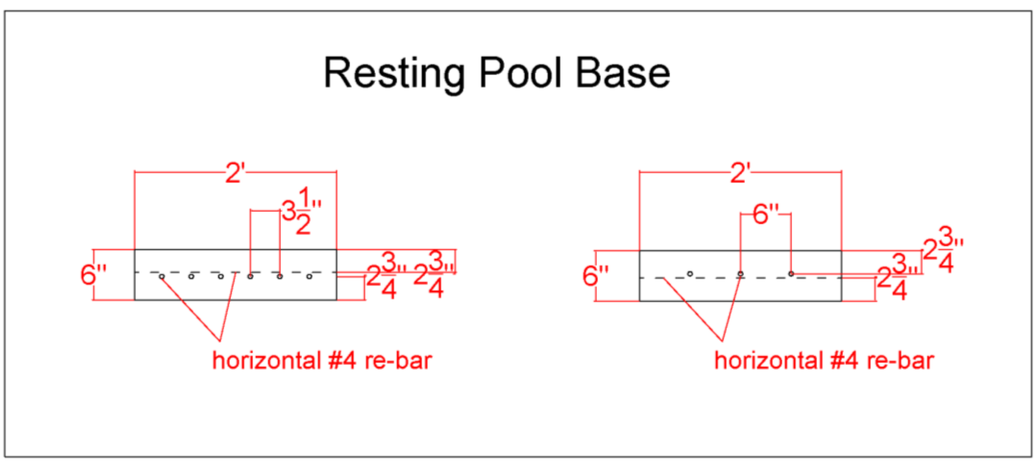


Figure 32: Resting Pool Base Design

4.6.5 Denil Resting pool Supports

Figure 33 shows a diagram of dimensions of the designed supports for the resting pool. The thickness of the supports were governed by the coverage needed for the re-bar. The height of the supports was determined by the slope of the passage. See Appendix F for full calculations.

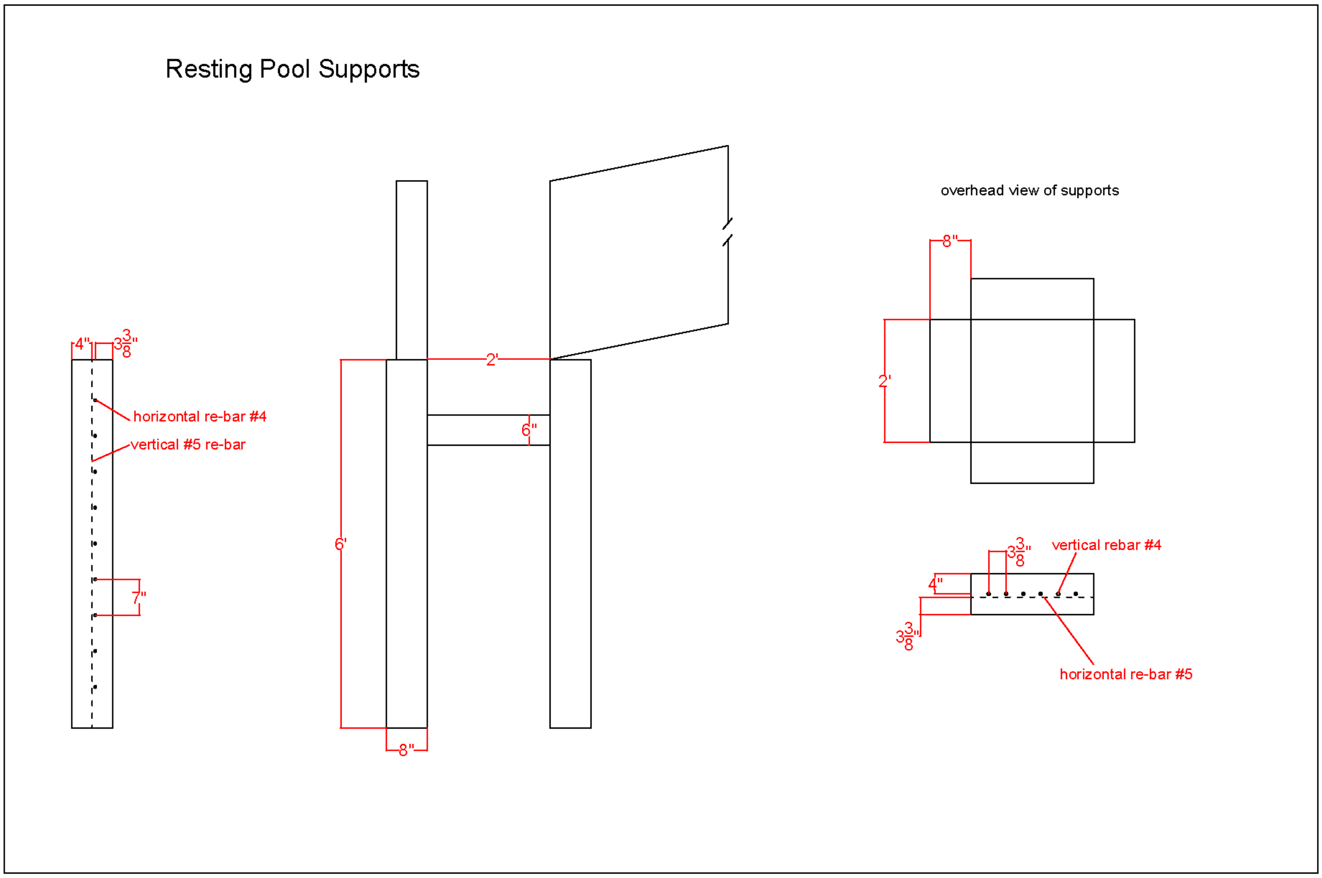


Figure 33: Resting Pool Supports

4.6.6 Denil Passage Impact on the Existing Dam

To determine the effect the passage would have on the dam, the axial compressive load, the stress due to water pressure, and the bending stress due to the vertical load were all calculated and summed. The total stress on the dam with the addition of the loading of the fish passage was found to be 280psi. If the concrete section was adequately designed with reinforcement, the dam should not need additional supports to carry the passage. Refer to Appendix F for full calculations.

4.7 Economic Analysis

The construction costs for general fish passages were obtained from Brian Waz and used to estimate a cost for the considered fish passages. The estimated costs of the fish passages considered in this project are presented in Table 8:

Table 8: Fish Way Pricing Per Foot Rise

Fishway Type	Cost/Foot Rise	Total Cost
Denil	$45,800	$503,400
Steeppass	$24,700	$271,300

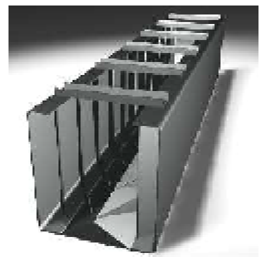
Note that the values above are estimates that account for material, labor, and permitting costs for the passages.

See Figure 34 for the quotation of the breakdown of general steeppass costs as provided by Nancy DeWall with Sheepscot Machine Works. Note that this is just a general cost estimate based on projects the company normal performs and that the quote provided does not include installation or permitting costs for the passage. This cost breakdown is not an estimate for this project in particular.

MACHINE WORKS
1130 ROUTE 1 * NEWCASTLE, ME 04553
TEL. 207-563-2299 * FAX. 207-563-2619

Budgetary Quotation

Quote No. 6325-1213
Quote Date:12/11/2013
Revision Date:12/11/2013



Anthony Guerra
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Worcester, MA 01609-2280
USA
Tel:
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Email: aguerra@wpi.edu#

Alaska Steeppass Fishway Assembly

Following is a list of items typically used to construct a variety of SteepPass Fishway configurations:

	Description	Ut Price	Qty	Ext Price
Overview Notes	Fishway components are built from superior marine grade 5052 aluminum plate.			
10 ft Aluminum Steeppass Fish Ladder	Includes necessary stainless steel fasteners. Joint plates are specified separately; dependent upon number of contiguous fishway sections.	$6,500	1	$6,500
5 ft Aluminum Steeppass Fish Ladder	Includes necessary stainless steel fasteners. Joint plates are specified separately; dependent upon number of contiguous fishway sections. Other lengths available.	$3,850	1	$3,850
10 ft Aluminum Steeppass Fish Ladder Shell	Designed and built without fins or 'V' plate for level runs; as recommended by State of CT DEEP Supervising Fisheries Biologist, Stephen Gephard as fish resting area ; fasteners are included.	$3,800	1	$3,800
Joint Plate	Aluminum joint plate assembly to connect fish ladders (straight span).	$510	1	$510
Angle Adapter	Aluminum Angle Adapter; specify upstream or downstream, flanged or unflanged. Includes stainless steel fasteners for joining to fishway.	$1,890	1	$1,890
Up Stream Adapter w/ Slide Gate	Aluminum Angle Adapter w/ Adjustable Aluminum Slide Gate, Upstream configuration (Flanged). Includes stainless steel fasteners for joining to fishway .	$2,130	1	$2,130
Grating	Aluminum Grating to cover Fishway units (price per 10 ft section)	$1,470	1	$1,470
Inlet Pool	Approximate dimensions: 12 ft x 12 ft (for budgetary purposes only).	$13,500	1	$13,500
Resting Pool	Approximate dimensions: 12 ft x 16 ft with flat bottom (for budgetary purposes only).	$20,000	1	$20,000
Custom Components	Other custom fabrications are available such as turning pools, and special adapters. Please contact us should you have further requirments.			

Page 1

Figure 34: Budgetary Quotation Provided by Sheepscot Machine Works

5.0 Conclusion and Recommendations

In summary, this project included a design of a denil passage and provided information on the feasibility of steeppass fishway to allow for fish passage for the Center Falls Dam on the Aberjona River in Winchester, Massachusetts. The passage was designed through a series of different analyses. It started with a hydrologic analysis to estimate probable flows for the river followed by a hydraulic analysis of the area around the dam and of the fish passage to determine dimensions and placement for the structure to ensure proper flow in the channel of the passage. A structural analysis was then performed to determine structural stability and establish a public safety factor ending with an economic analysis to provide some basic information on costs of the project to the town. The analyses and design included in this report provide a basis for further efforts to implement a fish ladder at this site.

5.1 Fish Passage Recommendations

The following two sections provide some recommendations for the two fish passage alternatives that were evaluated in this report.

5.1.1 Recommendations for Implementing a Denil Passage

The final design for the denil passage does not include a mix design for the concrete used on the structure. One of the recommendations at the end of the design is for the concrete chosen to have proper air entrainment properties since the structure will have freeze thaw issues since it will be in constant contact with water and is placed in the New England area. Another recommendation is to use a sealant on the final concrete structure to provide a protective coating against moisture however; the sealant would need to be nontoxic as so to not have detrimental effects on the fish and the environment.

If the Town of Winchester decides to choose the denil passage for the fish passage they should also consider the possibility of a removable floating curtain or wall that can be used when the herring are attempting to return to the sea. This curtain would serve as a way to guide the fish back down the fish passage so they don't wind up injuring themselves trying to swim over the dam. Since the baffles could be removed at this point, the passage would serve as a smooth way back down the river.

A final recommendation to add to the fish passage would be a fish trap. Since there will be a portion of the passage that is a straight with no baffles, this section could be turned in a fish trap so that the herring could be tagged or a fish counting system could also be installed in the area if studies needed to be done on the herring using the pass.

5.1.2 Recommendation to Implement a Steeppass

The hydraulic analysis conducted on the steeppass for the area showed that it would be feasible to have a steeppass positioned on the Center Falls Dam. Although the design may be less aesthetically pleasing due to its aluminum framework, it is still recommended that Sheepscot Machine works be contacted to create a formal design for a steeppass for the dam. The reasoning behind this is the fact that economically the steeppass is the best choice from the information presented in the previous chapter. The cost for the denil can be expected to be almost double that of the steeppass. Since available funding is uncertain at this time due to the need to repair the dam, it would be advisable to look further into the less expensive steeppass design as a short-term solution.

5.2 Future Research

Future research that could benefit fish passage design would be more research into steeppass design. Currently there is little information on steeppass design available to the general public since steeppasses are always prefabricated. It is recommended that a future MQP be done with a steeppass design company so that there could be a published paper available for general use. This would provide a base from which a steeppass could be fabricated for any dam based off of recommended values laid out by the designers.

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Appendix A: MQP Proposal

Major Qualifying Project Report Proposal:

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

____

Peter Eggleston

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Anthony Guerra

Date: 17 October 2013

Approved:

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Professor Leonard Albano, Major Advisor

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Professor Paul Mathisen, Major Advisor

Abstract

Due to the increasing number of dams in Massachusetts, river herring populations have been declining over the course of the past decade. The focus of this project is a fish passage for the Center Falls Dam on the Aberjona River in downtown Winchester. Through the use of hydraulic and structural analysis the dam will be assessed and a fish passage designed to provide a way for river herring to properly spawn upstream of the dam.

1.0 Introduction

Throughout the course of history dams have been used for retaining water and collecting water for storage. While dams serve their purpose to humans for things such as reservoirs of drinking water and flood control, they also have a rather large environmental impact on the different ecosystems in which they are placed. Some impacts that dams have on the environment are trapping of sediment that are critical to physical processes downstream of the dam, changes in temperature, chemical composition, and dissolved oxygen levels, and the blocking of fish migrations. New England and Massachusetts specifically is home to a variety of different types of dams in various bodies of water across the state.

The Aberjona River is one of many rivers that lie in the Mystic River Watershed. It runs for over nine miles through the northwestern suburbs of Boston before it empties into the Mystic Lakes. As the areas around it have become more settled, people have started to affect the river system, and the wildlife within it, more and more. With the advent of dams for flood control, the river's environmental habitat has been changing drastically. Two particular species affected by the changes are alewife and blueback herring, collectively known as river herring. Due to the dams built at various points on the Aberjona River, herring populations have declined over the course of time because of these obstructions to their migration patterns. Through the manufacturing of fish passages, river herring can be provided an opportunity to reach more appropriate spawning grounds. The objective of this project is to design a fish passage to be implemented by the Town of Winchester in the Center Falls Dam on the Aberjona River in order to accommodate the migration of aquatic life, in particular herring.

1.1 Project Scope

The Center Falls Dam, as seen in Figure 1, in downtown Winchester on the Aberjona River is the focus of this project. The dam is a concrete arch dam used mainly as flood control. Typically before a big storm the water level in the adjacent pond is drained to allow for more storage as necessary to avoid flooding in the downtown area. The purpose of this project is to develop a fish passage design for the Town of Winchester that works aesthetically, fitting into the historical feel of the area, while also being affordable. The passage will be designed by performing a hydraulic analysis on the dam, designing a fish passage including style of the passage, placement of entrance and exit to the passage, and additional features, a structural analysis of the designed fish passage, and a structural analysis of the dam with the new loads from the fish passage. The following sections of report will cover the capstone design requirements of the project, background information to understand the project, and the proposed methodolgy for the project.

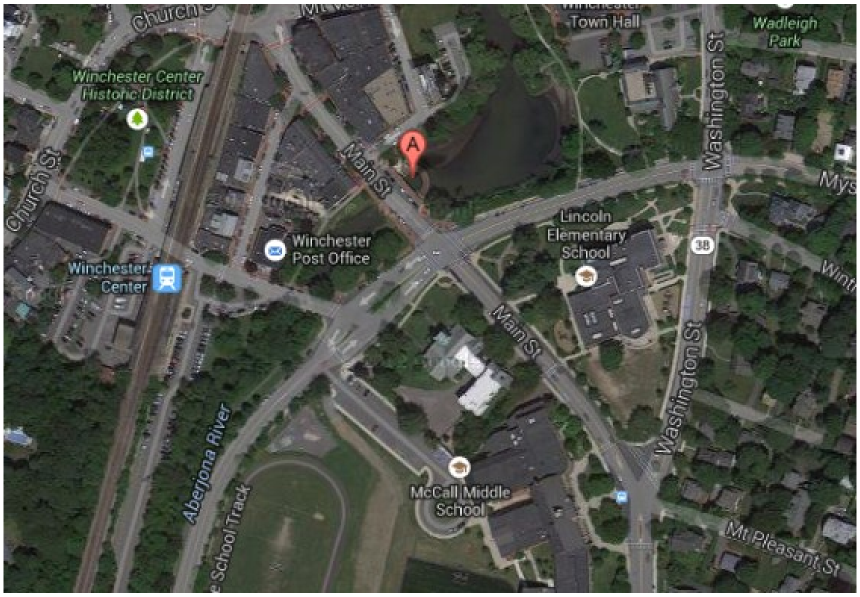

Figure 35: Map of downtown Winchester and the Aberjona River. Point A marks the Center Falls Dam (Google Maps, 2013)

1.2 Capstone Design

This project focuses on the design of a fish passage for the Town of Winchester in the Center Falls Dam on the Aberjona River. Two students will author the project, both majoring in civil engineering with focusses in structural engineering and environmental engineering. Through environmental and structural design analysis of existing conditions, a design that meets the needs of the project will be developed while meeting the Capstone Design requirements set by the American Society of Civil Engineers.

An in-depth study on the herring will be conducted to ensure that the fish will be able to traverse the passage created in a safe and natural manner. There will also be a hydraulic analysis to establish flows around the dam. The analysis will determine the flows that will run through the passage and help to identify the turbulence that will affect the fish attempting to enter the stream from the pass. These aspects of the project will cover environmental, health, safety, sustainability, and ethical issues. The structural design produced for the passage will cover the actual physical design and placement of the pass, the forces that the structure must be able to withstand from year-round flows, and the material the pass will be constructed of that allow for proper structural integrity. These aspects of the design will illustrate manufacturability and health and safety issues.

Some constraints on the project also stem from the Town of Winchester itself since the location of the passage will be in the downtown area. The passage needs to fit aesthetically with the dam since it is considered a historical part of town and is placed in a populated area. The passage will also have different regulatory issues due to the nature of construction along with the anticipated needed future maintenance of the fish passage. These constraints show social and political issues. Overall the design of the passage will also be constrained by the funding provided. Due to the need to renovate the dam itself, there is now less money set aside for the construction of the fish passage than originally anticipated so the design needs to account for a smaller budget. This economic limitation will also affect the design of the passage for the design needs to take its construction cost into consideration.

2.0 Background

In order to understand the scope of the project, background research was conducted. The more critical information needed to analyze the project was compiled into the following sections to provide information on existing conditions at the dam, herring, and fish passages.

2.1 Herring

The Mystic River Watershed is home to a variety of aquatic life including river herring. Although there are two different types of river herring, they are generally categorized together due to the difficulties of distinguishing the two species. Both species of herring are considered to be anadromous, meaning that they are born in freshwater but then migrate to saltwater in the earlier stages of life. Some of the distinguishing characteristics of the two types of herring can be found in Table 1.

Table 1: Traits of Alewife and Blueback Herring

	Alewife	Blueback
Lifespans	Up to 10 years	Up to 8 years
Size	Lengths of 14 to 15 inches	Maximum size of 16 inches
Color Scheme	Bronze coloring in the dorsal region	Blue coloring in the dorsal region
Egg Production while Spawning	Females produce 60,000-300,000 eggs	Females produce 60,000-103,000 eggs

One important characteristic that the two types of river herring share though is swimming speeds. Herring, and other fish, have three basic swimming speeds: cruising, sustained, and darting. A cruising swim speed is one typically used for movement and migration that can be continuous for hours at a time. Sustained speeds are those that are maintained for minutes at a time, usually used to get through obstacles while migrating. Darting speed is a single effort used when feeding or sometimes for evasion purposes. The main ability for fish to navigate obstructions though can be based off of the species' sustained swimming speed but should be well under the darting speed of the fish. Fish passages can be considered as an obstacle that a sustained swimming speed throughout is acceptable for aquatic life migration. For blueback and alewife herring, the sustained speed is about 1.5 m/s. (Bell, 1990)

A rather unfortunate piece of data about river herring is the decline of the species. In a study by Peter Marteka (2004), he showed that from 1985 to 2003 there was a drastic drop in herring counts in the Connecticut River from approximately 600,000 herring to only 1300 respectively. These declining trends have also been observed in various states throughout New England including Massachusetts and the Mystic River Watershed. Today, both alewife and blueback herring are considered species of concern meaning that the NOAA National Marine Fisheries Service has inadequate information to place the species under the Endangered Species Act but there is concern for the viability of the species. Some factors behind the decline of the herring are habitat degradation, fishing, and loss of habitat from dam construction. (NOAA)

One way the decline of herring from dam construction is fought is through the installation of fish passages which allow for the fish to migrate upstream to spawn.

2.2 Fish Passages

The ideal solution for allowing fish to swim up an obstructed stream is to remove the obstruction. In the case that the obstruction is necessary, such as a dam for flood control, removal may not be a viable option as it may cause problems in the area. A fish passage is solution that can be applied in such a case. A fish passage is a structure that provides an alternate pathway that allows fish to navigate around a major obstacle. Implementing a passage for fish to swim around the obstruction will allow fish to migrate upstream relatively uninhibited while allowing the dam or other obstruction to remain where it is.

The United States National Oceanic and Atmospheric Administration (NOAA) and the United Nations Fisheries and Aquaculture Department (FAD) provide information on what should be considered when implementing a fish passage.

The FAD(2002) and NOAA(2013) state that the flow passing through a fish passage should be high enough for fish to migrate upstream while not being so high that the fish become fatigued. NOAA suggests that the flow within the fish passage be controlled within a range between a minimum flow and a maximum flow. The minimum flow is the lowest flow in which the species of concern is expected to be present while the maximum flow is the highest flow in which the species is expected to be present. The flow within the passage should exceed the minimum flow 95% of the time and exceed the maximum flow 5% of the time during the spawning season of the fish. If the distance of the passage can tire fish, it is recommended to include rest areas of little to no flow where fish can stop for a while traveling up the passage.

The placement and orientation of the fish passage entrance should be considered carefully. Both NOAA and the FAD state that the entrances should be as far downstream from the obstacle as possible, but should also be placed in an area that the fish will notice the flow emitting from the entrance, known as the attraction flow. If there are high or turbulent flows near the obstacle, the fish may not notice the attraction flow and may miss the entrance. It may be better to place the entrance downstream of the obstacle where the water flow is calmer. The FAD suggests that the ideal orientation of the entrance is parallel with the river flow. This orientation will allow fish to enter without having to change direction too much. According to NOAA, the direction the entrance is oriented depends on the attraction flow conditions. An entrance with a flow velocity higher than that of the surrounding river should be oriented 0 to 45 degrees from the direction of river flow while an entrance with flow lower velocity than that of the surrounding river should be oriented 45 to 90 degrees from the direction of river flow. If a flow high enough to attract fish cannot be achieved without exceeding the flow limits in the passage, NOAA suggests that additional flow be routed from elsewhere to increase the attraction flow near the entrance of the passage without increasing the flow within the passage.

The placement of the exit of the passage also needs to be considered upstream of the obstruction. Both NOAA and the FAD stress the importance of choosing a safe, calm location for the exit. Too much turbulence or a large change in velocity may make it difficult for fish to re-enter the stream and continue upstream. The exit should also be far enough upstream from the obstruction so that the fish do not get caught near the obstruction. For example, the high water velocities near the top of a dam may sweep fish entering the river back downstream.

Additional features may be included to increase the functionality of the passage. NOAA and the FAD both suggest a floating "trash boom" to block floating debris from entering the passage and to provide a means to perform maintenance; this may include a gate at the exit to cut off flow through the passage. The FAD suggests placing a layer of substrate similar to that of the river bed along the bottom of the passage to create a more natural environment and to allow smaller migratory organisms to more easily navigate upstream. NOAA suggests implementing a hydraulic drop at the exit to increase the attraction flow into the river. NOAA also suggests placing an angled trash rack at the upstream exit to provide a method of filtering out debris that is easy to maintain.

2.2.1 Types of fish passages

Both the United States National Oceanic and Atmospheric Administration's "Diadromous Fish Passage: A Primer on Technology, Planning, and Design for the Atlantic and Gulf Coasts" (2013) and the United Nations Fisheries and Aquaculture Department's "FISH PASSES Design, Dimensions and Monitoring" (2002) present similar options for various aquatic passage designs. The three main types of fish passage design mentioned by the documents include Pool and Weir Fishways, Vertical Slot Fishways, and Baffled Chute Fishways.

Pool and Weir fishways consist of consecutive chambers each with a weir located at the top of the downstream wall allowing water to flow into the next chamber. The fish swimming through this type of passage are able to swim over the weirs or, if they are present, though orifices located near the bed of the passages. Orifices are only added when there is enough water; otherwise, the passage may be dewatered. These fishways function well with low flows; however, they require well-controlled head water. Variations in headwater will cause inconsistent flow within the passage. (UN FAD 2002, US NOAA 2013)

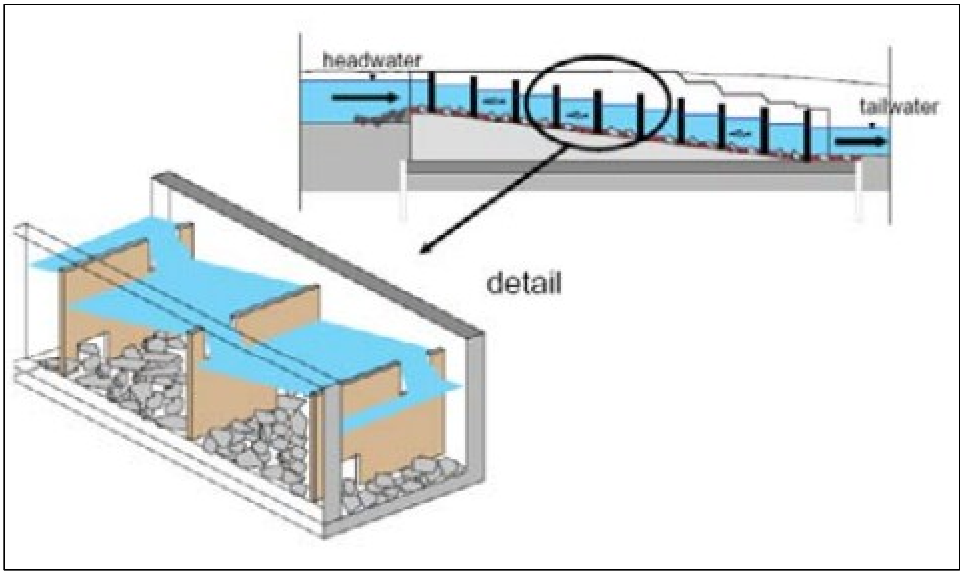

Figure 36: A diagram of a pool and Weir Fish Passage. (US NOAA)

Vertical Slot fishways are more common along the Atlantic Coast of the U.S than the pool and weir passages and are effective in a wide range of flow conditions. This style of passage is both versatile and yields positive results for many Atlantic coast species including American shad, river herring, and striped bass. These fishways consist of consecutive walls with one or two vertical openings in each wall. Baffle plates are usually included to reduce turbulence and dissipate energy. The benefit of the vertical openings is that as the water level changes, the percentage of the wall that the water can flow through remains the same. The pools between the vertical slot walls also provide an area for fish to rest why traveling up the passage. The problem with this type of passage is that narrow slots may cause the descaling and death of some fish. (US NOAA 2013)

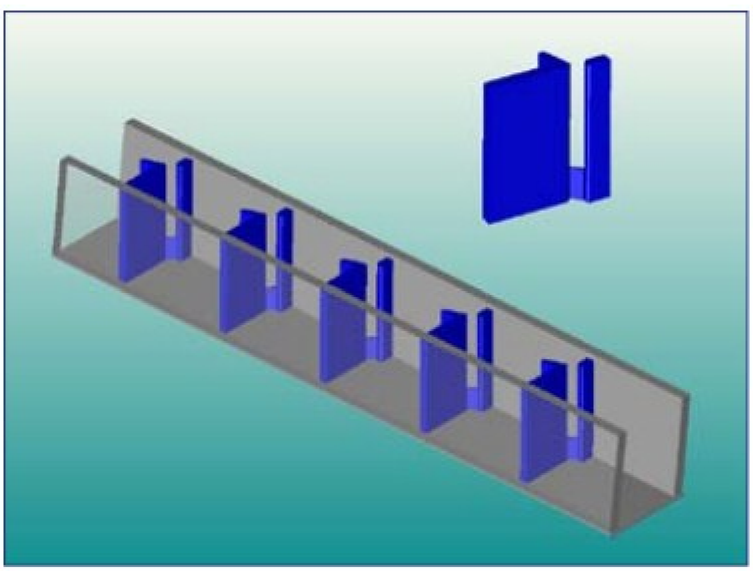

Figure 37: A diagram of a Vertical Slot Fish Passage. (US NOAA)

Baffled Chute Fishways incrementally reduce hydraulic head through the use of baffles. The baffles allow for a controlled hydraulic step and the dissipation of energy. There are two main types of a Baffled Chute Fishway, the Denil Fishway and the Steeppass. Standard Denil Fishways tend to be easier to build than Steeppasses but standard Denil passages usually have a lower incline. Steeppasses are more complex and more effective at dissipating energy than Denil passage which allows Steeppasses to be built with greater inclines. (US NOAA 2013) This is useful for areas that require a large change in elevation in a short distance. Both types of Baffled Chute Fishways can be built from a variety of materials and can be built for a relatively low cost compared to other fishways, such as pool and weir passages. Baffled Chute Fishways also have a few downsides to their use. If not properly maintained, the passage may become clogged. These fishways require a larger minimum flow than other passage styles. This flow needs to be met for the passage to function. During low flow conditions, the larger demand for water may increase the possibility of dewatering upstream. The high flow in this system may also cause problems for weaker fish. As with Vertical Slot Fishways, the baffles in the Baffled Chute Fishways may cause injury to the fish. (UN FAD 2002, US NOAA 2013)

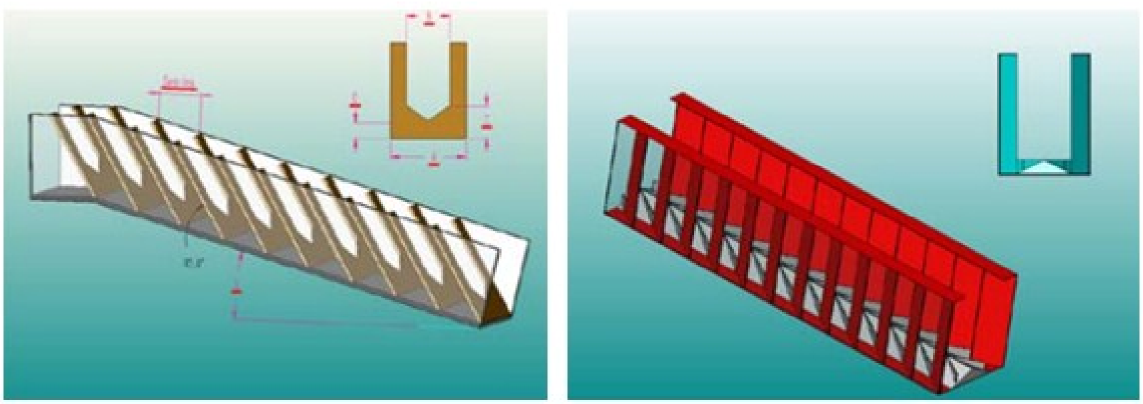

Figure 38: Diagrams of Baffled Chute Fish Passages. A Standard Denil Pass is shown on the left, and a Steep Pass is shown on the right. (US NOAA)

2.3 Center Falls Dam

The Center Falls Dam in Winchester Massachusetts is an arched dam that water flows over and down arched steps. This dam is located in the path of herring migration. Juvenile herring have been observed by the project team near the base of the dam and most likely spawn near or under a bridge that is located just downstream of the dam (B. Chase, October 2013). Adult herring most likely mate in this location because they cannot travel further upstream due to the dam. The dam may be considered a curved, broad-crested weir to calculate characteristics of flow passing over the top. (Refer to Appendix B for blueprints of the physical structure of the dam)

Figure 39: The Center Falls Dam, Winchester MA

2.3.1 Existing Condition of the Center Falls Dam

At the time of this project the Center Falls Dam is currently under construction. The construction began with the replacement of a gate valve and was extended when it was discovered that a portion of the dam's cascading steps had collapsed and needed to be repaired. During construction, water flowing from the Aberjona River has been diverted through a butterfly valve normally used for low flow conditions.

2.4 Summary

The Center Falls Dam needs a fish passage to allow for the herring population in the area to thrive. Although there are various types of passages for different situations, one will be decided on for the project that will best fit the constraints of the project scope. The next chapter will detail the methods used to determine the right fish passage to use for the dam. It will encompass data collection, a literature review, design and analysis of the hydraulic and structural aspects for both the passage and dam, and the creation of deliverables for the town of Winchester.

3.0 Methods

The goal of this project was to develop a design that will accommodate fish passage for the Center Falls Dam on the Aberjona River in Winchester, MA. The main tasks done to achieve this design are outlined in this chapter and are as follows:

data collection

literature review

hydraulic analysis

design of the passage

report preparation and deliverables

3.1 Data Collection

The collection of data was the start of research for the project. During a site visit on September 18, 2013, general observations of the dam were made. Blueprints of the dam were also obtained from Brian Waz, a Hydraulic Engineer from the Department of the US Fish and Wildlife Service, who explained details of the dam including the necessary determined location for the fish passage. Historical flow data of the Aberjona River was obtained from the USGS website. The data obtained includes the average flow for each day of an average year.

3.2 Literature Review

Background information used during the project was gathered from various sources such as textbooks, journal articles, and meetings with an engineer and biologist from the Division of Marine Fisheries and the US Fish and Wildlife Service. The range of subjects of information included biology, hydrology, fluid mechanics, structural analysis, and fish passage design.

Different Styles of fish passages were researched. Both the United Nations Fisheries and Aquaculture Department and the United States National Oceanic and Atmospheric Administration have produced documents presenting fish passage styles and designs. Using these documents, multiple styles of fish passages were examined to gain an understanding of the benefits and problems produced by each style. The overall knowledge obtained from these resources allowed for a base to which the passage could be designed.

3.3 Hydraulic Analysis

The United States Geological Survey (USGS) records flow data from points throughout the United States by monitoring stream gauges. Using data from the gauge upstream of the Center Falls Dam, the team will estimate the flow characteristics of the river and the water flowing over the dam during the migratory months of the river herring. The amount of flow will influence the flow available to pass through the fish passage while the velocity of the flow and turbulence will affect the ability of the fish to enter the stream from the passage.

Khosrojerdi and Kavianpour wrote a research article that includes an equation for calculating flow over a curved broad crested weir. The equation used is $\boldsymbol{Q = Cd * B * h^{1.5}}$ where ***Q*** is the flow passing over the dam, ***B*** is the length of the dam, and ***h*** is the depth of water over the dam. ***Cd*** is a constant determined by the equation $\boldsymbol{Cd = \left(0.5 + 0.33 * \frac{h}{P} + \frac{h}{L}\right)^{0.6}}$ where ***L*** is the thickness of dam and ***P*** is the height of the dam. Using these equations, excel will be used to graph a relationship between the flow over the dam (***Q***) and interval values for (***h***). The graph will be used to generate an equation to solve for ***h*** from given values of ***Q***. Values for ***h*** will then be determined from the daily flows retrieved from the USGS database. Using the calculated values of ***h***, flow velocity will then be calculated. In order to estimate downstream flow characteristics, riverbed dimensions will be researched. If dimensions cannot be found, assumptions of the slope of the riverbed will be made. The team will also use hydraulic analysis in order to determine loadings on the fish passage and to properly identify structural requirements. The United Nations FAD provides some equations and methods for analyzing hydraulic flows through the different styles of fish passages. (Refer to Appendix A for USGS flow data for the Aberjona River)

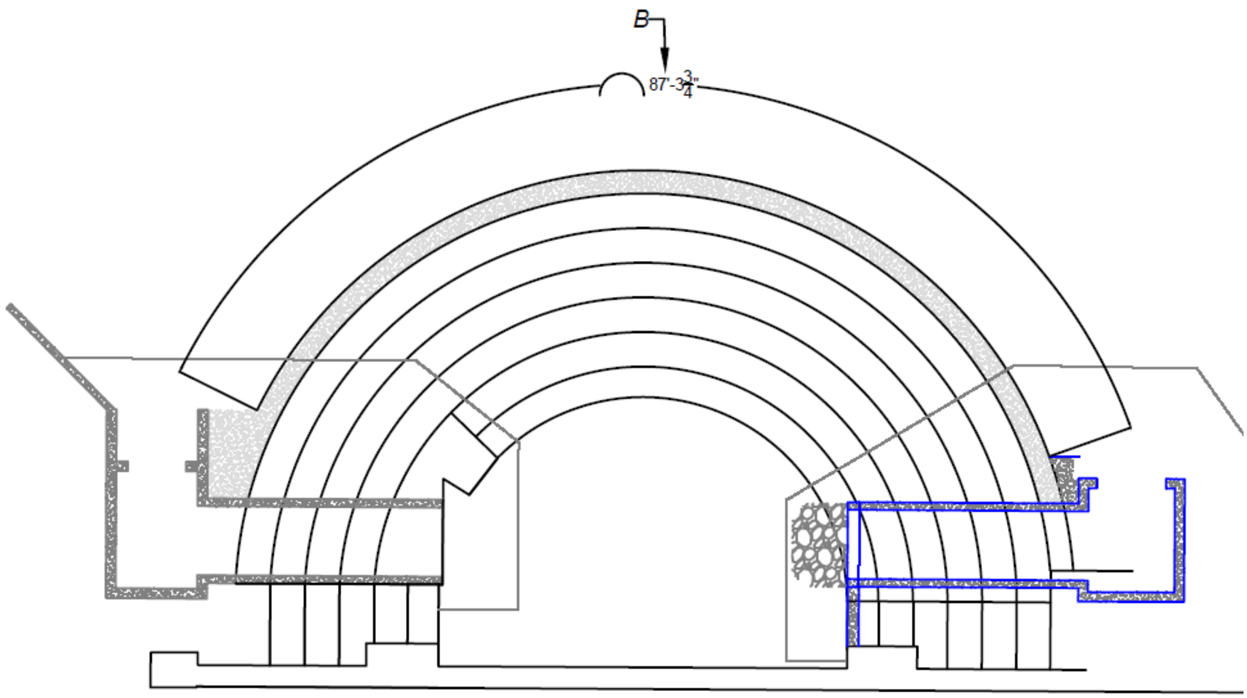

Figure: Overview of the Center Falls Dam from blueprints in Appendix B

Length = *B*

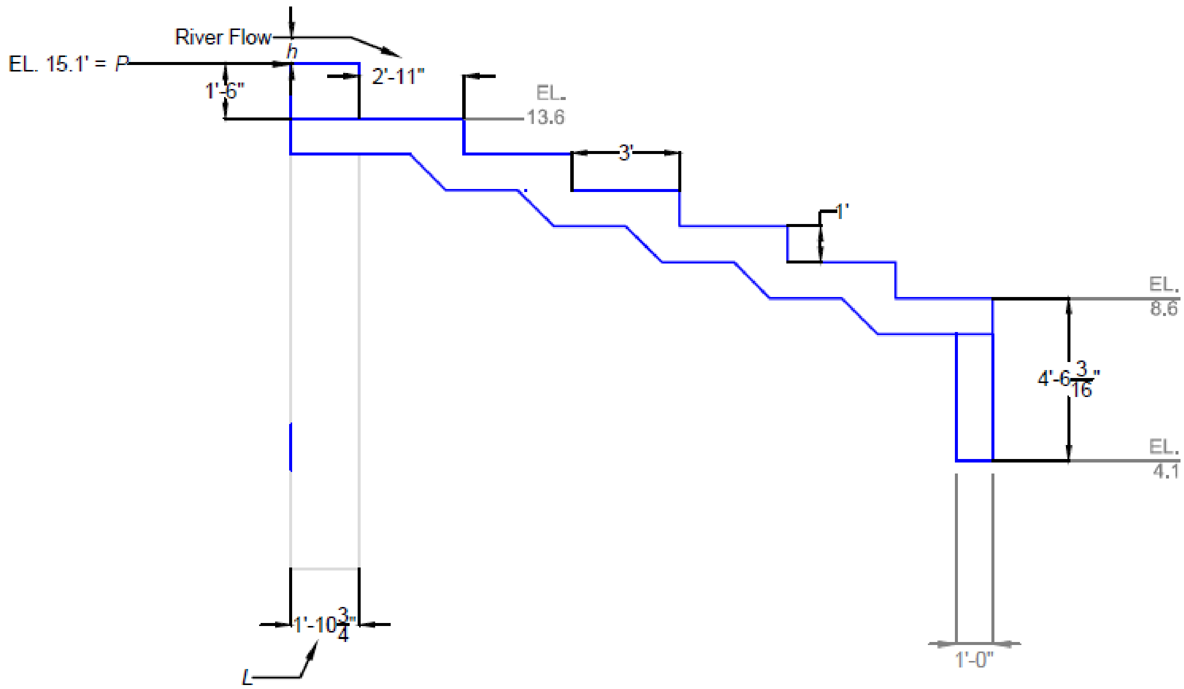

Figure: Section of the Center Falls Dam from blueprints in Appendix B

Width = *L*, Height of dam = *P*, Height of flow above dam = *h*

3.4 Design of the Passage

A style of fish passage will be chosen that best fits both spatial and flow restrictions. The style chosen will have to be capable of carrying adequate flow for the migrating fish while remaining small enough to fit in the allotted area. Due to spatial restraints, the styles available to be implemented may be restricted, however several appropriate designs will be considered. Different building materials will also be considered. The material chosen should be as inexpensive as possible while providing adequate structural integrity. The material and style of the passage should also provide a pleasant appearance.

Using the results of the hydraulic analysis of the dam, the best locations for the entrance and the exit of the passage will be chosen. The entrance location should ensure that the fish notice the attracting flow. The characteristics of the water at the base of the dam will be estimated based on the flow off the dam to get an idea of how much turbulence is occurring and to determine how far downstream the entrance should be located so that the attraction flow is not interrupted by the turbulence. The exit location will be far enough upstream to ensure the fish do not get swept back downstream due to the high water velocities occurring near the top of the dam. The velocity of the water at the top of the dam will be calculated to get an idea of what a safe, upstream distance will be.

Based on the placement of the entrance and exit of the passage, the required size of the passage will be determined. The size should allow adequate flow for the migrating fish to pass through and notice the attraction flow. Rest areas may be implemented to help prevent the fish from becoming fatigued. The rest areas may fit well in the turns of the fish passage (where baffles may be excluded anyway) so to limit fish injury. The addition of rest areas will impact the nature of the flow passing through the passage. The available flow to be diverted through the passage will be impacted by the placement of the entrance and exit of the passage. During the flow analysis within the passage, equations from the UN FAD "FISH PASSES Design, Dimensions and Monitoring" (UN FAD 2013) will be used. During this stage, alternative designs with different dimensions may be considered. An alternative design may be considered for an ideal setting without the spatial restraints provided by the dam reconstruction allowing for alternative passage styles and placements of the passage.

3.4.1 Structural Analysis

A structural analysis of the passage will be performed. Any necessary changes to the design will be made to ensure the passage can withstand loadings from the flows of the river throughout the year. The passage will also have to withstand loadings due to water pressure caused by different water levels between the river and the passage. Loadings and varying flows caused by an obstruction in the passage will also be considered during the analysis.

During the structural analysis, the impact of the passage on the dam will be analyzed to ensure that the structural integrity of the dam is not compromised. Loadings caused during the construction of the passage and while the passage is in use will be calculated. The stress and deflection of the dam due to the applied loadings and the normal loadings of the river will be calculated to make sure they remain within a safe range.

3.4.2 Hydraulic Design

Additional features of the passage will be considered. A gate or other mechanism may be designed to divert flow around the passage to allow for maintenance. Diverting the flow may also help decrease ice buildup in the passage in the winter. A means of preventing debris from entering the passage may also be designed. This may include a floating beam placed at the upstream exit of the passage.

Operation of the Passage

A description of how the passage should be used will be supplied. This may include operating the low flow valves to affect the attraction flow and shutting off the flow through the passage for the winter.

3.5 Economic Evaluation

The project will also include a cost estimation for the final design of the fish passage. Using project and material cost values found in the ENR Construction and Materials Cost Indexes, the cost of the project will be estimated. A final value will be recorded in the report at the end of the project since values may fluctuate and an as accurate as possible value is desired.

3.6 Report Preparation and Deliverables

A final report including a CAD drawing, cost estimates, design calculations, and recommendations for the passage will be prepared to summarize the results of the project's findings. The finalized document will serve as a guide to the Town of Winchester for construction of a fish passage in the Center Falls Dam. Lastly a tentative schedule for the work to be completed next term can be found in Appendix C at the end of this proposal.

Works Cited

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Appendix B: USGS Flow Gage

00060, Discharge, cubic feet per second,												
Day of month	Mean of daily mean values for each day for 73 - 74 years of record in, ft3/s (Calculation Period 1938-10-01 -> 2012-09-30) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	35	34	49	78	40	38	16	15	8.9	10	18	30
2	37	37	51	84	37	40	17	12	7.8	12	19	30
3	35	44	58	74	38	36	15	9.8	9	11	20	31
4	36	46	56	70	39	33	13	12	9.9	13	20	30
5	36	40	54	73	37	33	12	9.8	8.9	11	24	29
6	32	36	55	73	35	39	13	8.1	8.9	18	24	29
7	33	41	58	70	34	40	12	9.3	9.2	21	21	35
8	35	43	58	60	35	34	13	13	9	17	22	37
9	38	37	59	55	37	28	13	13	10	18	27	35
10	36	34	60	56	44	28	12	16	9.4	15	25	34
11	34	36	58	55	42	23	12	14	12	12	27	35
12	33	36	59	54	39	23	14	16	15	14	26	41
13	31	38	62	54	40	27	14	16	12	14	26	40
14	32	40	71	54	47	34	13	13	10	17	27	38
15	34	40	85	52	47	29	10	12	11	24	28	39
16	33	41	80	59	44	25	9.7	12	11	23	27	36
17	30	43	75	60	41	22	8.5	9.8	12	18	30	38
18	31	46	75	55	37	21	9.8	11	14	17	26	37
19	35	46	73	53	38	20	9.2	17	13	18	22	37
20	36	43	72	51	36	19	9.1	18	13	22	22	33
21	39	41	71	49	34	18	11	14	12	30	25	36
22	43	41	87	51	32	18	11	12	12	24	28	36
23	38	42	91	51	29	21	12	11	15	19	29	34
24	40	47	76	50	31	20	17	9.6	13	17	26	34
25	52	57	69	48	33	19	20	14	13	18	30	34
26	61	57	65	45	34	18	14	11	15	19	32	34
27	53	49	67	46	31	16	13	9.1	16	17	29	41
28	50	48	63	45	28	15	13	11	14	17	27	36
29	42	47	63	45	26	14	13	13	16	18	29	33
30	38		73	43	29	16	14	11	12	16	31	33
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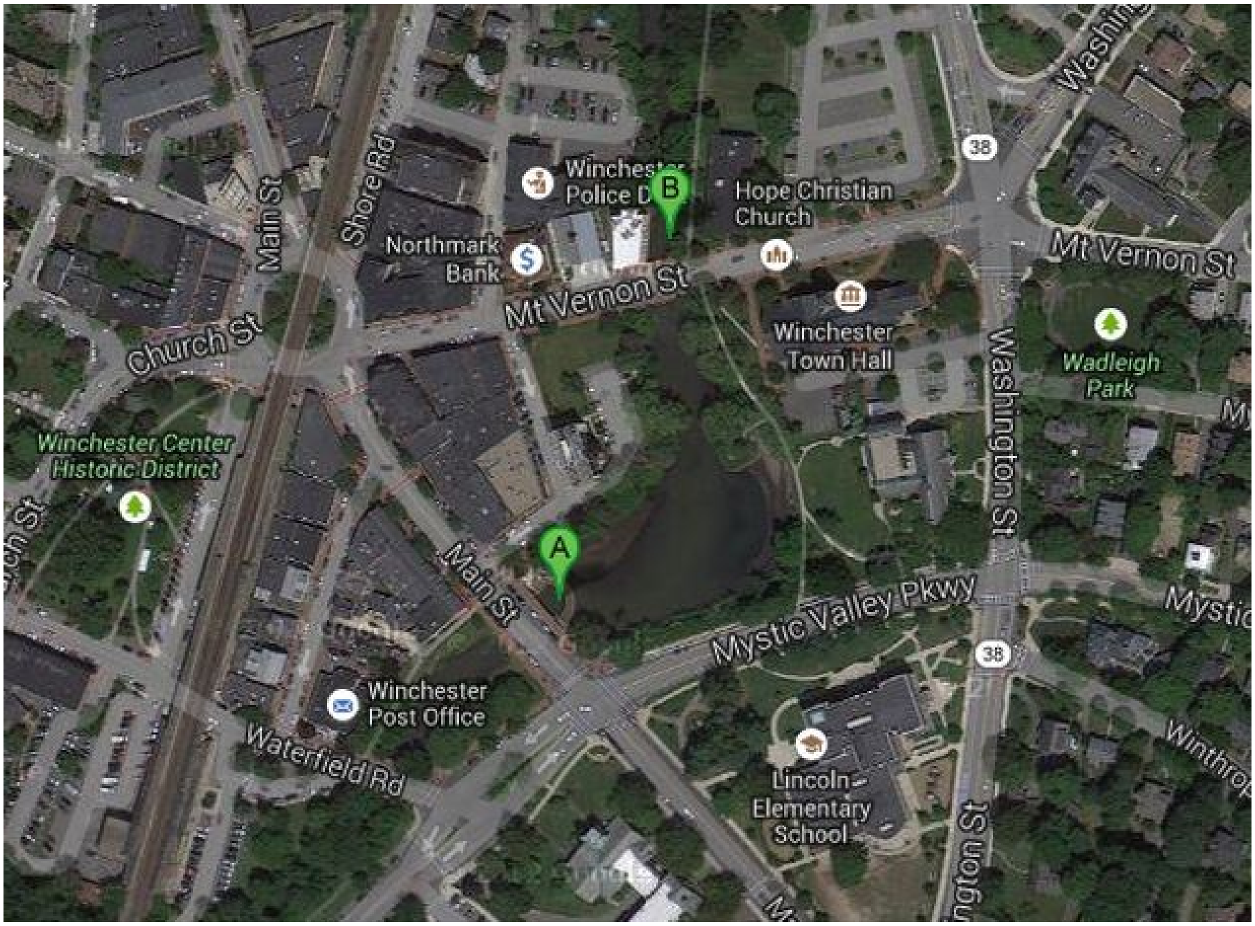
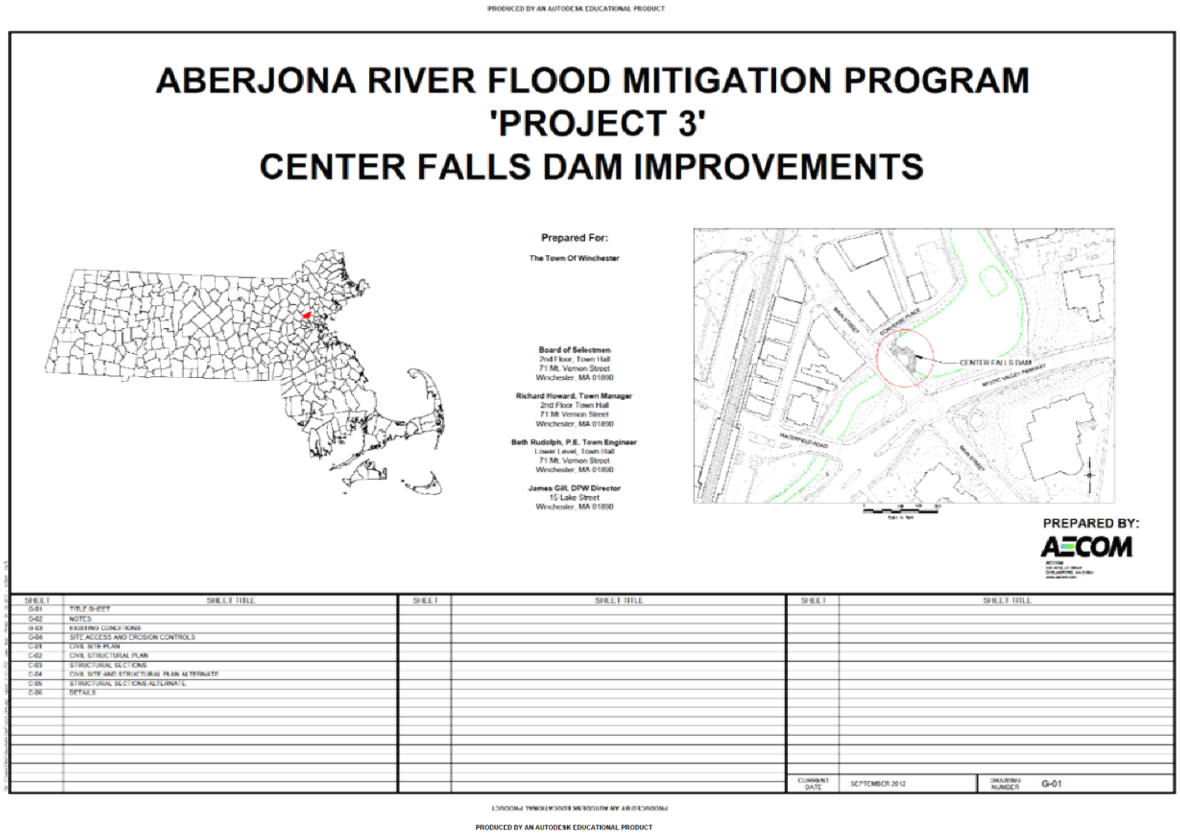
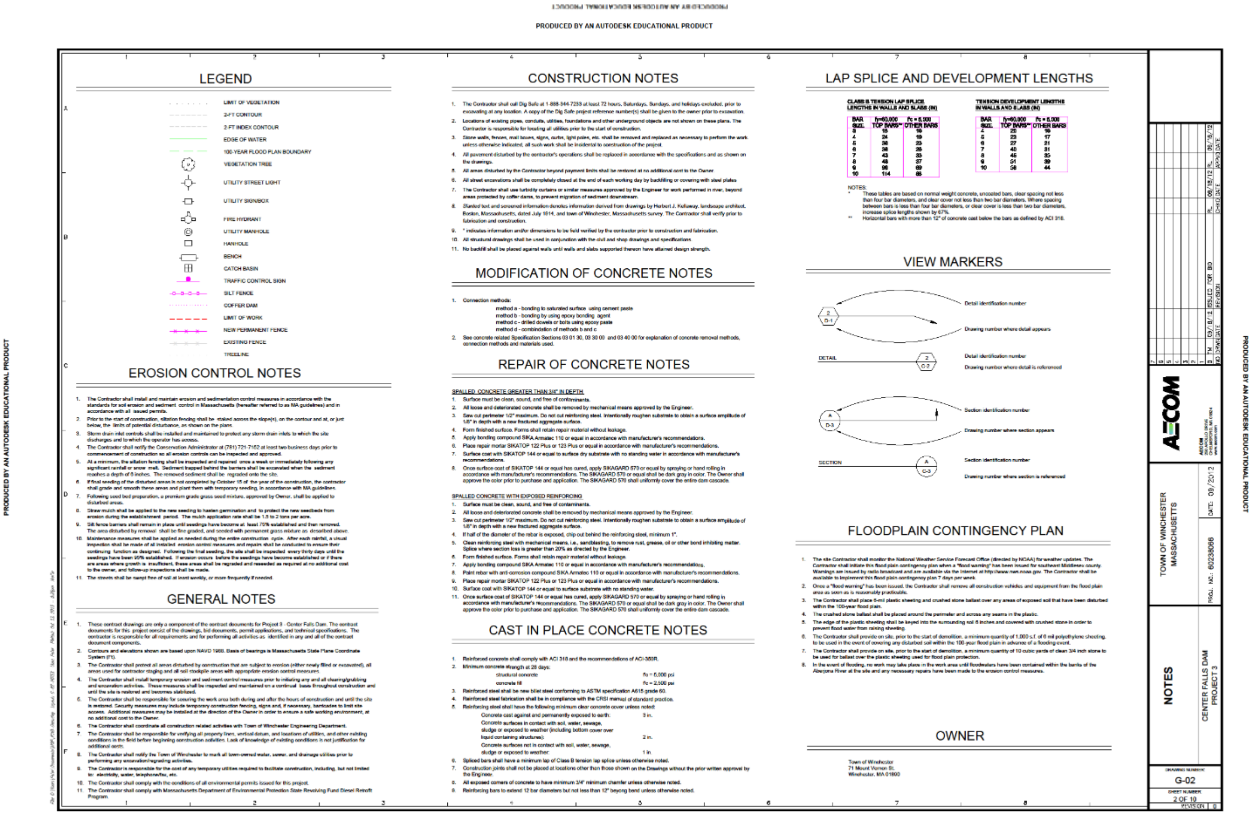
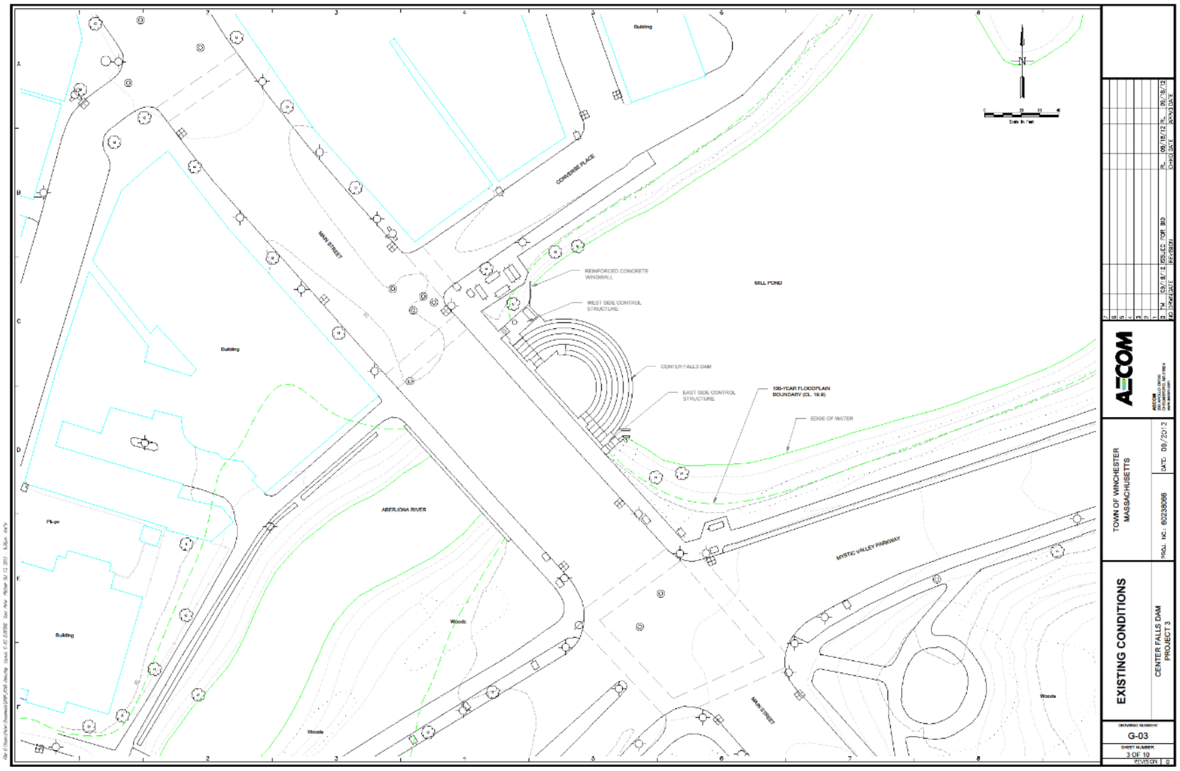
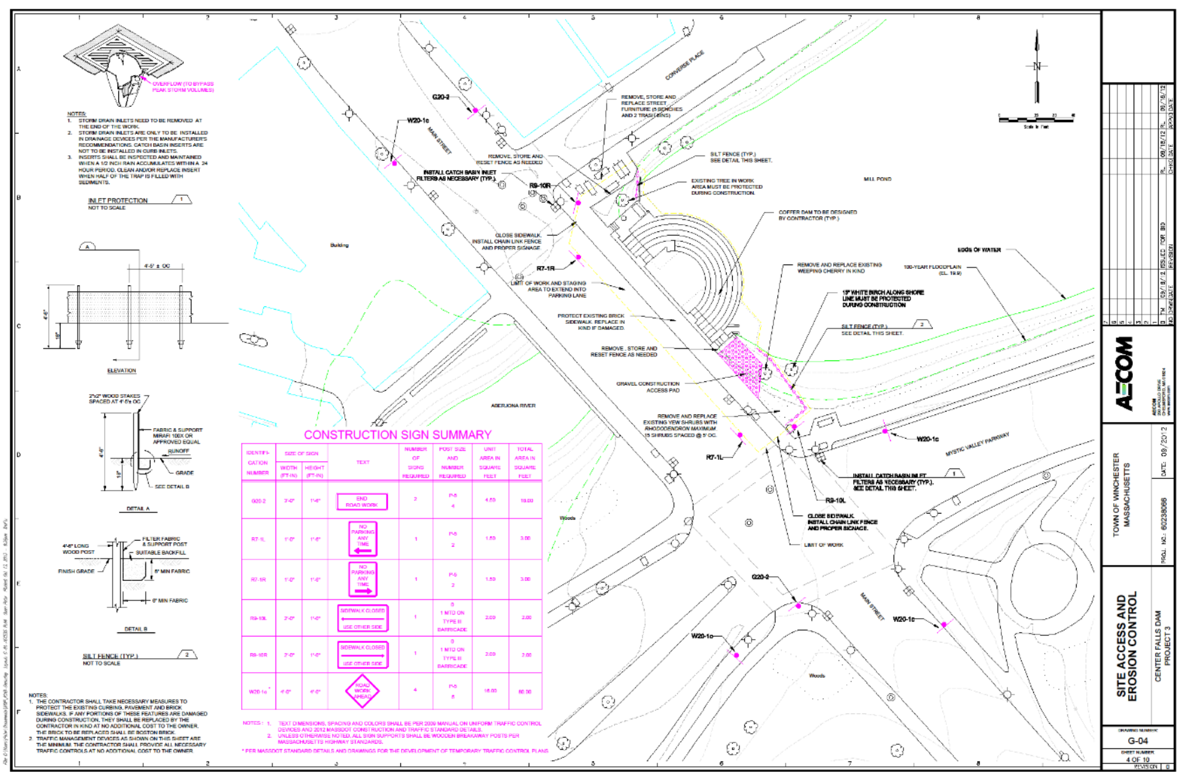

Winchester Police D
B
Hope Christian Church
Northmark Bank
Mt Vernon St
Mt Vernon St
Winchester Town Hall
Washington St
Wadleigh Park
Main St
Shore Rd
Church St
Winchester Center Historic District
A
Main St
Mystic Valley Pkwy
38
38
Winchester Post Office
Waterfield Rd
Lincoln Elementary School

Appendix C: Blueprints of the Center Falls Dam







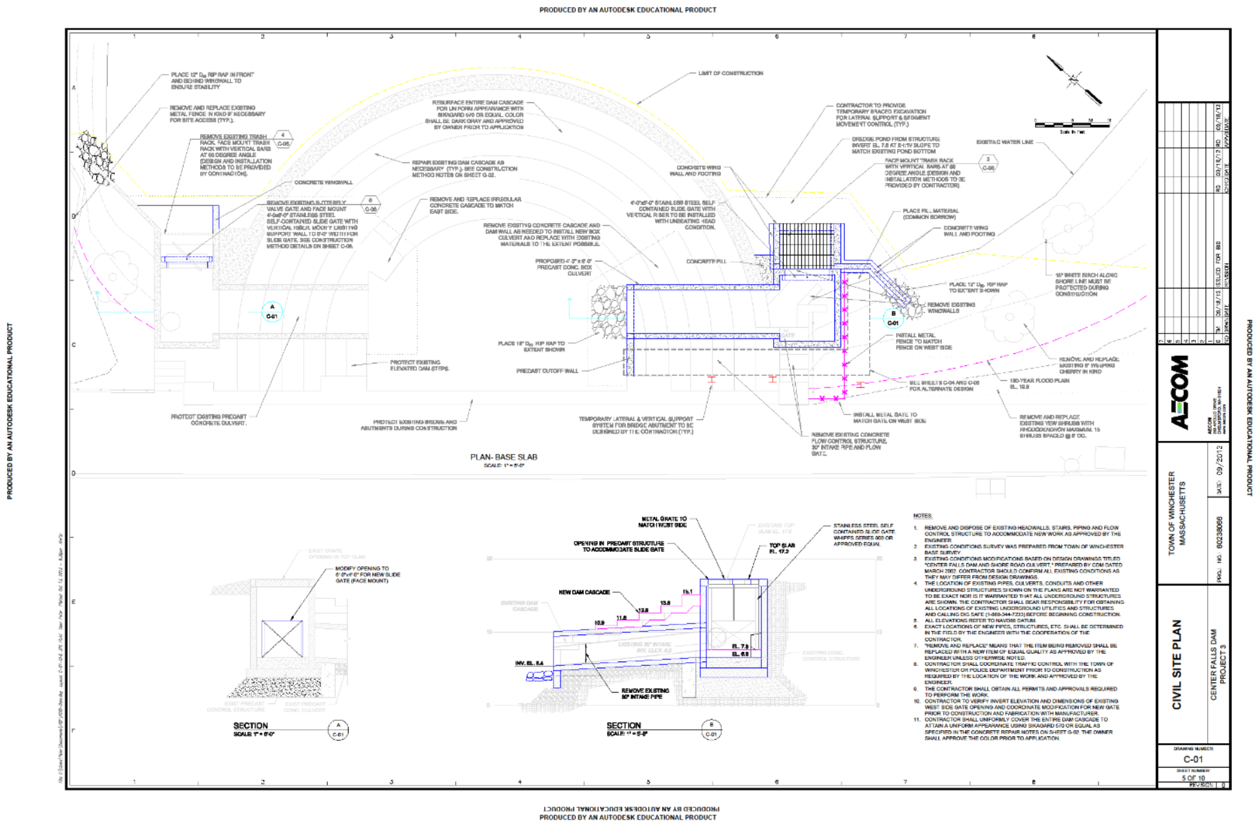


CONSTRUCTION SIGN SUMMARY

IDENTIFICATION NUMBER	SIZE OF SIGN WIDTH (FT-IN)	SIZE OF SIGN HEIGHT (FT-IN)	TEXT	NUMBER OF SIGNS REQUIRED	POST SIZE AND NUMBER REQUIRED	UNIT AREA IN SQUARE FEET	TOTAL AREA IN SQUARE FEET
G20-2	3'-0"	1'-6"	END ROAD WORK	2	P-5 4	4.50	18.00
R7-1L	1'-0"	1'-6"	NO PARKING ANY TIME ←	1	P-5 2	1.50	3.00
R7-1R	1'-0"	1'-6"	NO PARKING ANY TIME →	1	P-5 2	1.50	3.00
R9-10L	2'-0"	1'-0"	SIDEWALK CLOSED ← USE OTHER SIDE	1	0 1 MTD ON TYPE III BARRICADE	2.00	2.00
R9-10R	2'-0"	1'-0"	SIDEWALK CLOSED → USE OTHER SIDE	1	0 1 MTD ON TYPE III BARRICADE	2.00	2.00
W20-1c *	4'-0"	4'-0"	ROAD WORK AHEAD	4	P-5 8	16.00	80.00

NOTES: 1. TEXT DIMENSIONS, SPACING AND COLORS SHALL BE PER 2009 MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES AND 2012 MASSDOT CONSTRUCTION AND TRAFFIC STANDARD DETAILS.
2. UNLESS OTHERWISE NOTED, ALL SIGN SUPPORTS SHALL BE WOODEN BREAKAWAY POSTS PER MASSACHUSETTS HIGHWAY STANDARDS.

* PER MASSDOT STANDARD DETAILS AND DRAWINGS FOR THE DEVELOPMENT OF TEMPORARY TRAFFIC CONTROL PLANS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PLAN- BASE SLAB
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CIVIL SITE PLAN
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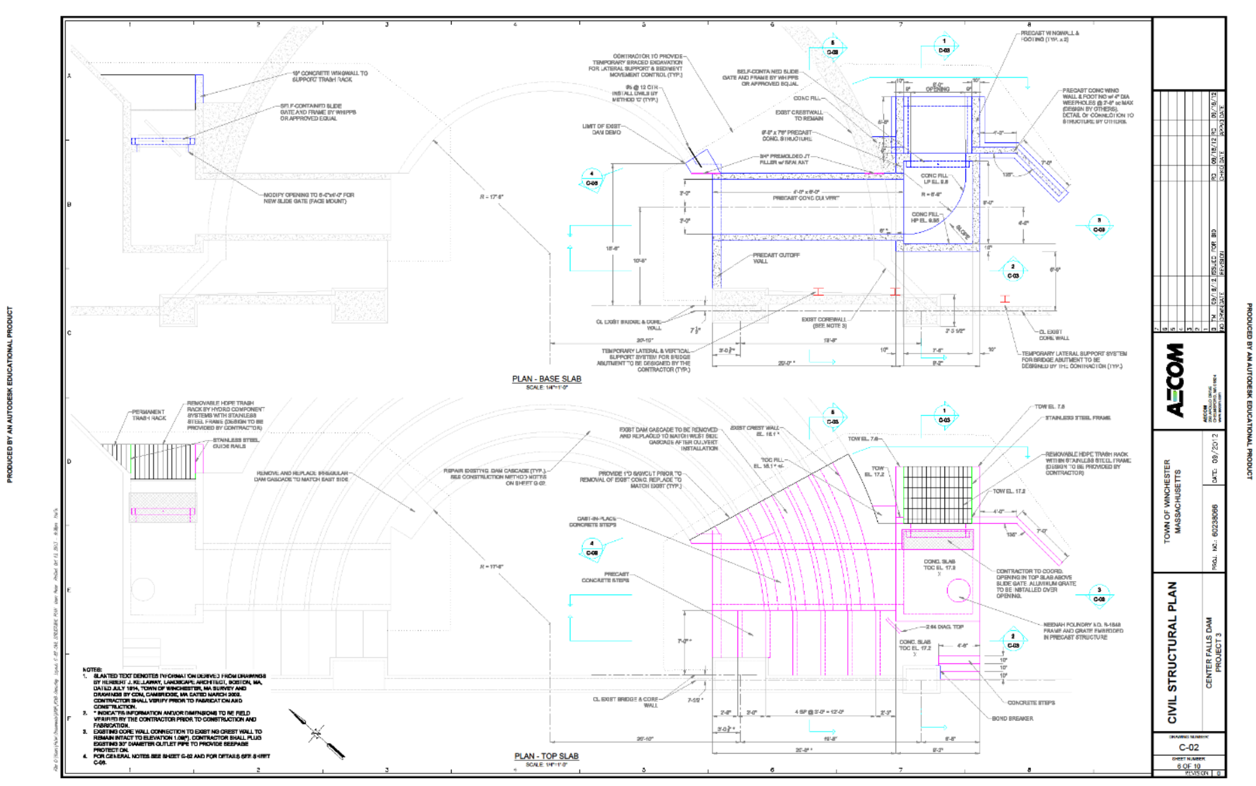
C-01
5 OF 10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PLAN - TOP SLAB
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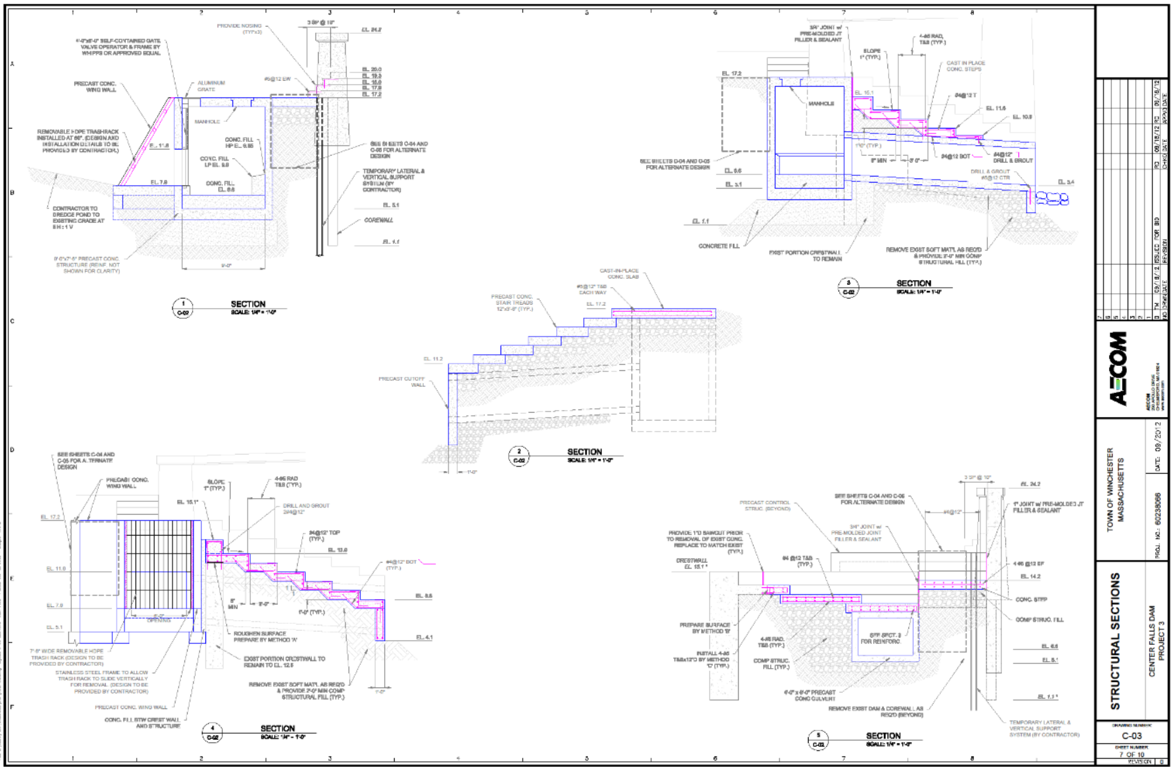
6 OF 10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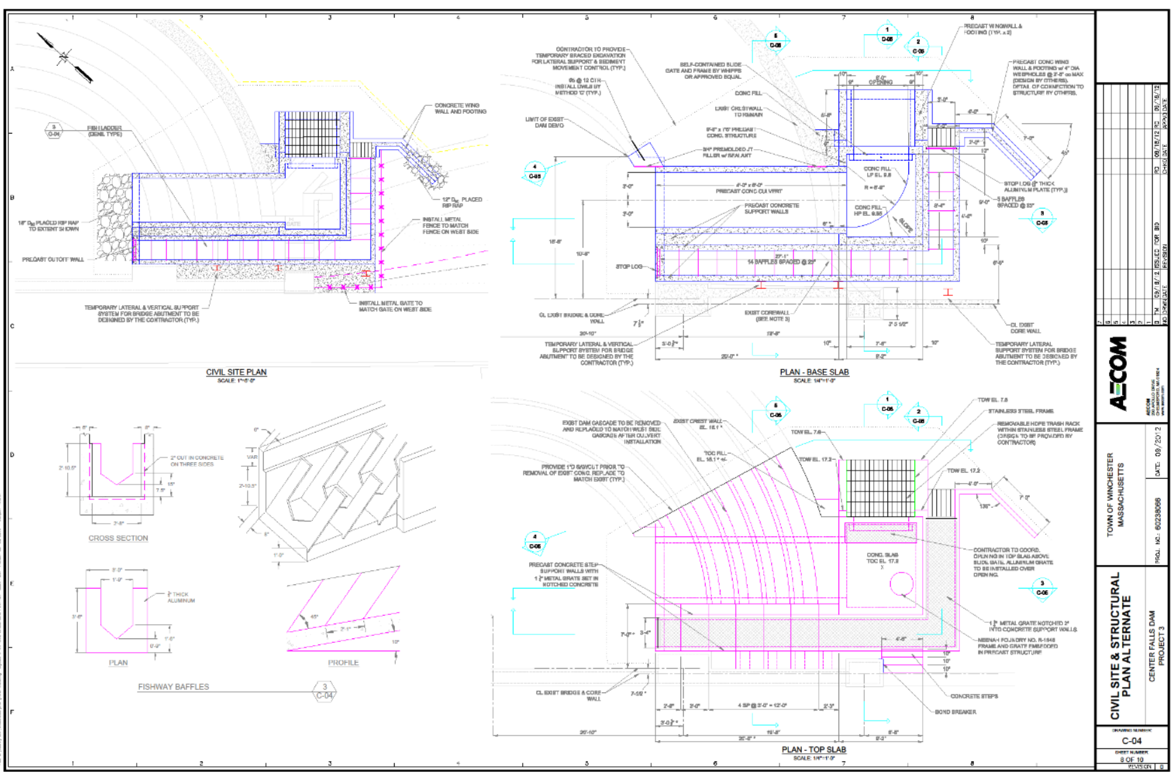
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CROSS SECTION
PLAN
PROFILE
FISHWAY BAFFLES
PLAN - TOP SLAB
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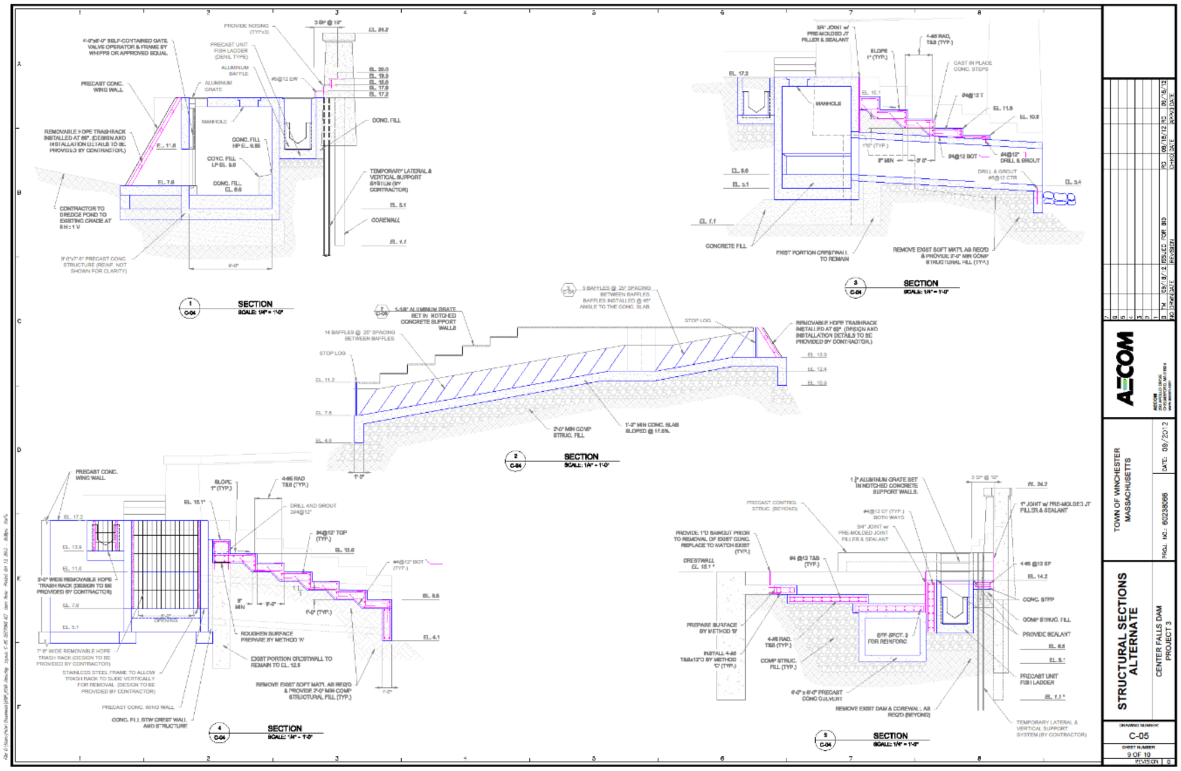
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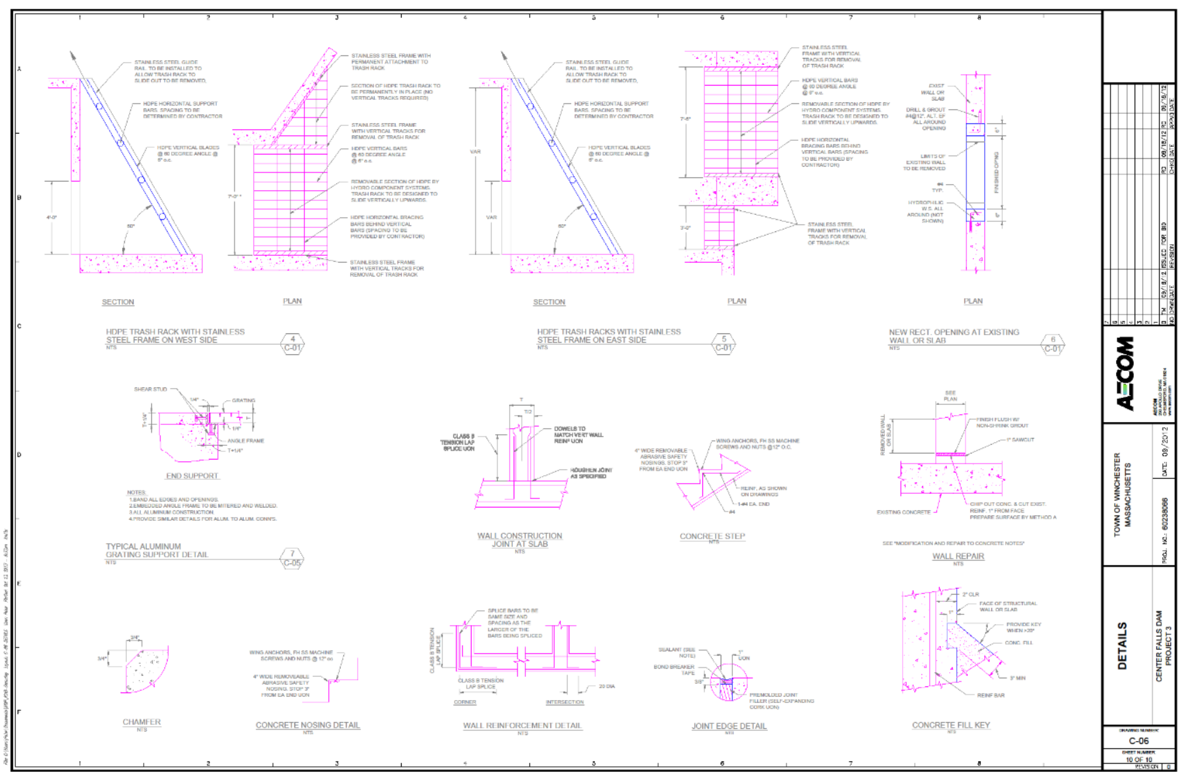
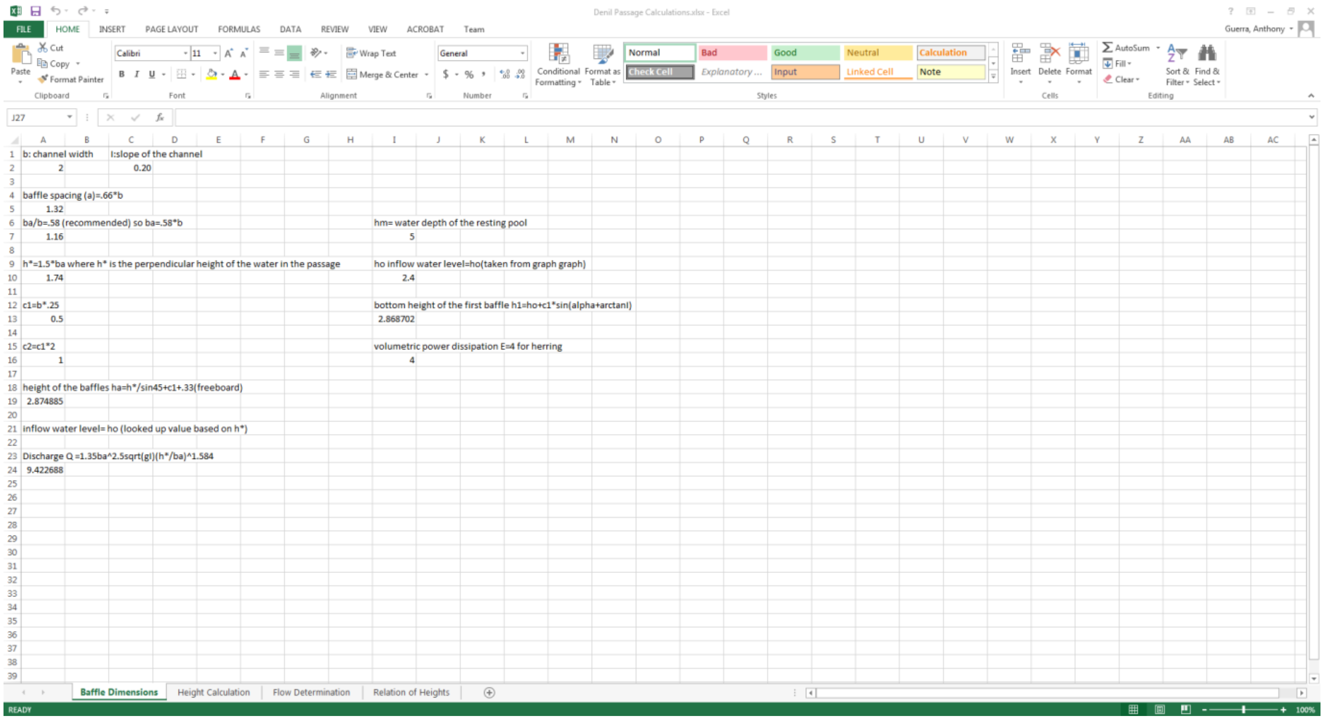
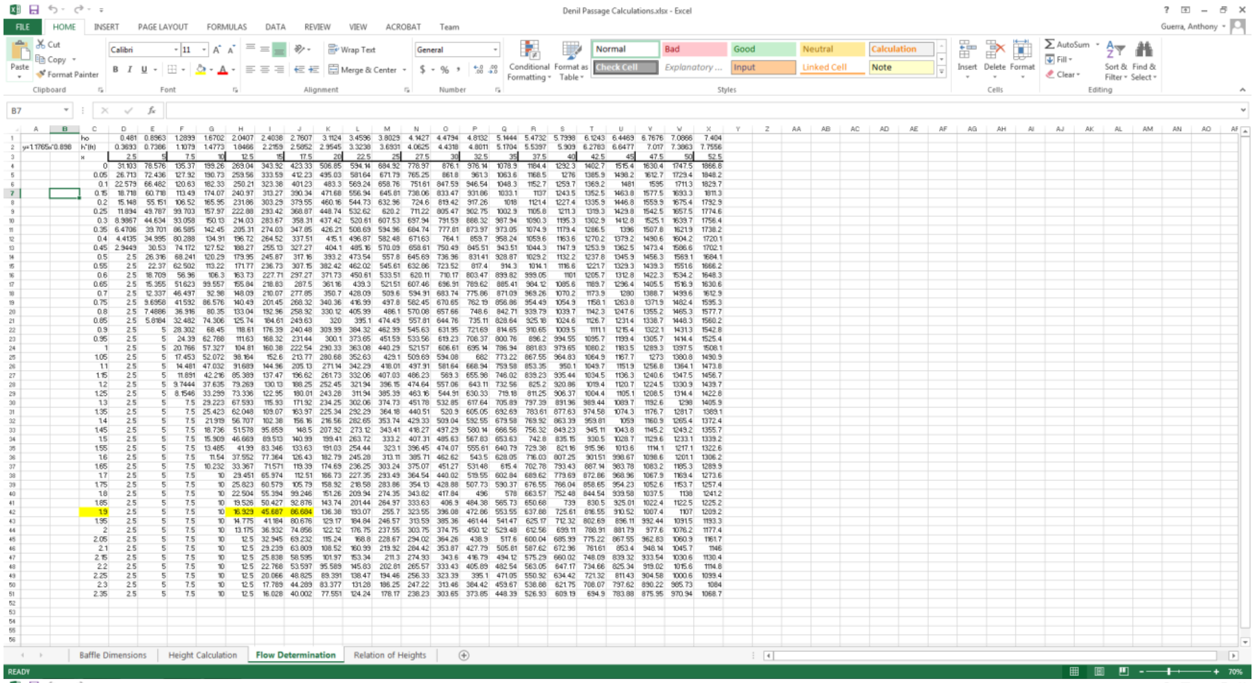

HDPE TRASH RACK WITH STAINLESS STEEL FRAME ON WEST SIDE
HDPE TRASH RACKS WITH STAINLESS STEEL FRAME ON EAST SIDE
NEW RECT. OPENING AT EXISTING WALL OR SLAB
TYPICAL ALUMINUM GRATING SUPPORT DETAIL
WALL CONSTRUCTION JOINT AT SLAB
CONCRETE STEP
WALL REPAIR
CHAMFER
CONCRETE NOSING DETAIL
WALL REINFORCEMENT DETAIL
JOINT EDGE DETAIL
CONCRETE FILL KEY
TOWN OF WINCHESTER MASSACHUSETTS
DETAILS
CENTER FALLS DAM PROJECT 3
AECOM
C-06

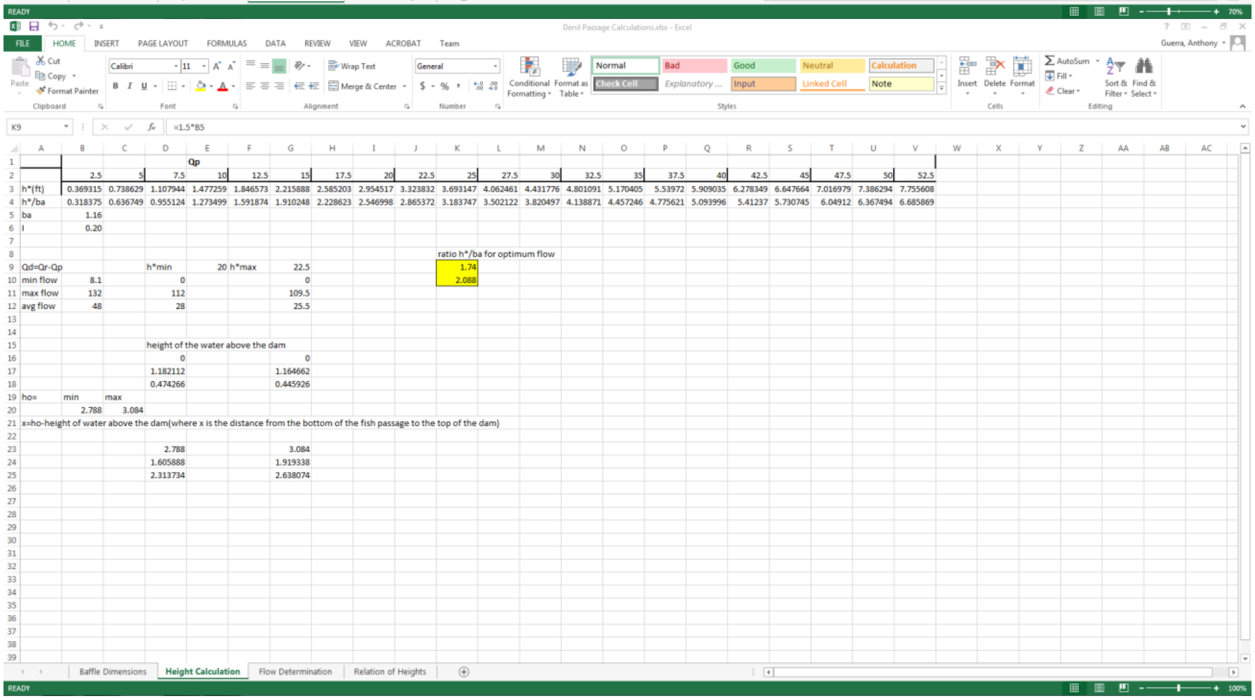
Appendix D: Denil Passage Excel Spreadsheet Calculations



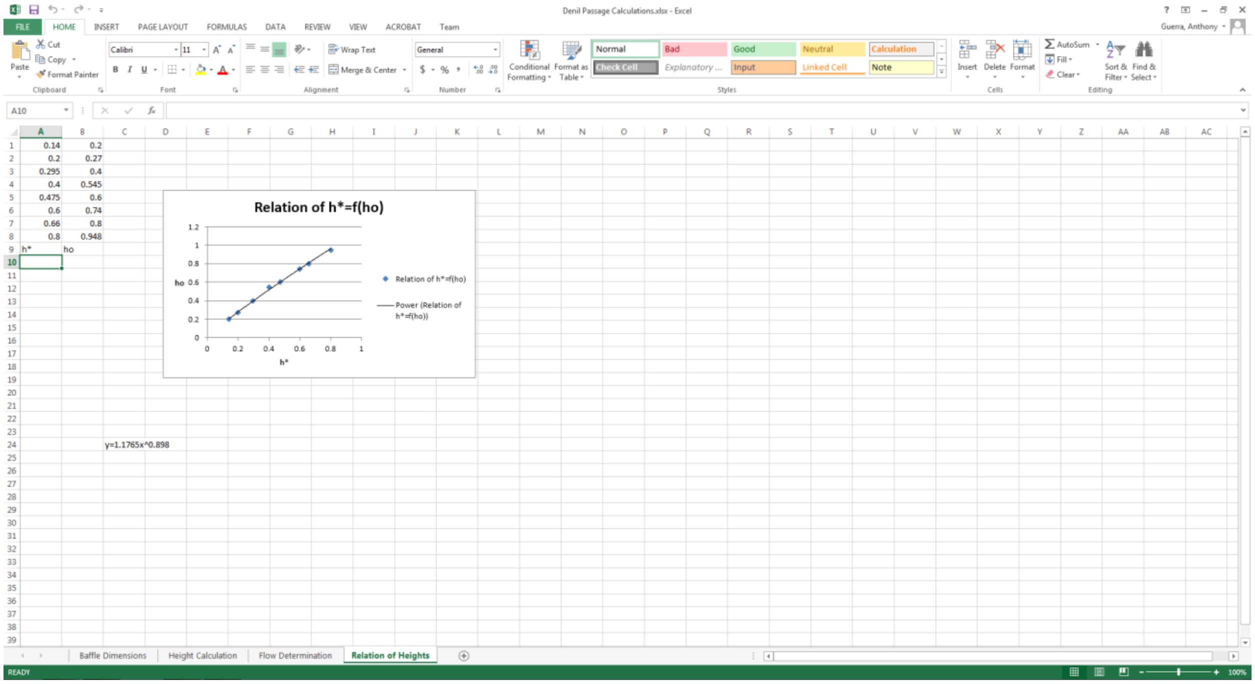
	A	I
1	b: channel width (C1: I:slope of the channel)	
2	2 (C2: 0.20)	
3		
4	baffle spacing (a)=.66*b	
5	1.32	
6	ba/b=.58 (recommended) so ba=.58*b	hm= water depth of the resting pool
7	1.16	5
8		
9	h*=1.5*ba where h* is the perpendicular height of the water in the passage	ho inflow water level=ho(taken from graph graph)
10	1.74	2.4
11		
12	c1=b*.25	bottom height of the first baffle h1=ho+c1*sin(alpha+arctanI)
13	0.5	2.868702
14		
15	c2=c1*2	volumetric power dissipation E=4 for herring
16	1	4
17		
18	height of the baffles ha=h*/sin45+c1+.33(freeboard)	
19	2.874885	
20		
21	inflow water level= ho (looked up value based on h*)	
22		
23	Discharge Q =1.35ba^2.5sqrt(gI)(h*/ba)^1.584	
24	9.422688	

Baffle Dimensions | Height Calculation | Flow Determination | Relation of Heights

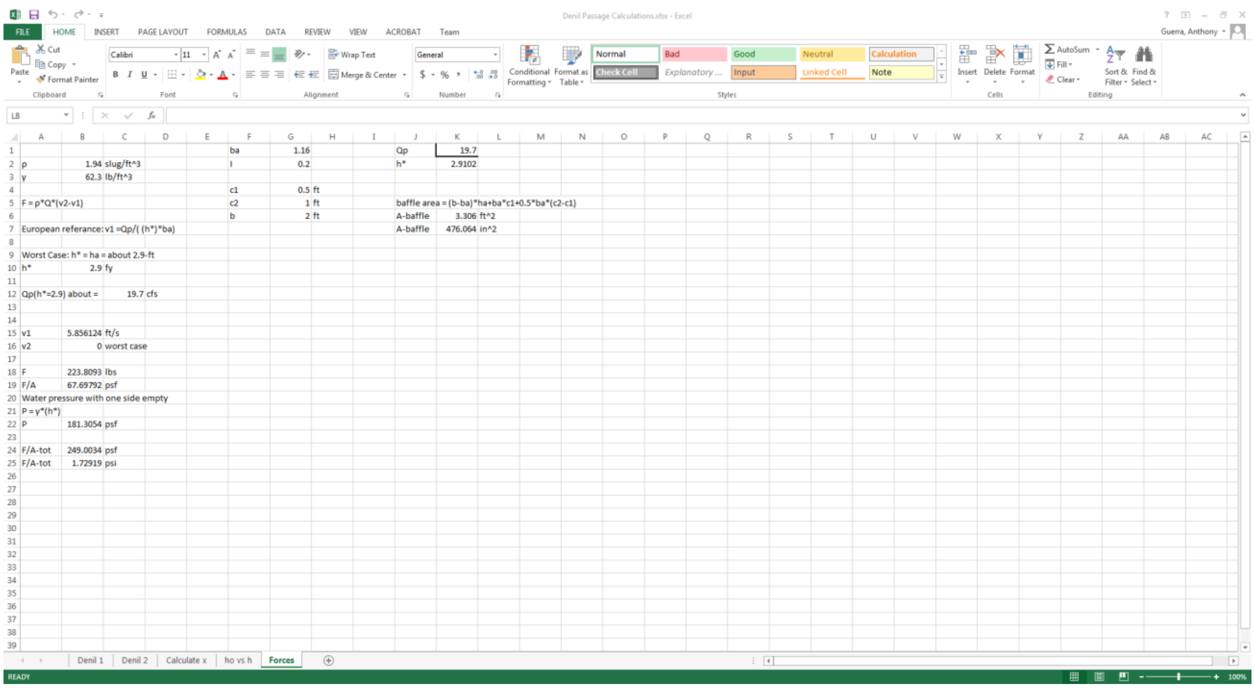




	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1					Qp																	
2		2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5
3	h*(ft)	0.369315	0.738629	1.107944	1.477259	1.846573	2.215888	2.585203	2.954517	3.323832	3.693147	4.062461	4.431776	4.801091	5.170405	5.53972	5.909035	6.278349	6.647664	7.016979	7.386294	7.755608
4	h*/ba	0.318375	0.636749	0.955124	1.273499	1.591874	1.910248	2.228623	2.546998	2.865372	3.183747	3.502122	3.820497	4.138871	4.457246	4.775621	5.093996	5.41237	5.730745	6.04912	6.367494	6.685869
5	ba	1.16																				
6	l	0.20																				
7																						
8											ratio h*/ba for optimum flow											
9	Qd=Qr-Qp			h*min	20	h*max	22.5				1.74											
10	min flow	8.1		0			0				2.088											
11	max flow	132		112			109.5															
12	avg flow	48		28			25.5															
13																						
14																						
15				height of the water above the dam																		
16				0			0															
17				1.182112			1.164662															
18				0.474266			0.445926															
19	ho=	min	max																			
20		2.788	3.084																			
21	x=ho-height of water above the dam(where x is the distance from the bottom of the fish passage to the top of the dam)																					
22																						
23				2.788			3.084															
24				1.605888			1.919338															
25				2.313734			2.638074															



Denil Passage Calculations.xlsx - Excel
A10
0.14 0.2
0.2 0.27
0.295 0.4
0.4 0.545
0.475 0.6
0.6 0.74
0.66 0.8
0.8 0.948
h* ho
Relation of h*=f(ho)
ho
h*
Relation of h*=f(ho)
Power (Relation of h*=f(ho))
y=1.1765x^0.898
Baffle Dimensions
Height Calculation
Flow Determination
Relation of Heights

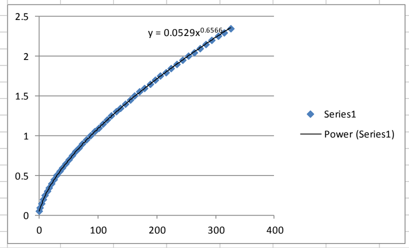


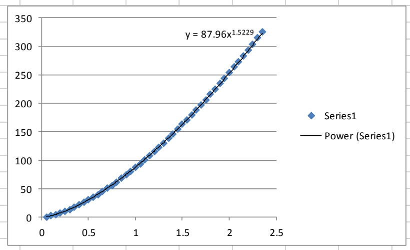
Denil Passage Calculations.xlsx - Excel
L8
ρ 1.94 slug/ft^3
γ 62.3 lb/ft^3
F = ρ*Q*(v2-v1)
European referance: v1 =Qp/((h*)*ba)
Worst Case: h* = ha = about 2.9-ft
h* 2.9 fy
Qp(h*=2.9) about = 19.7 cfs
v1 5.856124 ft/s
v2 0 worst case
F 223.8093 lbs
F/A 67.69792 psf
Water pressure with one side empty
P = γ*(h*)
P 181.3054 psf
F/A-tot 249.0034 psf
F/A-tot 1.72919 psi
ba 1.16
l 0.2
c1 0.5 ft
c2 1 ft
b 2 ft
Qp 19.7
h* 2.9102
baffle area = (b-ba)*ha+ba*c1+0.5*ba*(c2-c1)
A-baffle 3.306 ft^2
A-baffle 476.064 in^2
Denil 1
Denil 2
Calculate x
ho vs h
Forces

Appendix E: Steep Pass Calculations

distance	45	ft								
rise	11	ft								
So	0.244444444	ft/ft								
				Flow (ft^3/s)				**Flow (Liters/s)**		
g	32.2	ft/s^2		April	May	June		April	May	June
g	9.81	m/s^2		78	40	38		2208.71	1132.672	1076.038
				84	37	40		2378.611	1047.722	1132.672
max velocity	1.5	m/s		74	38	36		2095.443	1076.038	1019.405
max velocity	4.921259843	ft/s		70	39	33		1982.176	1104.355	934.4544
				73	37	33		2067.126	1047.722	934.4544
Q/sqrt(g*So*b^5) = 0.97*(yo/b)^1.55				73	35	39		2067.126	991.088	1104.355
yo = (Q/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b				70	34	40		1982.176	962.7712	1132.672
				60	35	34		1699.008	991.088	962.7712
V = Q/(yo*b)				55	37	28		1557.424	1047.722	792.8704
				56	44	28		1585.741	1245.939	792.8704
				55	42	23		1557.424	1189.306	651.2864
STD for March, April, and Mid-May		85.93132		54	39	23		1529.107	1104.355	651.2864
AVG for March, April, and Mid-May		**48**		54	40	27		1529.107	1132.672	764.5536
				54	47	34		1529.107	1330.89	962.7712
				52	47	29		1472.474	1330.89	821.1872
95% max flow	132			59	44	25		1670.691	1245.939	707.92
95% min Flow	8.1			60	41	22		1699.008	1160.989	622.9696
				55	37	21		1557.424	1047.722	594.6528
				53	38	20		1500.79	1076.038	566.336
				51	36	19		1444.157	1019.405	538.0192
				49	34	18		1387.523	962.7712	509.7024
				51	32	18		1444.157	906.1376	509.7024
				51	29	21		1444.157	821.1872	594.6528
				50	31	20		1415.84	877.8208	566.336
				48	33	19		1359.206	934.4544	538.0192
				45	34	18		1274.256	962.7712	509.7024
				46	31	16		1302.573	877.8208	453.0688
				45	28	15		1274.256	792.8704	424.752
				45	26	14		1274.256	736.2368	396.4352
				43	29	16		1217.622	821.1872	453.0688
					31				877.8208	

							Q	h	h	Q	
P (height)			P	15.1	ft	Q	0	0	0	0	h = 0.0528*(Q^0.6588)
L (width)			L	1.895833	ft	h	0.939445	0.05	0.05	0.939445	
h (depth over weir)			h	0.3	ft	Q	2.665258	0.1	0.1	2.665258	
Cd (constant)			B	87.3142	ft	h	4.910605	0.15	0.15	4.910605	
B (length of weir)			Cd	0.975801		Q	7.581304	0.2	0.2	7.581304	
Yb (depth at edge of weir)			Q	14		h	10.62324	0.25	0.25	10.62324	
Yc (critical depth)							14	0.3	0.3	14	
Yb = (0.715*Yc)							17.68493	0.35	0.35	17.68493	
							21.65734	0.4	0.4	21.65734	
Q = Cd*B*h^1.5							25.9006	0.45	0.45	25.9006	
Cd = (0.5 + 0.33*h/P+h/L)^0.06							30.40092	0.5	0.5	30.40092	
Q = [(0.5 + 0.33*h/P+h/L)^0.06]*B*h^1.5							35.14662	0.55	0.55	35.14662	
							40.12765	0.6	0.6	40.12765	
							45.33521	0.65	0.65	45.33521	
							50.76152	0.7	0.7	50.76152	
			87.3142				56.39964	0.75	0.75	56.39964	
		71.462					62.2433	0.8	0.8	62.2433	
							68.28682	0.85	0.85	68.28682	
	r	37.35666					74.52503	0.9	0.9	74.52503	
							80.95316	0.95	0.95	80.95316	
							87.56681	1	1	87.56681	
							94.36192	1.05	1.05	94.36192	
							101.3347	1.1	1.1	101.3347	
							108.4816	1.15	1.15	108.4816	
							115.7993	1.2	1.2	115.7993	
							123.2848	1.25	1.25	123.2848	
							130.935	1.3	1.3	130.935	
							138.7472	1.35	1.35	138.7472	
							146.7188	1.4	1.4	146.7188	
							154.8473	1.45	1.45	154.8473	
							163.1304	1.5	1.5	163.1304	
							171.5657	1.55	1.55	171.5657	
							180.1512	1.6	1.6	180.1512	
							188.8849	1.65	1.65	188.8849	
							197.7646	1.7	1.7	197.7646	
							206.7887	1.75	1.75	206.7887	
							215.9552	1.8	1.8	215.9552	
							225.2624	1.85	1.85	225.2624	
							234.7088	1.9	1.9	234.7088	
							244.2927	1.95	1.95	244.2927	
							254.0125	2	2	254.0125	
							263.8668	2.05	2.05	263.8668	
							273.8542	2.1	2.1	273.8542	
							283.9733	2.15	2.15	283.9733	
							294.2226	2.2	2.2	294.2226	
							304.6011	2.25	2.25	304.6011	
							315.1073	2.3	2.3	315.1073	
							325.7401	2.35	2.35	325.7401	

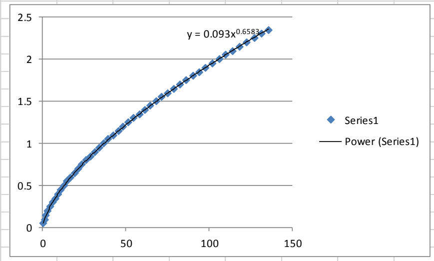




Flow (ft^3/s)				h = 0.0528*(Q^0.6588)				V(velocity-ft/s) = Q/(h*B)			B =	87.3142
April	May	June		0.931421	0.599889	0.579956		0.9591	0.763667	0.750418		
78	40	38		0.978023	0.569856	0.599889		0.983661	0.743621	0.763667		
84	37	40		0.899671	0.579956	0.559662		0.942026	0.750418	0.736702		
74	38	36		0.86733	0.589966	0.528483		0.924333	0.757099	0.715152		
70	39	33		0.891643	0.569856	0.528483		0.937663	0.743621	0.715152		
73	37	33		0.891643	0.549371	0.589966		0.937663	0.729654	0.757099		
73	35	39		0.86733	0.538979	0.599889		0.924333	0.722473	0.763667		
70	34	40		0.783574	0.549371	0.538979		0.876973	0.729654	0.722473		
60	35	34		0.73992	0.569856	0.474266		0.85132	0.743621	0.676163		
55	37	28		0.748756	0.638764	0.474266		0.85657	0.78891	0.676163		
56	44	28		0.73992	0.619485	0.41662		0.85132	0.776486	0.63227		
55	42	23		0.73103	0.589966	0.41662		0.846007	0.757099	0.63227		
54	39	23		0.73103	0.599889	0.463038		0.846007	0.763667	0.667825		
54	40	27		0.73103	0.667132	0.538979		0.846007	0.806865	0.722473		
54	47	34		0.713078	0.667132	0.485357		0.835183	0.806865	0.684308		
52	47	29		0.774946	0.638764	0.440146		0.871959	0.78891	0.650517		
59	44	25		0.783574	0.609728	0.404596		0.876973	0.770128	0.622753		
60	41	22		0.73992	0.569856	0.392385		0.85132	0.743621	0.612946		
55	37	21		0.722083	0.579956	0.379973		0.840629	0.750418	0.602827		
53	38	20		0.704014	0.559662	0.367347		0.829668	0.736702	0.592368		
51	36	19		0.685702	0.538979	0.354493		0.81842	0.722473	0.581541		
49	34	18		0.704014	0.517877	0.354493		0.829668	0.707682	0.581541		
51	32	18		0.704014	0.485357	0.392385		0.829668	0.684308	0.612946		
51	29	21		0.694889	0.507158	0.379973		0.824081	0.700058	0.602827		
50	31	20		0.67645	0.528483	0.367347		0.812682	0.715152	0.592368		
48	33	19		0.648291	0.538979	0.354493		0.794982	0.722473	0.581541		
45	34	18		0.657747	0.507158	0.328026		0.800966	0.700058	0.558633		
46	31	16		0.648291	0.474266	0.314371		0.794982	0.676163	0.546466		
45	28	15		0.648291	0.451667	0.300402		0.794982	0.65928	0.533753		
45	26	14		0.629163	0.485357	0.328026		0.782746	0.684308	0.558633		
43	29	16		0	0.507158	0		0	0.700058	0		
	31											

	Assuming All flow passes through Fish Pass				
	Qavg	1359.2064	L/s =	1.359206	m^3/s
values for "b" (ft)	values for "b" (m)	values for "b" (m)	yo (m)		V (m/s)
0.05	0.01524	0.01524	2.757313		32.34554
0.1	0.03048	0.03048	1.80295		24.73356
0.15	0.04572	0.04572	1.406232		21.14084
0.2	0.06096	0.06096	1.178912		18.91293
0.25	0.0762	0.0762	1.028218		17.34784
0.3	0.09144	0.09144	0.919506		16.1657
0.35	0.10668	0.10668	0.836609		15.22929
0.4	0.12192	0.12192	0.770867		14.46209
0.45	0.13716	0.13716	0.717179		13.81752
0.5	0.1524	0.1524	0.672331		13.26532
0.55	0.16764	0.16764	0.634181		12.78482
0.6	0.18288	0.18288	0.601246		12.36138
0.65	0.19812	0.19812	0.572462		11.98424
0.7	0.21336	0.21336	0.547042		11.64533
0.75	0.2286	0.2286	0.524392		11.33844
0.8	0.24384	0.24384	0.504054		11.05868
0.85	0.25908	0.25908	0.485668		10.80218
0.9	0.27432	0.27432	0.468949		10.5658
0.95	0.28956	0.28956	0.453663		10.34697
1	0.3048	0.3048	0.439623		10.14355
1.05	0.32004	0.32004	0.426671		9.953769
1.1	0.33528	0.33528	0.414678		9.776129
1.15	0.35052	0.35052	0.403533		9.609349
1.2	0.36576	0.36576	0.393143		9.452334
1.25	0.381	0.381	0.383428		9.304142
1.3	0.39624	0.39624	0.374321		9.163951
1.35	0.41148	0.41148	0.365762		9.031047
1.4	0.42672	0.42672	0.357699		8.9048
1.45	0.44196	0.44196	0.350088		8.784658
1.5	0.4572	0.4572	0.342889		8.670128
1.55	0.47244	0.47244	0.336067		8.560775
1.6	0.48768	0.48768	0.329591		8.456209
1.65	0.50292	0.50292	0.323433		8.356079
1.7	0.51816	0.51816	0.317569		8.260072
1.75	0.5334	0.5334	0.311976		8.167904
1.8	0.54864	0.54864	0.306636		8.079318
1.85	0.56388	0.56388	0.30153		7.994081
1.9	0.57912	0.57912	0.296641		7.911982
1.95	0.59436	0.59436	0.291956		7.832825
2	0.6096	0.6096	0.287461		7.756435
2.05	0.62484	0.62484	0.283143		7.682649
2.1	0.64008	0.64008	0.278992		7.611317
2.15	0.65532	0.65532	0.274997		7.542304
2.2	0.67056	0.67056	0.271149		7.475481
2.25	0.6858	0.6858	0.26744		7.410733
2.3	0.70104	0.70104	0.263862		7.34795
2.35	0.71628	0.71628	0.260407		7.287033
2.4	0.73152	0.73152	0.257068		7.227887
2.45	0.74676	0.74676	0.25384		7.170426
2.5	0.762	0.762	0.250716		7.114569
2.55	0.77724	0.77724	0.247691		7.06024
2.6	0.79248	0.79248	0.244761		7.00737
2.65	0.80772	0.80772	0.24192		6.955891
2.7	0.82296	0.82296	0.239164		6.905742
2.75	0.8382	0.8382	0.23649		6.856865
2.8	0.85344	0.85344	0.233892		6.809206
2.85	0.86868	0.86868	0.231369		6.762712
2.9	0.88392	0.88392	0.228916		6.717337
2.95	0.89916	0.89916	0.22653		6.673033
3	0.9144	0.9144	0.224208		6.62976

Critical depth									Q	h	h	Q
hydraulic jump					P	15.1	ft	Q	0	0	0	0
					L	2.692708	ft	h	0.397293	0.05	0.05	0.397293
					h	0.3	ft	Q	1.12622	0.1	0.1	1.12622
		Final Step			B	36.95833	ft	h	2.073448	0.15	0.15	2.073448
	height	4.515625	ft		Cd	0.971534		Q	3.198911	0.2	0.2	3.198911
					Q	5.900003		h	4.479586	0.25	0.25	4.479586
	river width	35.42	ft						5.900003	0.3	0.3	5.900003
	assume flat grade								7.448838	0.35	0.35	7.448838
	assume rectangullar river bed								9.117333	0.4	0.4	9.117333
									10.89845	0.45	0.45	10.89845
									12.78636	0.5	0.5	12.78636
	natural cahannel								14.77615	0.55	0.55	14.77615
	assume n=	0.03							16.86358	0.6	0.6	16.86358
									19.04495	0.65	0.65	19.04495
									21.31701	0.7	0.7	21.31701
					87.3142				23.67684	0.75	0.75	23.67684
									26.12182	0.8	0.8	26.12182
									28.64959	0.85	0.85	28.64959
									31.25797	0.9	0.9	31.25797
									33.94498	0.95	0.95	33.94498
									36.70879	1	1	36.70879
									39.54772	1.05	1.05	39.54772
									42.46017	1.1	1.1	42.46017
									45.44469	1.15	1.15	45.44469
									48.4999	1.2	1.2	48.4999
									51.6245	1.25	1.25	51.6245
									54.81729	1.3	1.3	54.81729
									58.0771	1.35	1.35	58.0771
									61.40287	1.4	1.4	61.40287
									64.79355	1.45	1.45	64.79355
									68.24818	1.5	1.5	68.24818
									71.76582	1.55	1.55	71.76582
									75.34558	1.6	1.6	75.34558
									78.98662	1.65	1.65	78.98662
									82.68813	1.7	1.7	82.68813
									86.44934	1.75	1.75	86.44934
									90.2695	1.8	1.8	90.2695
									94.1479	1.85	1.85	94.1479
									98.08386	1.9	1.9	98.08386
									102.0767	1.95	1.95	102.0767
									106.1258	2	2	106.1258
									110.2306	2.05	2.05	110.2306
									114.3904	2.1	2.1	114.3904
									118.6047	2.15	2.15	118.6047
									122.8729	2.2	2.2	122.8729
									127.1946	2.25	2.25	127.1946
									131.5691	2.3	2.3	131.5691
									135.9961	2.35	2.35	135.9961



$y = 0.093x^{0.6583}$

Flow (ft^3/s) April	May	June	$h = 0.093x^{0.6583}$			V(velocity-ft/s) = Q/(h*B)			B =	36.95833
78	40	38	1.637001	1.054676	1.019658	1.289239	1.026192	1.008363		
84	37	40	1.718842	1.001913	1.054676	1.322303	0.999216	1.026192		
74	38	36	1.581241	1.019658	0.984004	1.266255	1.008363	0.989904		
70	39	33	1.524442	1.037244	0.929225	1.242438	1.017352	0.960906		
73	37	33	1.567142	1.001913	0.929225	1.260382	0.999216	0.960906		
73	35	39	1.567142	0.965924	1.037244	1.260382	0.980421	1.017352		
70	34	40	1.524442	0.947666	1.054676	1.242438	0.970758	1.026192		
60	35	34	1.377336	0.965924	0.947666	1.178688	0.980421	0.970758		
55	37	28	1.30066	1.001913	0.833964	1.14416	0.999216	0.908445		
56	44	28	1.31618	1.122969	0.833964	1.151226	1.060163	0.908445		
55	42	23	1.30066	1.0891	0.73267	1.14416	1.043444	0.84939		
54	39	23	1.285043	1.037244	0.73267	1.137008	1.017352	0.84939		
54	40	27	1.285043	1.054676	0.814235	1.137008	1.026192	0.897226		
54	47	34	1.285043	1.172803	0.947666	1.137008	1.084328	0.970758		
52	47	29	1.25351	1.172803	0.853453	1.12244	1.084328	0.919403		
59	44	25	1.362181	1.122969	0.774011	1.171938	1.060163	0.873938		
60	41	22	1.377336	1.07196	0.711541	1.178688	1.034887	0.836586		
55	37	21	1.30066	1.001913	0.690081	1.14416	0.999216	0.823393		
53	38	20	1.269328	1.019658	0.668269	1.129769	1.008363	0.809779		
51	36	19	1.237589	0.984004	0.64608	1.115017	0.989904	0.79571		
49	34	18	1.205422	0.947666	0.623489	1.099878	0.970758	0.781144		
51	32	18	1.237589	0.910591	0.623489	1.115017	0.950855	0.781144		
51	29	21	1.237589	0.853453	0.690081	1.115017	0.919403	0.823393		
50	31	20	1.22156	0.891757	0.668269	1.107497	0.940596	0.809779		
48	33	19	1.18917	0.929225	0.64608	1.092156	0.960906	0.79571		
45	34	18	1.139706	0.947666	0.623489	1.068335	0.970758	0.781144		
46	31	16	1.156316	0.891757	0.576973	1.076388	0.940596	0.75033		
45	28	15	1.139706	0.833964	0.552973	1.068335	0.908445	0.733965		
45	26	14	1.139706	0.794255	0.52842	1.068335	0.885729	0.716864		
43	29	16	1.106102	0.853453	0.576973	1.051867	0.919403	0.75033		
	31		0	0.891757	0	0	0.940596	0		

g = 32.2 ft/s^2

b weir = 36.95833 ft

yc = (Q^2/(g*b^2))^(1/3)

H = V^2/(2g)+y+z

V = sqrt((H-y-z)*2g)

V = Q/(b*y)

Final Step

height 4.515625 ft

river width 35.42 ft

assume flat grade

assume rectangullar river bed

natural cahannel

assume n= 0.03

yc weir			**Yb (depth at edge of weir)**			**V(velocity-ft/s) = Q/(h*B)**			**H**	z =	4.515625
0.517173	0.331345	0.320206	0.369779	0.236911	0.228947	5.707422	4.568375	4.49093	5.391222	5.076605	5.057747
0.543366	0.314563	0.331345	0.388507	0.224913	0.236911	5.850166	4.451186	4.568375	5.435567	5.048194	5.076605
0.499338	0.320206	0.308869	0.357026	0.228947	0.220842	5.608142	4.49093	4.410718	5.361025	5.057747	5.038554
0.481177	0.325799	0.291462	0.344042	0.232946	0.208396	5.505217	4.529984	4.284628	5.330279	5.067216	5.009083
0.494829	0.314563	0.291462	0.353803	0.224913	0.208396	5.582766	4.451186	4.284628	5.353392	5.048194	5.009083
0.494829	0.303123	0.325799	0.353803	0.216733	0.232946	5.582766	4.369494	4.529984	5.353392	5.028825	5.067216
0.481177	0.297321	0.331345	0.344042	0.212585	0.236911	5.505217	4.327477	4.568375	5.330279	5.019002	5.076605
0.434184	0.303123	0.297321	0.310442	0.216733	0.212585	5.229484	4.369494	4.327477	5.250717	5.028825	5.019002
0.409715	0.314563	0.261223	0.292946	0.224913	0.186775	5.079988	4.451186	4.056279	5.20929	5.048194	4.957887
0.414666	0.353081	0.261223	0.296486	0.252453	0.186775	5.110591	4.715843	4.056279	5.217672	5.113407	4.957887
0.409715	0.342299	0.229118	0.292946	0.244744	0.163819	5.079988	4.64328	3.798841	5.20929	5.095152	4.903531
0.404733	0.325799	0.229118	0.289384	0.232946	0.163819	5.049012	4.529984	3.798841	5.200856	5.067216	4.903531
0.404733	0.331345	0.254966	0.289384	0.236911	0.182301	5.049012	4.568375	4.007403	5.200856	5.076605	4.947293
0.404733	0.368954	0.297321	0.289384	0.263802	0.212585	5.049012	4.820674	4.327477	5.200856	5.140279	5.019002
0.394677	0.368954	0.267406	0.282194	0.263802	0.191196	4.985892	4.820674	4.104004	5.18383	5.140279	4.968356
0.429346	0.353081	0.242214	0.306983	0.252453	0.173183	5.200269	4.715843	3.905906	5.242527	5.113407	4.925704
0.434184	0.336844	0.222427	0.310442	0.240844	0.159036	5.229484	4.606132	3.742967	5.250717	5.085917	4.892204
0.409715	0.314563	0.215635	0.292946	0.224913	0.154179	5.079988	4.451186	3.685374	5.20929	5.048194	4.880704
0.399721	0.320206	0.208734	0.285801	0.228947	0.149245	5.017651	4.49093	3.625922	5.19237	5.057747	4.869021
0.389601	0.308869	0.201717	0.278565	0.220842	0.144228	4.953724	4.410718	3.564454	5.175236	5.038554	4.85714
0.379347	0.297321	0.194575	0.271233	0.212585	0.139121	4.888105	4.327477	3.500789	5.157877	5.019002	4.84505
0.389601	0.285544	0.194575	0.278565	0.204164	0.139121	4.953724	4.240904	3.500789	5.175236	4.999063	4.84505
0.389601	0.267406	0.215635	0.278565	0.191196	0.154179	4.953724	4.104004	3.685374	5.175236	4.968356	4.880704
0.384491	0.279564	0.208734	0.274911	0.199888	0.149245	4.921133	4.19626	3.625922	5.166585	4.988939	4.869021
0.374169	0.291462	0.201717	0.267531	0.208396	0.144228	4.854623	4.284628	3.564454	5.149108	5.009083	4.85714
0.358411	0.297321	0.194575	0.256264	0.212585	0.139121	4.751302	4.327477	3.500789	5.12243	5.019002	4.84505
0.363701	0.279564	0.179881	0.260047	0.199888	0.128615	4.786239	4.19626	3.366008	5.131387	4.988939	4.820172
0.358411	0.261223	0.172306	0.256264	0.186775	0.123199	4.751302	4.056279	3.294369	5.12243	4.957887	4.807347
0.358411	0.248631	0.16456	0.256264	0.177771	0.117661	4.751302	3.957305	3.219471	5.12243	4.936568	4.794233
0.347711	0.267406	0.179881	0.248614	0.191196	0.128615	4.679843	4.104004	3.366008	5.104315	4.968356	4.820172
0	0.279564	0	0	0.199888	0	0	4.19626	0		4.988939	

	Final Step			assume flat grade														
height	4.515625 ft			assume rectangullar river bed										hydraulic jump				
				natural cahannel									eqn. 6.7	y2/y1 = 1/2*(sqrt(1+8*(V1/sqrt(g*y1))^2)-1)				
river width	35.42	ft		assume n= 0.03										y2=y1/2*sqrt(1+8*(V1/sqrt(g*y1))^2)-1)				
eqation 3.12	V1^2/2g+P1/Y +h1=V2^2/2g+P2/Y +h2				h1 =	4.515625		y = Q/(V*b)										
	P1 = P2				h2 =	0		b =	35.42									
	V2 = sqrt(2g*(V1^2/(2g)+h1-h2))				g =	32.2												

V1			V2			y (base of dam)			Flow (ft^3/s) April	May	June	y (downstream after hydraulic jump)			v (downstream after hydraulic jump)		
5.707422	4.568375	4.49093	17.9828	17.65436	17.63447	0.122458	0.063968	0.060838	78	40	38	1.5083	1.08128	1.054024	1.460018	1.044415	1.017852
5.850166	4.451186	4.568375	18.02861	17.6244	17.65436	0.131543	0.059271	0.063968	84	37	40	1.565165	1.040127	1.08128	1.515203	1.004307	1.044415
5.608142	4.49093	4.410718	17.95153	17.63447	17.61422	0.116381	0.060838	0.057702	74	38	36	1.469182	1.054024	1.026042	1.422027	1.017852	0.990579
5.505217	4.529984	4.284628	17.91964	17.64446	17.58307	0.110286	0.062403	0.052987	70	39	33	1.429003	1.067739	0.982566	1.382982	1.031219	0.948208
5.582766	4.451186	4.284628	17.94362	17.6244	17.58307	0.114859	0.059271	0.052987	73	37	33	1.45924	1.040127	0.982566	1.412367	1.004307	0.948208
5.582766	4.369494	4.529984	17.94362	17.60394	17.64446	0.114859	0.056132	0.062403	73	35	39	1.45924	1.011758	1.067739	1.412367	0.976658	1.031219
5.505217	4.327477	4.568375	17.91964	17.59356	17.65436	0.110286	0.05456	0.063968	70	34	40	1.429003	0.99727	1.08128	1.382982	0.962538	1.044415
5.229484	4.369494	4.327477	17.83687	17.60394	17.59356	0.09497	0.056132	0.05456	60	35	34	1.323266	1.011758	0.99727	1.280135	0.976658	0.962538
5.079988	4.451186	4.056279	17.79361	17.6244	17.52882	0.087267	0.059271	0.045098	55	37	28	1.267108	1.040127	0.905448	1.225464	1.004307	0.873064
5.110591	4.715843	4.056279	17.80237	17.69309	17.52882	0.08881	0.07021	0.045098	56	44	28	1.278536	1.133821	0.905448	1.236592	1.09562	0.873064
5.079988	4.64328	3.798841	17.79361	17.67389	17.47105	0.087267	0.067092	0.037167	55	42	23	1.267108	1.107863	0.821055	1.225464	1.070323	0.790873
5.049012	4.529984	3.798841	17.78479	17.64446	17.47105	0.085723	0.062403	0.037167	54	39	23	1.255575	1.067739	0.821055	1.214234	1.031219	0.790873
5.049012	4.568375	4.007403	17.78479	17.65436	17.51758	0.085723	0.063968	0.043515	54	40	27	1.255575	1.08128	0.889216	1.214234	1.044415	0.857251
5.049012	4.820674	4.327477	17.78479	17.72132	17.59356	0.085723	0.074878	0.05456	54	47	34	1.255575	1.171677	0.99727	1.214234	1.132508	0.962538
4.985892	4.820674	4.104004	17.76697	17.72132	17.53993	0.082631	0.074878	0.046679	52	47	29	1.232187	1.171677	0.921392	1.191456	1.132508	0.888598
5.200269	4.715843	3.905906	17.82832	17.69309	17.49464	0.093431	0.07021	0.040345	59	44	25	1.312226	1.133821	0.85582	1.269389	1.09562	0.824724
5.229484	4.606132	3.742967	17.83687	17.66416	17.45898	0.09497	0.06553	0.035576	60	41	22	1.323266	1.094652	0.803103	1.280135	1.057448	0.773397
5.079988	4.451186	3.685374	17.79361	17.6244	17.44673	0.087267	0.059271	0.033983	55	37	21	1.267108	1.040127	0.784737	1.225464	1.004307	0.755522
5.017651	4.49093	3.625922	17.77591	17.63447	17.43426	0.084177	0.060838	0.032388	53	38	20	1.243936	1.054024	0.765925	1.202899	1.017852	0.737217
4.953724	4.410718	3.564454	17.75797	17.61422	17.42158	0.081083	0.057702	0.030791	51	36	19	1.220325	1.026042	0.746635	1.179902	0.990579	0.718451
4.888105	4.327477	3.500789	17.73978	17.59356	17.40867	0.077983	0.05456	0.029192	49	34	18	1.196249	0.99727	0.726827	1.156448	0.962538	0.699186
4.953724	4.240904	3.500789	17.75797	17.57246	17.40867	0.081083	0.051413	0.029192	51	32	18	1.220325	0.967638	0.726827	1.179902	0.93366	0.699186
4.953724	4.104004	3.685374	17.75797	17.53993	17.44673	0.081083	0.046679	0.033983	51	29	21	1.220325	0.921392	0.784737	1.179902	0.888598	0.755522
4.921133	4.19626	3.625922	17.74891	17.56174	17.43426	0.079533	0.049836	0.032388	50	31	20	1.208347	0.952474	0.765925	1.168234	0.918883	0.737217
4.854623	4.284628	3.564454	17.73058	17.58307	17.42158	0.076431	0.052987	0.030791	48	33	19	1.184027	0.982566	0.746635	1.14454	0.948208	0.718451
4.751302	4.327477	3.500789	17.70257	17.59356	17.40867	0.071767	0.05456	0.029192	45	34	18	1.146579	0.99727	0.726827	1.108052	0.962538	0.699186
4.786239	4.19626	3.366008	17.71198	17.56174	17.38207	0.073323	0.049836	0.025988	46	31	16	1.159196	0.952474	0.685478	1.120347	0.918883	0.658989
4.751302	4.056279	3.294369	17.70257	17.52882	17.36834	0.071767	0.045098	0.024383	45	28	15	1.146579	0.905448	0.663826	1.108052	0.873064	0.637952
4.751302	3.957305	3.219471	17.70257	17.50619	17.35429	0.071767	0.041931	0.022776	45	26	14	1.146579	0.872679	0.641436	1.108052	0.841144	0.616206
4.679843	4.104004	3.366008	17.68353	17.53993	17.38207	0.068652	0.046679	0.025988	43	29	16	1.120917	0.921392	0.685478	1.083045	0.888598	0.658989
	4.19626			17.56174			0.049836			31			0.952474			0.918883	

distance	45	ft
rise	11	ft
So	0.244444444	ft/ft
g	32.2	ft/s^2
g	9.81	m/s^2
max velocity	1.5	m/s
max velocity	4.921259843	ft/s
Q/sqrt(g*So*b^5) = 0.97*(yo/b)^1.55		
yo = (Q/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b		
V = Q/(yo*b)		
STD for March, April, and Mid-May	85.93132	
AVG for March, April, and Mid-May	48	
95% max flow	132	
95% min Flow	8.1	

Flow (ft^3/s) April	May	June	Flow (Liters/s) April	May	June
78	40	38	2208.71	1132.672	1076.038
84	37	40	2378.611	1047.722	1132.672
74	38	36	2095.443	1076.038	1019.405
70	39	33	1982.176	1104.355	934.4544
73	37	33	2067.126	1047.722	934.4544
73	35	39	2067.126	991.088	1104.355
70	34	40	1982.176	962.7712	1132.672
60	35	34	1699.008	991.088	962.7712
55	37	28	1557.424	1047.722	792.8704
56	44	28	1585.741	1245.939	792.8704
55	42	23	1557.424	1189.306	651.2864
54	39	23	1529.107	1104.355	651.2864
54	40	27	1529.107	1132.672	764.5536
54	47	34	1529.107	1330.89	962.7712
52	47	29	1472.474	1330.89	821.1872
59	44	25	1670.691	1245.939	707.92
60	41	22	1699.008	1160.989	622.9696
55	37	21	1557.424	1047.722	594.6528
53	38	20	1500.79	1076.038	566.336
51	36	19	1444.157	1019.405	538.0192
49	34	18	1387.523	962.7712	509.7024
51	32	18	1444.157	906.1376	509.7024
51	29	21	1444.157	821.1872	594.6528
50	31	20	1415.84	877.8208	566.336
48	33	19	1359.206	934.4544	538.0192
45	34	18	1274.256	962.7712	509.7024
46	31	16	1302.573	877.8208	453.0688
45	28	15	1274.256	792.8704	424.752
45	26	14	1274.256	736.2368	396.4352
43	29	16	1217.622	821.1872	453.0688
	31			877.8208	

Assuming All flow passes through Fish Pass

Qavg	1359.2064 L/s =		1.359206 m^3/s	
values for "b" (ft)	values for "b" (m)	values for "b" (m)	yo (m)	V (m/s)
0.05	0.01524	0.01524	2.757313	32.34554
0.1	0.03048	0.03048	1.80295	24.73356
0.15	0.04572	0.04572	1.406232	21.14084
0.2	0.06096	0.06096	1.178912	18.91293
0.25	0.0762	0.0762	1.028218	17.34784
0.3	0.09144	0.09144	0.919506	16.1657
0.35	0.10668	0.10668	0.836609	15.22929
0.4	0.12192	0.12192	0.770867	14.46209
0.45	0.13716	0.13716	0.717179	13.81752
0.5	0.1524	0.1524	0.672331	13.26532
0.55	0.16764	0.16764	0.634181	12.78482
0.6	0.18288	0.18288	0.601246	12.36138
0.65	0.19812	0.19812	0.572485	11.98424
0.7	0.21336	0.21336	0.547042	11.64533
0.75	0.2286	0.2286	0.524392	11.33844
0.8	0.24384	0.24384	0.504054	11.05868
0.85	0.25908	0.25908	0.485668	10.80218
0.9	0.27432	0.27432	0.468949	10.5658
0.95	0.28956	0.28956	0.453663	10.34697
1	0.3048	0.3048	0.43962	10.14355
1.05	0.32004	0.32004	0.426671	9.953769
1.1	0.33528	0.33528	0.414678	9.776129
1.15	0.35052	0.35052	0.403533	9.609349
1.2	0.36576	0.36576	0.393143	9.452334
1.25	0.381	0.381	0.383428	9.304142
1.3	0.39624	0.39624	0.374321	9.163951
1.35	0.41148	0.41148	0.365762	9.031047
1.4	0.42672	0.42672	0.357698	8.904805
1.45	0.44196	0.44196	0.350088	8.784658
1.5	0.4572	0.4572	0.342889	8.670128
1.55	0.47244	0.47244	0.336067	8.560775
1.6	0.48768	0.48768	0.329591	8.456209
1.65	0.50292	0.50292	0.323433	8.356079
1.7	0.51816	0.51816	0.317569	8.260072
1.75	0.5334	0.5334	0.311976	8.167904
1.8	0.54864	0.54864	0.306636	8.079318
1.85	0.56388	0.56388	0.30153	7.994081
1.9	0.57912	0.57912	0.296641	7.911982
1.95	0.59436	0.59436	0.291956	7.832825
2	0.6096	0.6096	0.287461	7.756435
2.05	0.62484	0.62484	0.283143	7.682649
2.1	0.64008	0.64008	0.278992	7.611317
2.15	0.65532	0.65532	0.274997	7.542304
2.2	0.67056	0.67056	0.271149	7.475481
2.25	0.6858	0.6858	0.26744	7.410733
2.3	0.70104	0.70104	0.263862	7.34795
2.35	0.71628	0.71628	0.260407	7.287033
2.4	0.73152	0.73152	0.25707	7.227887
2.45	0.74676	0.74676	0.253843	7.170426
2.5	0.762	0.762	0.250716	7.114569
2.55	0.77724	0.77724	0.247691	7.06024
2.6	0.79248	0.79248	0.244761	7.00737
2.65	0.80772	0.80772	0.24192	6.955891
2.7	0.82296	0.82296	0.239164	6.905742
2.75	0.8382	0.8382	0.23649	6.856865
2.8	0.85344	0.85344	0.233892	6.809206
2.85	0.86868	0.86868	0.231369	6.762712
2.9	0.88392	0.88392	0.228916	6.717337
2.95	0.89916	0.89916	0.22653	6.673033
3	0.9144	0.9144	0.224208	6.62976

Qmax	3737.8176 L/s =		3.737818 m^3/s	
values for "b" (ft)	values for "b" (m)	values for "b" (m)	yo (m)	V (m/s)
0.05	0.01524	0.01524	5.295738	46.3134
0.1	0.03048	0.03048	3.462775	35.41432
0.15	0.04572	0.04572	2.700831	30.27015
0.2	0.06096	0.06096	2.264238	27.08016
0.25	0.0762	0.0762	1.974811	24.8392
0.3	0.09144	0.09144	1.766018	23.14658
0.35	0.10668	0.10668	1.606805	21.80579
0.4	0.12192	0.12192	1.480539	20.7073
0.45	0.13716	0.13716	1.377426	19.78438
0.5	0.1524	0.1524	1.291288	18.99371
0.55	0.16764	0.16764	1.218018	18.30572
0.6	0.18288	0.18288	1.154763	17.69942
0.65	0.19812	0.19812	1.099479	17.15943
0.7	0.21336	0.21336	1.050657	16.67417
0.75	0.2286	0.2286	1.007155	16.23475
0.8	0.24384	0.24384	0.968094	15.83418
0.85	0.25908	0.25908	0.932782	15.46692
0.9	0.27432	0.27432	0.90067	15.12846
0.95	0.28956	0.28956	0.871313	14.81512
1	0.3048	0.3048	0.844347	14.52386
1.05	0.32004	0.32004	0.819472	14.25213
1.1	0.33528	0.33528	0.796437	13.99778
1.15	0.35052	0.35052	0.775031	13.75898
1.2	0.36576	0.36576	0.755076	13.53416
1.25	0.381	0.381	0.736418	13.32197
1.3	0.39624	0.39624	0.718927	13.12124
1.35	0.41148	0.41148	0.702488	12.93095
1.4	0.42672	0.42672	0.687003	12.75018
1.45	0.44196	0.44196	0.672385	12.57816
1.5	0.4572	0.4572	0.658558	12.41417
1.55	0.47244	0.47244	0.645455	12.2576
1.6	0.48768	0.48768	0.633017	12.10788
1.65	0.50292	0.50292	0.62119	11.96451
1.7	0.51816	0.51816	0.609927	11.82704
1.75	0.5334	0.5334	0.599187	11.69507
1.8	0.54864	0.54864	0.58893	11.56823
1.85	0.56388	0.56388	0.579123	11.44619
1.9	0.57912	0.57912	0.569734	11.32863
1.95	0.59436	0.59436	0.560735	11.21529
2	0.6096	0.6096	0.552101	11.10592
2.05	0.62484	0.62484	0.543809	11.00027
2.1	0.64008	0.64008	0.535836	10.89813
2.15	0.65532	0.65532	0.528164	10.79932
2.2	0.67056	0.67056	0.520774	10.70364
2.25	0.6858	0.6858	0.51365	10.61093
2.3	0.70104	0.70104	0.506777	10.52103
2.35	0.71628	0.71628	0.500141	10.43381
2.4	0.73152	0.73152	0.493729	10.34912
2.45	0.74676	0.74676	0.487528	10.26685
2.5	0.762	0.762	0.481529	10.18687
2.55	0.77724	0.77724	0.47572	10.10908
2.6	0.79248	0.79248	0.470092	10.03338
2.65	0.80772	0.80772	0.464635	9.959672
2.7	0.82296	0.82296	0.459343	9.887867
2.75	0.8382	0.8382	0.454206	9.817883
2.8	0.85344	0.85344	0.449217	9.749643
2.85	0.86868	0.86868	0.44437	9.683072
2.9	0.88392	0.88392	0.439659	9.618102
2.95	0.89916	0.89916	0.435076	9.554667
3	0.9144	0.9144	0.430618	9.492706

Qmin	1 L/s =		0.001 m^3/s	
values for "b" (ft)	values for "b" (m)	values for "b" (cm)	yo (cm)	V (m/s)
0.05	0.01524	0.0001524	38.04537842	0.172469826
0.1	0.03048	0.0003048	24.87709432	0.131881957
0.15	0.04572	0.0004572	19.40317283	0.112725203
0.2	0.06096	0.0006096	16.26662285	0.10084576
0.25	0.0762	0.000762	14.18733873	0.092500502
0.3	0.09144	0.0009144	12.68733761	0.086197225
0.35	0.10668	0.0010668	11.54352887	0.081204183
0.4	0.12192	0.0012192	10.63641177	0.077113409
0.45	0.13716	0.0013716	9.895633359	0.07367649
0.5	0.1524	0.001524	9.276810439	0.070732067
0.55	0.16764	0.0016764	8.75042148	0.068170013
0.6	0.18288	0.0018288	8.295990408	0.06591216
0.65	0.19812	0.0019812	7.898823948	0.063901234
0.7	0.21336	0.0021336	7.548077279	0.062094146
0.75	0.2286	0.002286	7.235553877	0.060457752
0.8	0.24384	0.0024384	6.954931975	0.058966067
0.85	0.25908	0.0025908	6.701249612	0.057598386
0.9	0.27432	0.0027432	6.470552131	0.056337969
0.95	0.28956	0.0028956	6.259644959	0.055171111
1	0.3048	0.003048	6.065916489	0.054086467
1.05	0.32004	0.0032004	5.887208775	0.053074548
1.1	0.33528	0.0033528	5.721721522	0.052127349
1.15	0.35052	0.0035052	5.56793972	0.051238059
1.2	0.36576	0.0036576	5.424578344	0.050400844
1.25	0.381	0.00381	5.290539575	0.049610666
1.3	0.39624	0.0039624	5.164879324	0.048863155
1.35	0.41148	0.0041148	5.046780773	0.048154495
1.4	0.42672	0.0042672	4.935533256	0.047481335
1.45	0.44196	0.0044196	4.830515254	0.046840722
1.5	0.4572	0.004572	4.731180599	0.046230038
1.55	0.47244	0.0047244	4.637047186	0.045646956
1.6	0.48768	0.0048768	4.54768768	0.045089397
1.65	0.50292	0.0050292	4.462721817	0.044555495
1.7	0.51816	0.0051816	4.381809975	0.044043576
1.75	0.5334	0.005334	4.304647791	0.043552127
1.8	0.54864	0.0054864	4.230961614	0.043079777
1.85	0.56388	0.0056388	4.16050466	0.042625285
1.9	0.57912	0.0057912	4.09305373	0.042187519
1.95	0.59436	0.0059436	4.028406408	0.041765448
2	0.6096	0.006096	3.966378649	0.041358128
2.05	0.62484	0.0062484	3.906802706	0.040964692
2.1	0.64008	0.0064008	3.849525332	0.040584347
2.15	0.65532	0.0065532	3.794406211	0.04021636
2.2	0.67056	0.0067056	3.741316604	0.039860055
2.25	0.6858	0.006858	3.690138151	0.03951481
2.3	0.70104	0.0070104	3.640761831	0.039180045
2.35	0.71628	0.0071628	3.593087035	0.038855226
2.4	0.73152	0.0073152	3.547020761	0.038539854
2.45	0.74676	0.0074676	3.502476891	0.038233466
2.5	0.762	0.00762	3.459375553	0.037935631
2.55	0.77724	0.0077724	3.417642557	0.037645946
2.6	0.79248	0.0079248	3.377208887	0.037364035
2.65	0.80772	0.0080772	3.338010247	0.037089544
2.7	0.82296	0.0082296	3.299986661	0.036822145
2.75	0.8382	0.008382	3.263082106	0.036561528
2.8	0.85344	0.0085344	3.227244186	0.036307402
2.85	0.86868	0.0086868	3.192423838	0.036059494
2.9	0.88392	0.0088392	3.158575064	0.035817547
2.95	0.89916	0.0089916	3.125654695	0.035581317
3	0.9144	0.009144	3.093622166	0.035350577

b	2.5
	45 ft
	11 ft
	0.244444 ft/ft
	32.2 ft/s^2
	3
	2.75
	2.5

ssage)/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b

*Q(dam)^0.6588)

e)/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b - x = 0.0528*(Q(dam)^0.6588)

ge)/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b - x)/0.0528)^(1/0.6588) = Q(dam)

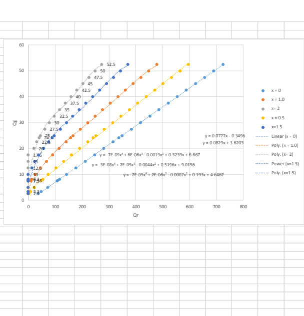
passage + Qriver

ge)/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b - x)/0.0528)^(1/0.6588) + Q(passage) = Q(river)

Qr values

Qp

X (ft)	2.5	3.3	5	7.5	7.58	8.1	10	12.5	15	17.5	20	22.5	24.1	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5
0	36.58984078	48.04069643	72.2083	107.4698	108.5939	115.8955	142.5015	177.3636	212.0909	246.7068	281.2275	315.6652	337.6662	350.0294	384.3276	418.5658	452.7494	486.8824	520.9687	555.0114	589.0133	622.9768	656.9041	690.7972	724.6578
0.05	31.91455847	42.88967847	66.26097	100.6347	101.734	108.8783	134.9614	169.2288	203.4369	237.5888	271.688	305.7381	327.5061	339.7426	373.7044	407.6263	441.5105	475.3593	509.1746	542.9581	576.7114	610.436	644.133	677.8038	711.4494
0.1	27.48028261	37.95792304	60.50448	93.96671	95.0406	102.0239	127.5734	161.2357	194.9165	228.5978	262.2702	295.9284	317.4607	329.5693	363.1914	396.7938	430.3761	463.9382	497.4803	531.0026	564.5055	597.9893	631.4545	664.9015	698.3307
0.15	23.29988896	33.25491185	54.9449	87.46975	88.5176	95.33624	120.3406	153.3865	186.5315	219.7357	252.9758	286.2373	307.5313	319.5107	352.7896	386.0694	419.3469	452.6199	485.8865	519.1456	552.3962	585.6376	618.8693	652.091	685.3024
0.2	19.38863939	28.79151423	49.58897	81.14812	82.16927	88.8191	113.266	145.6838	178.2842	211.0042	243.8062	276.6662	297.7193	309.5679	342.5	375.454	408.424	441.4053	474.3941	507.3878	540.3842	573.3813	606.3779	639.3728	672.3649
0.25	15.76503202	24.58036538	44.44416	75.00648	76.00019	82.47678	106.3531	138.1302	170.1766	202.405	234.763	267.2165	288.0258	299.7423	332.3238	364.9489	397.6084	430.2953	463.004	495.7302	528.4703	561.2214	593.9811	626.7475	659.519
0.3	12.4521502	20.63640774	39.51887	69.04988	70.01537	76.31388	99.60549	130.7285	162.211	193.9403	225.848	257.8898	278.4524	290.0351	322.2623	354.555	386.901	419.2908	451.717	484.1734	516.6552	549.1583	581.6795	614.2159	646.7651
0.35	9.479967907	16.97769906	34.82262	63.28384	64.22024	70.33541	93.02696	123.4816	154.3899	185.6118	217.0627	248.6874	269.0003	280.4478	312.3166	344.2734	376.3028	408.3928	440.5339	472.7183	504.9397	537.193	569.4738	601.7785	634.1039
0.4	6.889722458	13.6266854	30.36632	57.7144	58.62077	64.54682	86.62168	116.3928	146.7157	177.4219	208.4092	239.6111	259.6712	270.9817	302.488	334.1053	365.815	397.6023	429.4557	461.3657	493.3247	525.3261	557.3648	589.436	621.5361
0.45	4.743651383	10.61235491	26.16266	52.34825	53.22353	58.9541	80.39415	109.4653	139.1912	169.3726	199.8892	230.6624	250.4664	261.6383	292.7778	324.052	355.4386	386.9203	418.4834	450.1166	481.8108	513.5584	545.353	577.1892	609.0623
0.5	3.154056616	**7.974263906**	22.22667	47.19284	**48.03586**	53.56386	74.3492	102.7027	**131.8191**	161.4663	191.5047	221.8432	241.3876	252.4191	283.1875	314.1145	345.1747	376.3478	407.6178	438.9718	470.3991	501.8907	533.4394	565.0386	596.6831
0.55	#NUM!	5.771294138	18.57651	42.25651	43.06594	48.38344	68.49214	96.10885	124.6025	153.7055	183.2578	213.1551	232.4364	243.3258	273.7183	304.2943	335.0245	365.8858	396.86	427.9322	459.0902	490.3238	521.6246	552.9851	584.3994
0.6	#NUM!	4.106574054	15.23477	37.54872	38.32306	43.42108	62.82874	89.68788	117.5444	146.0928	175.1506	204.6	223.6146	234.3598	264.3718	294.5926	324.9892	355.5355	386.211	416.9988	447.8851	478.8585	509.9094	541.0294	572.2116
0.65	#NUM!	#NUM!	12.23068	33.0803	33.81781	38.68608	57.36538	83.44425	110.6484	138.6308	167.1855	196.1799	214.9239	225.523	255.1495	285.0108	315.07	345.2981	375.6718	406.1725	436.7847	467.4957	498.2946	529.1722	560.1206
0.7	#NUM!	#NUM!	9.604202	28.86386	29.56251	34.18912	52.10912	77.38275	103.9181	131.3224	159.3649	187.8969	206.3662	216.8171	246.0529	275.5503	305.2683	335.1745	365.2435	395.4543	425.79	456.2362	486.781	517.4142	548.1271
0.75	#NUM!	#NUM!	7.415001	24.91427	25.57165	29.94254	47.06787	71.50864	97.35724	124.1708	151.6912	179.7531	197.9435	208.244	237.0837	266.2126	295.5853	325.1662	354.9272	384.8453	414.9018	445.0809	475.3695	505.7563	536.2318
0.8	#NUM!	#NUM!	5.768321	21.24952	21.86268	25.96095	42.25052	65.82765	90.97011	117.1793	144.1671	171.7507	189.6577	199.8057	228.2437	256.9992	286.0223	315.2743	344.7241	374.3466	404.1212	434.0308	464.0609	494.1993	524.4355
0.85	#NUM!	#NUM!	#NUM!	17.89195	18.45717	22.2619	37.66721	60.34611	84.76121	110.3511	136.7955	163.8921	181.5111	191.5041	219.5345	247.9116	276.581	305.5001	334.6353	363.9591	393.4491	423.0867	452.8561	482.744	512.7389
0.9	#NUM!	#NUM!	#NUM!	14.87038	15.38278	18.86714	33.32966	55.07101	78.73542	103.6902	129.5794	156.1798	173.5059	183.3414	210.958	238.9515	267.2626	295.845	324.662	353.684	382.8867	412.2496	441.756	471.3912	501.1429
0.95	#NUM!	#NUM!	#NUM!	12.2241	12.67684	15.80459	29.25158	50.01016	72.89808	97.20056	122.5219	148.6164	165.6445	175.3198	202.5162	230.1207	258.0687	286.3103	314.8056	343.5225	372.4349	401.5206	430.7615	460.1418	489.6483
1	#NUM!	#NUM!	#NUM!	10.01143	10.39387	13.11198	25.44937	45.17237	67.25503	90.8864	115.6264	141.2047	157.9293	167.4417	194.2112	221.4209	249.001	276.8974	305.0672	333.4758	362.0948	390.9007	419.8736	448.9968	478.2558
1.05	#NUM!	#NUM!	#NUM!	8.334046	8.625903	10.84468	21.94311	40.56767	61.81273	84.75243	108.8966	133.9477	150.363	159.7095	186.0449	212.8539	240.061	267.6079	295.4484	323.5451	351.8677	380.3908	409.0933	437.9569	466.9665
1.1	#NUM!	#NUM!	#NUM!	#NUM!	7.602886	9.096733	18.75818	36.20759	56.5783	78.80372	102.3363	126.8485	142.9483	152.126	178.0198	204.4218	231.2506	258.4433	285.9504	313.7317	341.7547	369.9922	398.4215	427.0233	455.7811
1.15	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	8.11088	15.92825	32.10566	51.55974	73.04581	95.94975	119.9104	135.6883	144.6937	170.138	196.1265	222.5714	249.4052	276.5747	304.0369	331.7569	359.7058	387.8593	416.1968	444.7006
1.2	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	13.501	28.278	46.76607	67.48478	89.74143	113.137	128.5859	137.4157	162.4022	187.9702	214.0254	240.4953	267.3228	294.4621	321.8757	349.533	377.4078	405.4784	433.7259
1.25	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	11.55238	24.7443	42.20758	62.12733	83.71624	106.532	121.6446	130.295	154.8148	179.9552	205.6146	231.7153	258.1963	285.0086	312.1124	339.4747	367.0681	394.8691	422.858
1.3	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	10.23864	21.52939	37.89615	56.98095	77.87952	100.0997	114.868	123.335	147.3787	172.0837	197.3409	223.067	249.1968	275.678	302.4682	329.5324	356.8412	384.3701	412.0978
1.35	[illegible]																								
1.4	[illegible]																								
1.45	[illegible]																								
1.5	[illegible]																								
1.55	[illegible]																								
1.6	[illegible]																								
1.65	[illegible]																								
1.7	[illegible]																								
1.75	[illegible]																								
1.8	[illegible]																								
1.85	[illegible]																								
1.9	[illegible]																								
1.95	[illegible]																								
2	[illegible]																								



b = 2.5

*yo)

ssage)/(0.97*sqrt(g*So*b^5)))^(1/1.55)*b

*(Q(passage)/((0.97*sqrt(g*So*b^5)))^(1/1.55))*b)

	Qp																				
	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5
V (ft/s)	1.852135	2.36859	2.735104	3.029053	3.278645	3.497767	3.69442	3.873683	4.03901	4.192871	4.337097	4.473094	4.601961	4.724581	4.841673	4.95383	5.061551	5.165258	5.265311	5.362021	5.45566

	Qp		
	8	24.1	38
V (ft/s)	2.798463	4.138675	4.864482

x = 1.9-ft

	Qp		
	3.3	7.58	15
V (ft/s)	2.043888	2.745421	3.497767

x =0.5-ft

Qp < 38-cfs

45 ft
11 ft
0.244444 ft/ft

32.2 ft/s^2

1.5 m/s
4.92126 ft/s
4.9 ft/s

	Qp																			
	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
V (ft/s)	0.26109	0.462181	0.591057	0.682517	0.755869	0.818152	0.872832	0.921904	0.966638	1.007893	1.046288	1.082278	1.116215	1.148372	1.178971	1.20819	1.236177	1.263058	1.288937	1.313904	1.338037

	Qp																					
	2.5	3.3	5	7.5	8.1	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5
yo (ft)	0.539917	0.645828	0.844384	1.09685	1.152686	1.320545	1.52502	1.71538	1.894749	2.065218	2.228269	2.385001	2.536258	2.682707	2.824882	2.963225	3.098103	3.229824	3.358654	3.484821	3.608524	3.729937	3.849213

~ 3' max depth

Specific weight of water **62.4 lb/ft^3**
max expected Loading **7.5 plf**

Top of Dam Assumptions MADE

B = 87.3142

Qr	Qp	Flow (ft^3/s)	h = 0.0528*(Q^0.6588)	V(velocity-ft/s) = Q/(h*B)
7.97	3.3	4.67	0.14574	0.366988
48	7.58	40.42	0.604031	0.766394
131.8	15	116.8	1.215249	1.10076
8	8	0	0	0
48.2	24.1	24.1	0.429642	0.642429
130.4	35	95.4	1.063556	1.027314

Yb (depth at edge of weir)
Yc (critical depth)
Yb = (0.715*Yc)

g 32.2 ft/s^2
b weir 36.95833 ft
yc = (Q^2/(g*b^2))^(1/3)

H = V^2/(2g)+y+z
V = sqrt((H-y-z)*2g)
V = Q/(b*y)

Final Step
height 4.515625 ft
river width 35.42 ft

assume flat grade
assume rectangullar river bed
natural cahannel
assume n= 0.03

Flow (ft^3/s)	**yc weir**	**Yb (depth at edge of weir)**	**V(velocity-ft/s) = Q/(h*B)**	**H**
4.67	0.07915	0.056592	2.232788	4.649629
40.42	0.33366	0.238567	4.584309	5.080526
116.8	0.676916	0.483995	6.529642	5.661673
0	0	0	0	0
24.1	0.236366	0.169001	3.858461	4.915802
95.4	0.591478	0.422907	6.103673	5.517023

z = 4.515625

Bottom of Dam Assumptions MADE

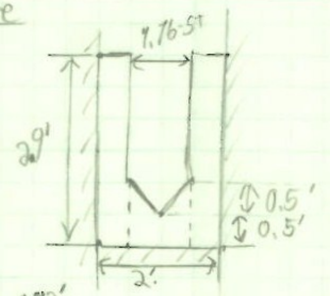
h1 = 4.515625
h2 = **0**
g = **32.2**

y = Q/(V*b)
b = 35.42

V2	**y (base of dam)**	Flow (ft^3/s)	**y (downstream after hydraulic jump)**	**v (downstream after hydraulic jump)**
17.19859	0.007666	4.67	0.371477	0.354925
17.65849	0.064624	40.42	1.086916	1.049909
18.26041	0.180586	116.8	1.845738	1.786587
17.05304	0	0	0	0
17.48411	0.038916	24.1	0.840356	0.809665
18.11246	0.148704	95.4	1.667942	1.6148

Appendix F: Structural Calculations

Baffle



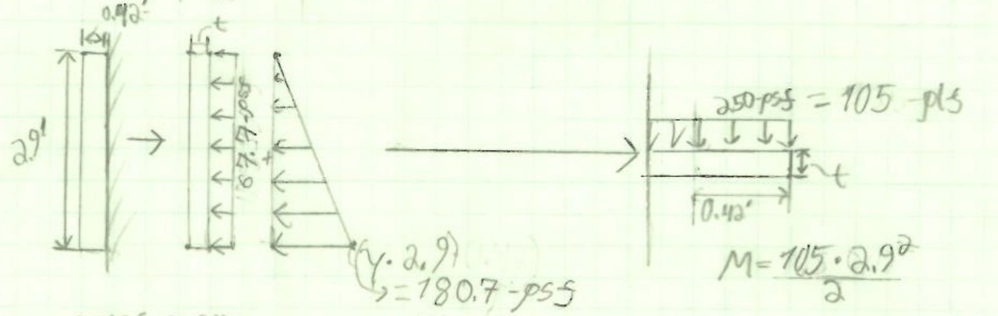
$P_{velocity} = 67.7\text{-psf} \cdot 2.9' = 196.4\text{-plf}$

$\lambda = 0.6$

$\phi K_F = 2.16$

$C_M = 0.85 \rightarrow F_b$

$C_M = 0.97 - F_v$

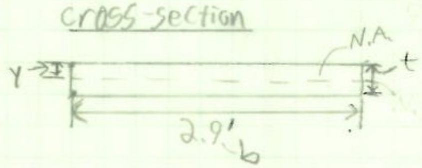


$M = \frac{105 \cdot 2.9^2}{2}$

$M = 63.95\text{-ft} \cdot \text{lbs}$

$M = 767.4\text{-in} \cdot \text{lbs}$

cross-section



$I = \frac{b \cdot t^3}{12}$

$y = \frac{t}{2}$

$b = 2.9' = 34.8\text{-in}$

$f_b = \frac{Mc}{I}$

$1.6 \cdot f_b = 1.6 \cdot \frac{767.4 \cdot \frac{t}{2}}{\frac{34.8 \cdot t^3}{12}} = \frac{212}{t^2} = f_b$

White Oak

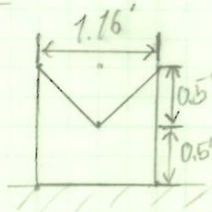
$F_b = 250\text{-psi}$

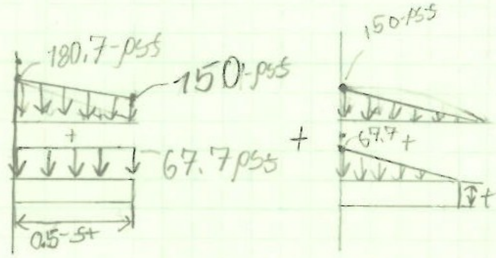
$F'_b = 0.6 \cdot 2.16 \cdot 0.85 \cdot 250 = 267\text{-psi}$

$\frac{212}{t^2} = 267 \text{ psi}$

$t_{min} = 0.9\text{-in}$ for bending

Baffle





$$M = \left(\frac{(67.7+150) \cdot (0.5)^2}{2} + \frac{(62.3) \cdot 1^2}{6} \right) + \frac{(67.7+150) \cdot 0.5}{2} \cdot \left(\frac{0.5}{3} + 0 \right.$$

$M = 84.6$-ft·lbs

$M_{max} = 1{,}015.2$-in·lbs

$f_b = \frac{Mc}{I}$

$I = \frac{bt^3}{12}$

$C = \frac{t}{2}$

$b = 1.16'$

$$1.6 \cdot f_b = \frac{M \cdot \frac{t}{2}}{\frac{bt^3}{12}} = \frac{700}{t^2}$$

White Oak

$F_b = 250$-psi

$F'_b = 0.6 \cdot 2.16 \cdot 0.85 \cdot 0.97 \cdot 250 = 267$-psi $= \frac{700}{t^2}$

$t = 1.7$-in ← governs

Baffle Shear

$P_{total} = 250\text{-psf} \cdot (2 \cdot 2.9 \cdot .42 + 1.16 \cdot 0.5 + 1.16 \cdot 0.5 \cdot 0.5)$

$P_{total} = 826.5\text{-lbs} = V$

$f_v = \frac{3 \cdot V}{2 \cdot b \cdot t}$, $b = 7.8'$

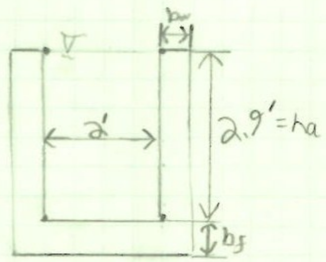
$f_v = \frac{3 \cdot 826.5}{2 \cdot 7.8 \cdot t} = \frac{159}{t}$

$F_b = 220\text{-psi}$

$F'_b = 0.6 \cdot 2.16 \cdot 0.97 \cdot 220 = 276\text{-psi} = \frac{159}{t}$

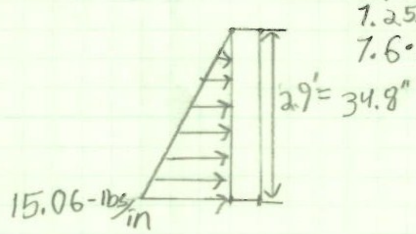
$\underline{t = 0.58\text{-in}}$

Concrete channel loading



$\gamma = 62.3$-pcf

Walls: loading = $\gamma \cdot ha$ = 180.67-lb/ft^2
= 1.255-psi
1.255-psi · 12-in/ft = 15.06-$\frac{lbs}{in}$ (per 1' section)
1.6 · L = 1.6 · 15.06 = 24.096



$M = \left(\frac{1}{2}(1.6 \cdot 15.06\text{-lbs/in}) \cdot 34.8''\right) \cdot \left(\frac{34.8''}{3}\right)$

$M = 4{,}864$-in·lbs

Shear

$\phi V_n = V_u$, $\phi = 0.75$

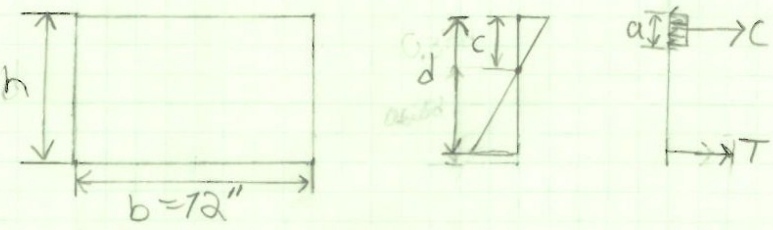
$V_c = 2\lambda \cdot \sqrt{f'c} \cdot bw \cdot d = 2 \cdot 1 \cdot \sqrt{3{,}000} \cdot 12'' \cdot d$

$V_c = 1{,}314 \cdot d$

$V = 15.06 \cdot \frac{2.9 \cdot 12}{2} = 263$-lbs

$\phi V_c = 1{,}182 \cdot d = 263$-lbs

$d_{min} = 0.23$-in



$f'_c = 3{,}000\text{-psi}$

$\beta_1 = 0.85$

$a = \beta_1 \cdot c$

$\phi = 0.9$

$I = \frac{bh^3}{12}$

$\sigma = \frac{M \cdot h/2}{I} = f'_c$

$M = 4{,}864\text{-in}\cdot\text{lb}$

$$\frac{4{,}864 \cdot h/2}{\frac{12 \cdot h^3}{12}} = \frac{2{,}432}{h^2} = 3{,}000$$

$h_{min} = 0.90\text{-in}$

Cantilever beam → $h_{min} = \frac{\ell}{8} = \frac{34.8\text{-in}}{8}$ (ACI 318-06, 9.5.2.2) + (ACI 318-08) (9.5.2)

$h\text{-}min = 4.35\text{-in}$ ← governs

Reinforcement

Min concrete cover = 1.5-in (ACI 318-08, 7.7.1)

2-in (ACI 350-06, 7.7.1)

↳ governs

$d = 2.35$-in − Dia. Steel

Assume "a" < N.A. = 2.175-in

guess $a = 1$-in

$A_s f_y = 0.85 \cdot f'_c \cdot b \cdot a$

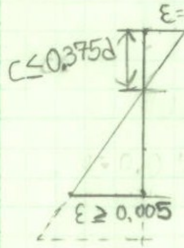
$M_u = \emptyset A_s f_y (d - a/2)$

$\emptyset = 0.9 \rightarrow$ for tension controlled

$M_u = 0.85 f'_c \cdot a \cdot b \cdot (d - \frac{a}{2})$

$A_s = \frac{0.85 f'_c \cdot b \cdot a}{f_y}$

$a = 2\left(d - \frac{M_u}{\emptyset A_s f_y}\right)$



$a = \beta_1 \cdot C = 0.85 \cdot 0.375 \cdot d$

$a = 0.31875 \cdot d$

$0.85 f'_c \cdot a \cdot b = A_s \cdot f_y$

$A_s = \frac{0.85 \cdot f'_c \cdot a \cdot b}{f_y} = \frac{0.85 \cdot f'_c \cdot 0.31875 \cdot d \cdot b}{f_y}$

$b = 12$-in
$f'_c = 3{,}000$
$f_y = 36{,}000$

$A_s = 0.2709 \cdot d$

$M_u = \emptyset \cdot A_s \cdot f_y \cdot (d - \frac{a}{2}) = (0.9) 0.2709 \cdot d \cdot 36{,}000 \cdot (d - \frac{0.31875 d}{2})$

$M_u = 7{,}378.3 \cdot d^2 = 4{,}864$-in·lb

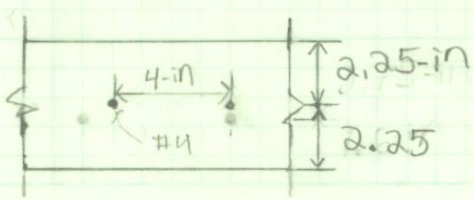
$d = 0.812$-in < 1.5-in → needed coverage

$d = 2.05$-in → $d = 2.25$-in (for coverage)

$A_s = 0.6095$-in²/12in section   spacing < 2·h < 12-in (ACI 350-06 7.6)

3.05 #4 Bars = 4-in spacing
(0.20-in²)

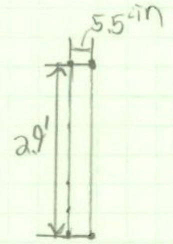
#4-reinforcement at 4-in spacing <



Freeze thaw reinforcement : Channel Walls

min: $A_s = 0.005 \cdot bd$, min coverage = 2.5-in

↳ use 6-in thicness



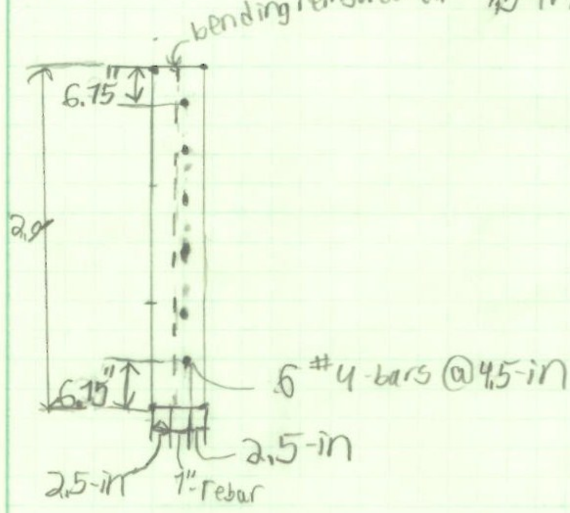
$A_s = 0.005 \cdot 6 \cdot 34.8$

$A_s = 1.044 \text{ -in}^2$

↳ use 6 #4-bars = 1.2-in^2

(0.2-in^2 =)

↳ 4.5-in spacing

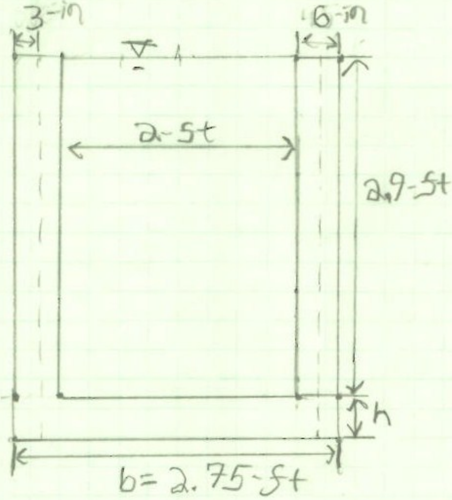


Final channel wall size = 6-in wide

vertical reinforcement = # 4-rebar @ 4-in

horizontal reinforcement = 6 # 4-rebar @ 4.5-in

Passage floor

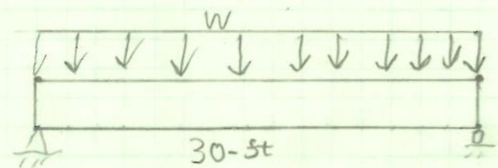


min Coverage = 2-in

min thickness = $\frac{l}{16}$

l_{max} = 30-ft

min thicknes = 1.875-ft < 2.9



$w = 1.2 \cdot D + 1.6\,L$

$W_L = \gamma \cdot 2.9\text{-ft} \cdot 2\text{-ft} = 361.34\text{-plf}$

$W_D = 0.50 \cdot 2.9 \cdot 150\,pcf \cdot 2 + (0.75 \cdot 2.75 \cdot 150) = 750\,plf$ (estimation)

$W = 1635\text{-plf}$

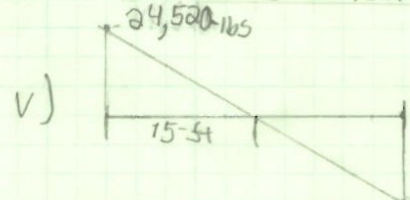
$$N.A. = \frac{0.5 \cdot 2.9\,(1.45 + h) \cdot 2 + 2.75 \cdot h \cdot \frac{h}{2}}{2 \cdot 0.5 \cdot 2.9 + 2.75 \cdot h} = \frac{3.154 + 2.175h + 1.375h^2}{2.175 + 2.75h}$$

$I = 1.524\ ft^4 + 0.229 \cdot h^3$

$y = (2.9 + h) - N.A$

$\sigma = \frac{My}{I}$

$M_{max} = 130{,}050\text{-ft}\cdot\text{lbs}$



$$\sigma = \frac{130{,}050 \cdot \left[(2.9 + h) - \left(\frac{3.154 + 2.175h + 1.375h^2}{2.175 + 2.75 \cdot h}\right)\right]}{1.524 + 0.229 \cdot h^3} = 432{,}000\text{-psf}$$

even if $h_{min} = 0$, $\sigma_{max} = 12,415\text{-psf} < 432,000\text{-psf}$

assume $h = 5.5$-in for steel coverage

Shear

$\phi V_n \geq V_u$
$\phi = 0.75$

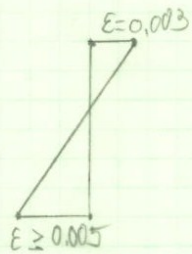
$V_c = 2 \cdot \lambda \cdot \sqrt{f'_c} \cdot b_w \cdot d$
$\lambda = 1$
$V_c = 2 \cdot 1 \cdot \sqrt{3{,}000} \cdot 33 \cdot d = 3{,}615 \cdot d$ $(d = h)$

$V_u = 24{,}520\text{-lbs}$

$0.75 \cdot 3{,}615 \cdot h = 24{,}520$

$h_{min} = 9.0\text{-in}$ ← governs

reinforcement



$a \leq 0.31875 \cdot d$ $b = 2 \cdot 6 = 12\text{-in}$

$A_s = \frac{0.85 \cdot f'_c \cdot a b}{f_y} = \frac{0.85 \cdot 3{,}000 \cdot 0.31875 \cdot d \cdot 12}{36{,}000}$

$A_s = 0.271 \cdot d$

$d = (34.8 + 9) - 4\text{-in} = 38.8\text{-in}$ (coverage)

$A_s = 10.5\text{-in}^2$

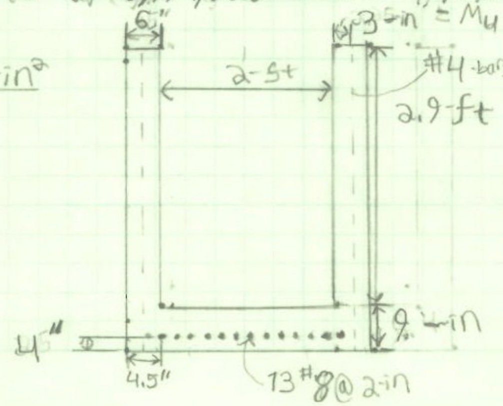
$a = \frac{A_s f_y}{0.85 \cdot f'_c \cdot b} = 12.35\text{-in} < 0.31875 \cdot d = 12.36$ → Tension Controled

$A_s f_y = 378{,}000\text{-lbs}$

$\phi A_s f_y \cdot (d - \frac{a}{2}) = 8{,}994{,}888\text{-in-lbs} \geq 24{,}520\text{-in-lb} = M_u$

$A_s = 13$ #8 bars $= 10.3\text{-in}^2$ (0.6-in^2)

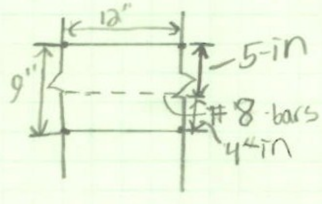
13 #8 bars @ 2-in spacing



Freeze Thaw reinforcement for passage floor

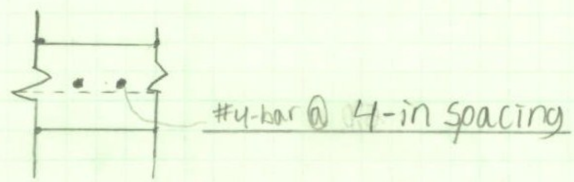
min $A_s = 0.003 \cdot b \cdot d$ ACI 350-06 (7.12.2.1)

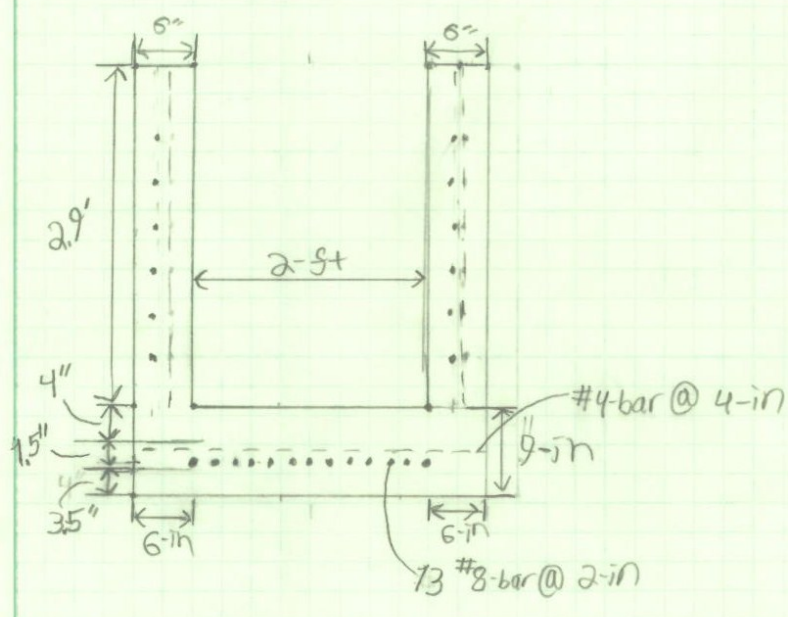
assume 12-in section



$A_s = 0.003 \cdot b \cdot d = 0.324\text{-in}^2$

use 2 #4-bar = 0.4-in^2
(0.2-in²)





Resting pool

$$E = \frac{\frac{\rho}{2} \cdot Q V^2}{b_m h_m l_b} < 25 \text{ to } 50 \; W/m^3 \longrightarrow \text{UN FAO (5.77)}$$

b_m = width = 2 ft
h_m = depth
l_b = length = 2 ft

$V = Q / h^* \cdot b_a$

$\rho = 1.94$ slug/ft^3

$Q = 19.7$ ft^3/s

$V = 5.86$ ft/s

$$\frac{\frac{1.94}{2} \cdot 19.7 \cdot 5.86^2}{2 \cdot h_m \cdot 2} < 50$$

$$164 < 50 \cdot h_m$$

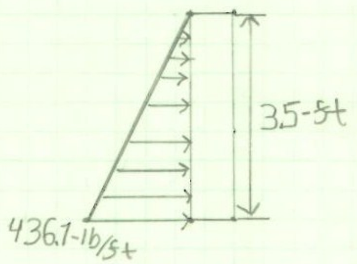
$h_m = 3.5$ ft

Resting pools strength

Walls

Load = $\gamma \cdot h_m \cdot b_m = 62.3 \cdot 3.5 \cdot 2 = 436.1$-lb/ft

$1.6 \cdot L = 697.76$-lb/ft



$M = \frac{1}{2} \cdot (697.76 \cdot 3.5) \cdot \left(\frac{3.5}{3}\right)$

$M = 1{,}425$-ft·lbs $= 17{,}095$-in·lbs

$\sigma = \frac{M \cdot \frac{h}{2}}{I} = f'_c$:

$I = \frac{b \cdot h^3}{12}$, $b = 2$-ft

$\sigma = \frac{1{,}425 \cdot \frac{h}{2}}{\frac{2 \cdot h^3}{12}} = 3{,}000$-psi $= 432{,}000$-pcf

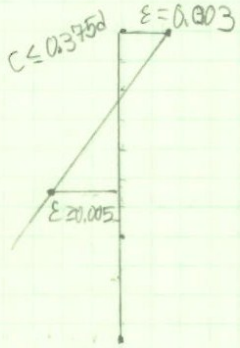
$\frac{4{,}275}{h^2} = 432{,}000$

$h_{min} = 0.70$-ft $= 1.19$-ft

$h_{min} = \frac{l}{8} = \frac{3.5}{8}$

$h_{min} = 0.4375$-ft $=$ 5.25-in ⟵ governs

Resting pool reinforcement



$a = 0.31875 \cdot d$

$A_s = \frac{0.85 \cdot f'c \cdot 0.3175 \cdot d \cdot b}{f_y}$

$b = 2\text{-ft} = 24\text{-in}$
$f_y = 36{,}000\text{-psi}$
$f'c = 3{,}000\text{-psi}$

$A_s = 0.53975 \cdot d$

$d = 5.25\text{-in} - 2.5\text{-in}$ ↳ coverage

$d = 2.75\text{-in}$

$A_s = 1.48\text{-in}^2$

$a = \frac{A_s \cdot f_y}{0.85 \cdot f'c \cdot b} = 0.871\text{-in}$

$\phi M_n = \phi \cdot A_s \cdot f_y \cdot (d - \frac{a}{2}) = 0.9 \cdot 1.48 \cdot 36{,}000 \cdot (2.75 - \frac{0.871}{2})$

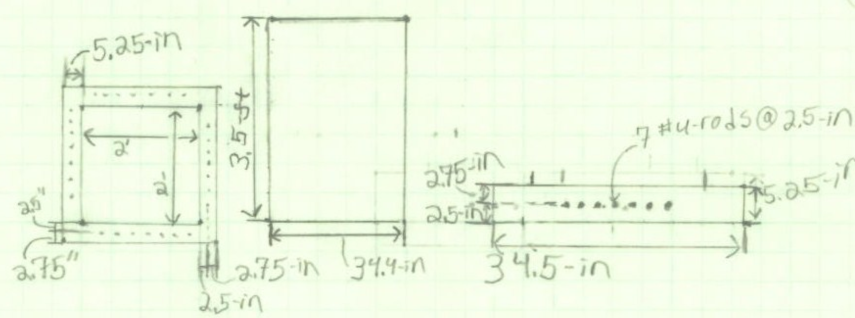
$\phi M_n = 9{,}248\text{-ft} \cdot \text{lb} > 1{,}425\text{-ft} \cdot \text{lb} = M_u$

$A_s = 7$ #4 rods @ 2.5-in spacing
0.2-in²

$A_s = 1.4\text{-in}^2$

$a = \frac{1.4 \cdot 36{,}000}{0.85 \cdot 3{,}000 \cdot 24} = 0.8235\text{-in}$

$\phi M_n = 0.9 \cdot A_s \cdot f_y \cdot (d - \frac{a}{2}) = 8{,}838\text{-ft} \cdot \text{lb} > 1{,}425\text{-ft} \cdot \text{lb}$ ✓



Resting pool wall freeze thaw reinforcement

$\min A_s = 0.003 \cdot b \cdot d$

additional coverage will be needed

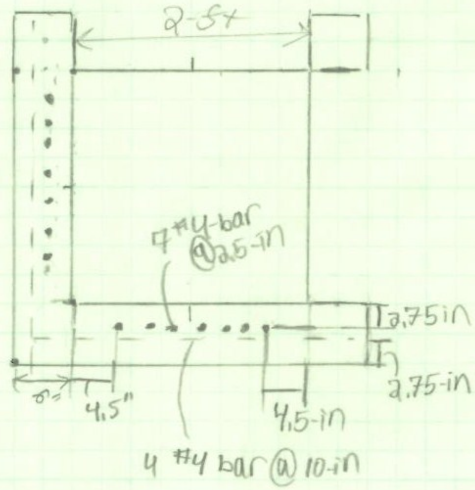
assume $d = 6$-in

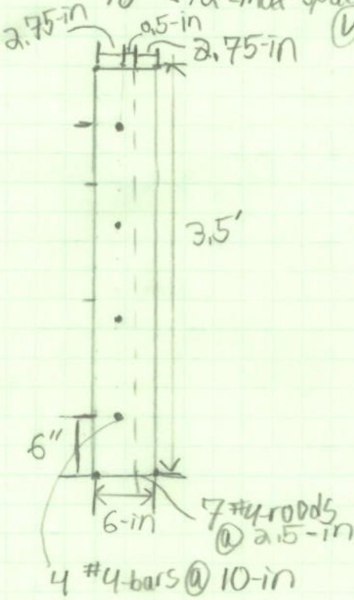
$b = 42$-in → vertical height = 3.5-ft

$A_s = 0.003 \cdot 6 \cdot 42 = 0.756$-in²

Use 4 #4-bars = 0.8-in² → use 10-in spacing

10" < 12" = max spacing ✓

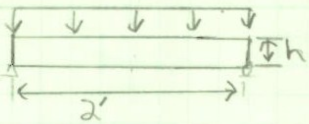




Resting pool floor

$\gamma \cdot h \cdot b = 62.3 \cdot 3.5 \cdot 2 = 436.1\text{-plf}$

$w = 1.6 \cdot 436.1 = 698\text{-plf}$



$$M = \frac{w\ell^2}{8} = \frac{698 \cdot 2^2}{8}$$

$$M = 349\text{-ft}\cdot\text{lbs} = 4{,}188\text{-in}\cdot\text{lbs}$$

$$\sigma = \frac{M \cdot h/2}{I} = f'c$$

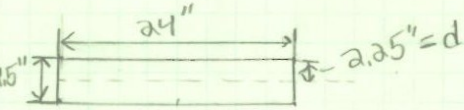
$$I = \frac{bh^3}{12}, \quad b = 2' = 24''$$

$$\sigma = \frac{4{,}188 \cdot \frac{h}{2}}{\frac{24 \cdot h^3}{12}} = 3{,}000\text{-psi}$$

$h_{min} = 0.60\text{-in}$

$h_{min} = \frac{\ell}{16} = \frac{24}{16} = 1.5\text{-in}$

→ 2-in coverage needed → use 4.5-in



$C \leq 0.375d$

$a = 0.31875 \cdot d$

$$A_s = \frac{0.85 \cdot f'c \cdot a \cdot b}{f_y} = \frac{0.85 \cdot 3{,}000 \cdot 0.31875 \cdot d \cdot 24}{36{,}000}$$

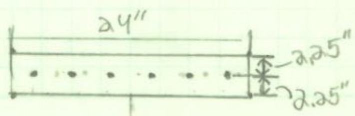
$A_s = 0.54 \cdot d^2$

$A_s = 1.215\text{-in}^2$

A_s = Use 6 # 4-bars (0.2-in^2) $= 1.2\text{-in}^2$ @ 3.5-in spacing

$a = 0.717$

$\phi A_s f_y \cdot \frac{a}{2} = 14{,}176\text{-in}\cdot\text{lbs} > 4{,}188\text{-in}\cdot\text{lbs}$ ✓



Resting pool freeze thaw reinforcement - floor

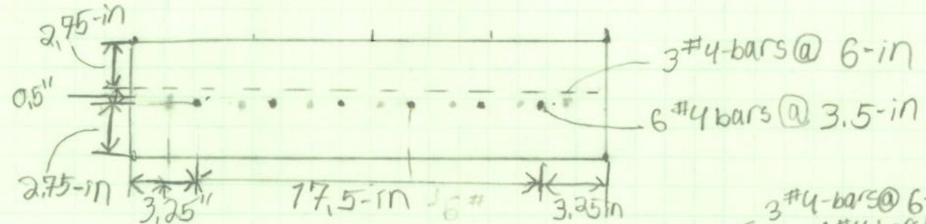
↳ need 2.5-in cover → use d = 6-in

min $A_s = 0.003 \cdot d \cdot b = 0.003 \cdot 6 \cdot 24$

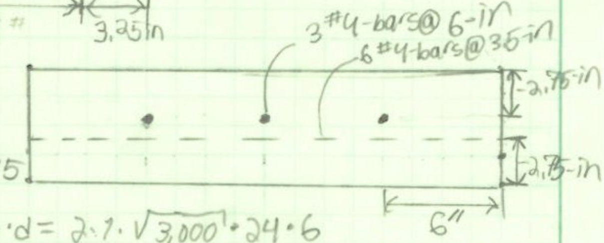
$A_s = 0.432\text{-in}^2$

use 3 #4-bars = 0.6-in^2

↳ us 6-in spacing



Check shear



$\phi V_n = V$, $\phi = 0.75$

$V_c = 2\lambda \cdot \sqrt{f'c} \cdot bw \cdot d = 2 \cdot 1 \cdot \sqrt{3{,}000} \cdot 24 \cdot 6$

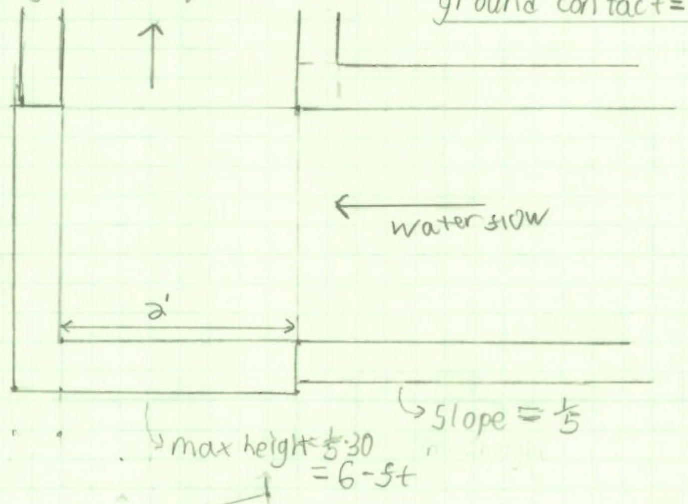
$V_c = 15{,}770\text{-lbs}$

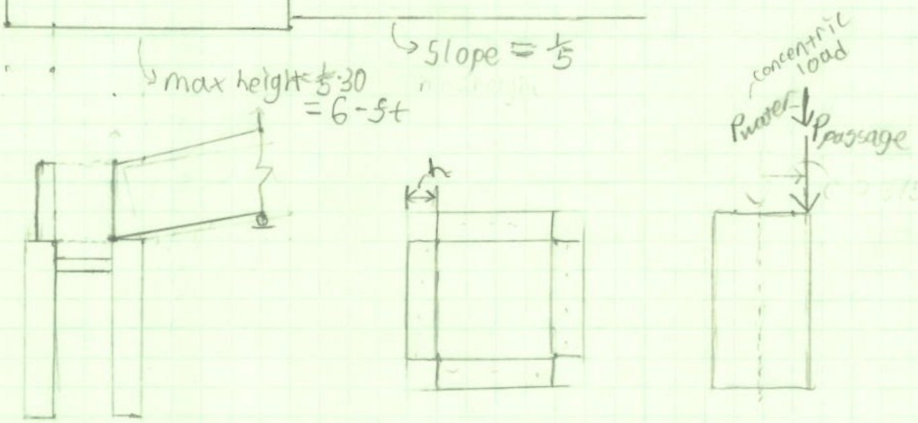
$V_u = 1.2 \cdot 150 \cdot (.5) + 1.6 \cdot (\gamma \cdot 3.5' \cdot 2' \cdot 2') = \underline{1{,}576\text{-lbs}}$

$0.75 \cdot 15{,}770 = 11{,}827\text{-lbs} > 1{,}396\text{-lbs}$ ✓

Resting pool support

ground contact = 3-in covering





$P_{passage} = \frac{1}{2}$ total passage $= 24{,}520$-lbs, $P_{water} = \frac{1}{2}$ total water $= 436.1$-lbs

$1.6 \cdot P_{water} = 697.8$, $P_{resting\ pool} = 150(0.5 \cdot 2.5 \cdot 3.5) + (0.5 \cdot 2 \cdot 2)$ $(= 957) \cdot 1.2 = 1{,}150$-lbs

$P_{total} = 26{,}370$-lbs

$e_{max} = \frac{h}{2}$

$M = P \cdot e = 26{,}370 \cdot \frac{h}{2} = 13{,}185 \cdot h$

$c = h/2$

$I = \frac{2' \cdot h^3}{12}$

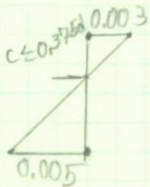
$\sigma_b = \frac{Mc}{I} = \frac{13{,}185\, h \cdot \frac{h}{2}}{\frac{h^3}{6}} = \frac{39{,}555}{h}$

$\sigma_{axial} = \frac{P}{A} = \frac{26{,}370}{h \cdot 2'} = \frac{13{,}185}{h}$

$\sigma_{total} = \frac{52{,}740}{h} = 3{,}000 \cdot (12 \cdot 12) \rightarrow h_{min} = 1.47$-in $\rightarrow$ need 3" cover

↳ use 7-in

Resting pool reinforcement - support



$d = \frac{1}{2} \cdot h = 3.5\text{-in}$

$a = 0.31875 \cdot d = 1.116\text{-in}$

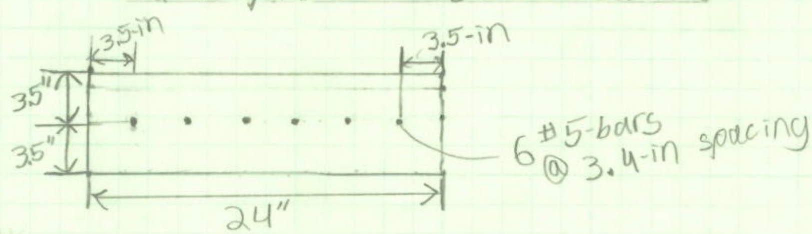
$A_s = \frac{0.85 \cdot f'_c \cdot a \cdot b}{f_y} = \frac{0.85 \cdot 3{,}000 \cdot 1.116 \cdot 24''}{36{,}000}$

$A_s = 1.89\text{-in}^2$

↳ use 6 #5 bars $= 1.86\text{ in}^2$ (0.31-in²)

$M_u = \phi \cdot A_s \cdot f_y (d - \frac{a}{2}) = 0.9 \cdot 1.86 \cdot 36{,}000 \cdot (2 - \frac{1.116}{2})$

$M_u = 86{,}900\text{-in} \cdot \text{lb} > P \cdot e = 36{,}076$



check Shear

① $V_n \geq V_u$ $\phi = 0.75$

$V_c = 2 \cdot \lambda \cdot \sqrt{f'_c} \cdot b_w \cdot d = 2 \cdot 1 \cdot \sqrt{3{,}000} \cdot 24 \cdot 7$

$V_c = 18{,}403.5\text{-lbs}$

$V_u = \gamma \cdot 3.5' \cdot 2' \cdot 2' = 872.2\text{-lbs}$

$0.75 \cdot 18{,}403.5 = 13{,}803\text{-lbs} > 872.2\text{-lbs}$ ✓

verify compression strength

$P_{total} = 26,370\text{-lb}$

$$P_{total} = 0.80 \cdot [0.85 \cdot f'_c \cdot (b \cdot t)]$$

$f'_c = 3,000$
$b = 2'$

$$0.80 \cdot [0.85 \cdot 3,000 \cdot (2' \cdot t)] = 26,370\text{-lb}$$

$t_{min} = 6.47\text{-in} < 8\text{-in}$ ✓

Freeze/thaw reinforcement for supports

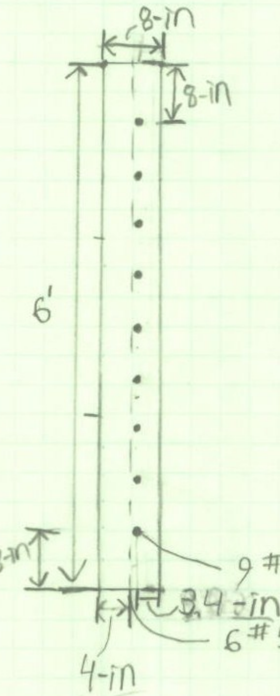
→additional coverage needed → $d = 8\text{-in}$

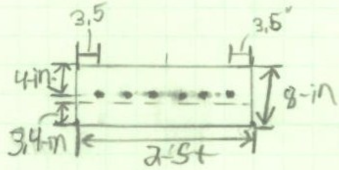
min $A_s = 0.003 \cdot d \cdot b = 0.003 \cdot 8 \cdot 72''$

$A_s = 1.73\text{-in}^2$

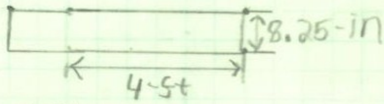
↳use 9 #4-rods = 1.8-in^2

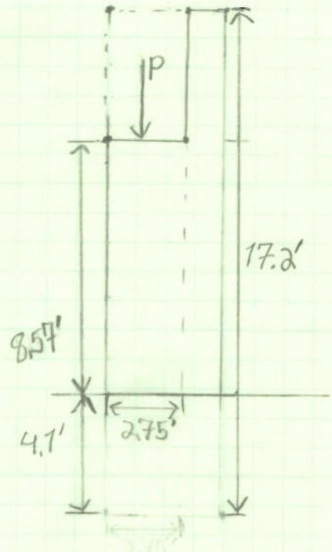
↳use 7-in spacing





Impact to dam



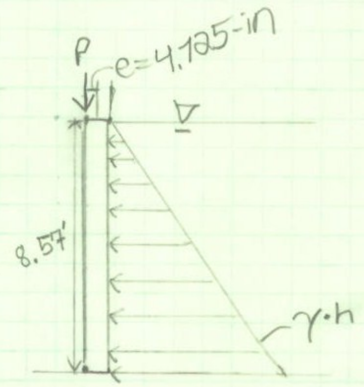


Dam height = 15.7'
Section heigt = 17.2'
passage heigt (channel) = 1.9' bellow dam

passage = 15.1 − 1.9 − $\frac{6.4''}{12}$ = 12.67'

ground ≃ 4.1'

Loading
↳ worst case



P = $\frac{1}{2}$ · passage loading = 24,520-lbs
1.6P = 27,744

$M_{passage}$ = P·e = 24,520 · 4.125-in = 101,145-in·lb

(ACI 318-10.3.7) = combined axial and compression loaded member

$\sigma_f = \frac{Mc}{I}$ c = 4.125-in
I = (2.75·12)·(8.25)³ = 18,530-in⁴

$\sigma_f = \frac{101,145 \cdot 4.125}{18,530}$ σ_f = 23-psi worst case: compression etirely on $\frac{1}{2}$ crossectional area

$P = 24,520\text{-lbs}$

$A = \frac{1}{2} \cdot (2.75' \cdot 12 \cdot \frac{in}{ft}) \cdot 8.25\,in$

$A = 136\text{-}in^2$

$\sigma_{axial} = \frac{P}{A} = 180.3\text{-psi}$

$\sigma_{applied} = \sigma_p \cdot \sigma_{axial} = 23 + 180.3$

$\sigma_{applied} = 203\text{-psi}$ = stress add to dam by fish passage

Stress due to water pressuer

$\gamma \cdot h \cdot b = 62.3 \cdot 8.57 \cdot 2.75' = 1,470\text{-lbs/ft} = w$

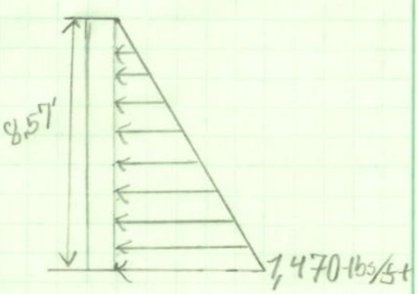
$M = (1,470 \cdot 8.57) \cdot \frac{1}{2} \cdot (8.57 \cdot \frac{1}{3})$

$M = 17,994\text{-ft} \cdot \text{lbs} = 215,928\text{-in-lbs}$

$1.6M = 345,485\text{-in-lbs}$

$\sigma_w = \frac{Mc}{I} = \frac{345,485 \cdot 4.125}{18,530}$

$\sigma_w = 77\text{-psi}$



$\sigma_{Total} = \sigma_{applied} + \sigma_w$

$\sigma_{Total} = 280\text{-psi} < 3,000\text{-psi}$

The total stress on the dam with the addition of the loading of the fish passage is only 280-psi. If the concrete section was adequately designed with reinforcement, the dam should not need additional support to carry the passage.

Check stress on nearby dam section

$b = 7.25'$
$h = 8.25\text{-in}$
$\ell = 13.7\text{-ft}$

$\gamma \cdot \ell \cdot b = 1{,}035\text{-plf}$

$M = (1{,}035\text{-pls} \cdot 13.7) \cdot \frac{1}{2} \cdot (\frac{1}{3} \cdot 13.7) = 29{,}603\text{-ft-lb} = 355{,}233\text{-in-lbs}$

$1.6 \cdot M = 568{,}373\text{-in-lb}$

$\sigma = \frac{Mc}{I} = \frac{568{,}373 \cdot 4.125}{18{,}530}$

$\sigma = 127\text{-psi} < 3{,}000$ ✓

Appendix G: Economic Information

Fishway Costs (2007$)[1]

Fishway Type	Cost Range	Cost/ Foot Rise
Steep Pass (17)	$30,133 - $624,653	$21,899
Pool-and Weir (4)	$83,507 - $341,242	$37,947
Denil (5)	$374,049 - $470,469	$40,644
Nature-like (10)	$25,580 - $620,685	$36,653

[1]Costs include design, permitting and construction; excludes fishway repair projects and dam repair costs

RC-NE Dam Removal Experience – Costs (2007$)[1]

Project Phase	N	Cost – Median	Cost – Mean	Cost Range
Feasibility/assessment	30	$109,270	$106,145	$8,695 – $236,355
Design and Permitting	11	$95,528	$87,940	$8,695 – $187,807
Removal/Implementation	20	$68,318	$114,021	$6,509 – $721,000
Total Costs		$273,116	$308,106	
Combined Project Costs	18	$188,781	$284,419	$32,235 – $1,318,124
Mean Cost		**$230,949**	**$296,263**	
Cost/ Foot Rise		**$28,869**	**$37,033**	

[1]Excludes cost of performance monitoring