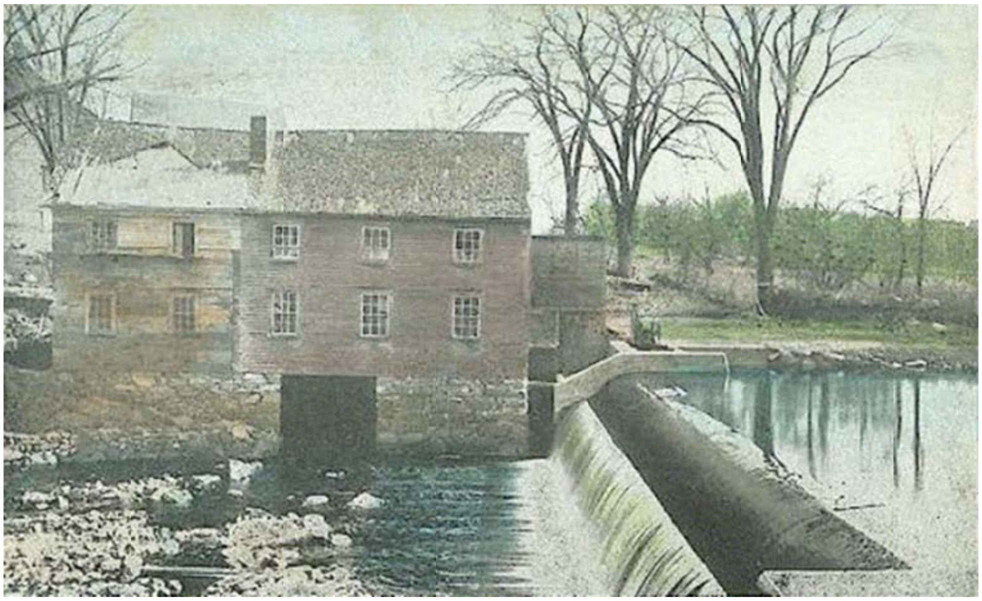
Oyster River Dam Restoration

Senior Project 2012



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Abstract

The rehabilitation and implementation of a low head hydro-electric generator on the Oyster River Dam was the focus of the senior design project. The Oyster River Dam, which was first built in 1913, is experiencing some cracking on the upstream face of the spill way and the gate structure. Our goal when approaching this project was to implement a power generator and rehabilitate the structure without damaging the historical aspect. The dam is classified as an Ambursen dam and is the last remaining of its type in New Hampshire. An arch structure was determined to be the best method to reinforce the dam and strengthen the spill way, while keeping the structural integrity of an Ambursen dam intact. An Archimedes screw was also determined to be the best hydropower for the dam. This form of hydropower generation is popular in Europe, but is relatively new in the United States. With the implementation of this form of hydroelectric generation, the site will maintain its historical status and create and educational experience for students and town's people alike. Moreover, a hydrologic study was performed, and the peak monthly flows of the Oyster river were determined, providing information on how much hydroelectric power can be generated during a given time period.

Introduction

The Oyster River dam was built in 1913, however the site had functioning timber dams prior to its current structure for over 300 years. The town of Durham, like many small towns in the New England area, depended on hydro power to drive the construction industry and the economy. The Oyster River dam provided the means to facilitate the growth of Durham and the surrounding area. The dam is a symbol of innovation in early America and a historical piece of engineering, representative of hard work and ingenuity.

Preserving the historical aspect of the dam, while providing sufficient structural support, was the main goal when deciding on the structural rehabilitation aspect of the project. A concrete arch supporting each individual bay was selected as the best method to reinforce the spillway, while maintaining the historical structural integrity. Hydropower will be generated by an Archimedes Screw, a form of hydroelectric generation most common in Europe that will provide educational opportunities to UNH students as well as residents.

An evaluation of permitting required with the implementation of hydropower at the site was studied. Appropriate measures to register the dam as a functional hydro electric generator were taken into account along with environmental conditions that must be met. The applicability of the Federal Energy Regulatory Commission permit was contingent on the usage of power generated, which is outlined in the hydroelectric section of the report. A detailed evaluation of the watershed and the hydrologic conditions surrounding the dam was also met.

History

The Oyster River Dam was originally constructed in 1913. It was built to provide power to the Jenkins Mill that once stood there. It replaced on of the old timber dams that had been built on the Oyster River in the 1600's. The dam is at the center of the town of Durham and had a major influence on the industrial era of the local area. The river was a major trade route during the 1800's. Trade boats came all the way up from the Portsmouth harbor to Durham. Residents would come from surrounding towns to gather goods. There are many ties with the University as well. The dam was built in honor of Hamilton Smith, step father of Mrs. Edith Angela Congreve Onderdonk. She was very involved and generous to the University. The design engineer was Professor Charles Elbert Hewitt who was the first Head of Electrical Engineering at UNH and the builder was Daniel Chesley. The dam was built using the unique Ambursen design; there are eight walls that create nine empty bays that have a spillway structure over the top. The upstream side of the dam angles down into the riverbed and the downstream side has a hydrodynamic shaped lip that allows water to flow efficiently. The abutment on the south side, where the mill stood, has a gate structure with two openings which can be opened and closed to reduce head during flood events. In 1975, there was a rehabilitation of the dam. The repairs included patching cracks in the concrete and erosion control around the abutments. A fish ladder was also installed by the N.H. Fish and Game Department on the north abutment. The fish ladder allows fish to bypass the dam and move upriver.

Presently the dam is experiencing concrete cracking, spalling erosion and efflorescence. Exposed corroded reinforcing steel is exposed on the downstream face, inside the cells and on the right abutment. Foundation footings of the supporting walls are not in good condition and erosion around both abutments poses a threat.

Hydrology

Dam and Stream Gauge Locations:

The Oyster River Dam is located on the Oyster River 3 miles upstream from Great Bay. This location is also where NH Route 108 and the Oyster River intersect. Located upstream of the dam is Mill Pond. The data collection point used to analyze the dam is the USGS 01073000 stream gauge, located approximately 4 miles upstream of the dam where the Oyster River and Main Street (NH Route 155A) intersect.

Methods

USGS Stream Statistics:

USGS Stream stats program was used in order to obtain watershed characteristics of the dam and stream gauge that would be used in subsequent analysis for this report. Upon a watershed delineation of the dam the approximate area of the watershed is 20.37 square miles, 7.6% of which is covered in wetlands. The average slope of the stream over the course of the watershed is 15.2 feet per mile. For USGS 01073000 the basin characteristics were that the basin covered approximately 12.2 square miles and has a wetland area of 9.6%. In the case of this basin the average stream slope is approximately 17.9 feet per mile. Both of these watersheds have a mean average April precipitation of 4.16” and 4.18” respectively that are used for calculating the 100 year flood. To clarify the stream gauge being upstream from dam has a smaller watershed is within the watershed of the dam; however due to the characteristics of the watershed being specific to the geography alters the characteristics determined for the dam. The USGS historical data represents hydrologic conditions that pertain to a stream gauge, being represented by watershed characteristics. For calculations for the 100 year flood interval these differences must be taken into account during calculations and must be recorded.

Watershed Scaling:

Watershed scaling was used to approximate the stream flow of the water that is passing over the dam. In order to do this both watershed areas of the dam and stream gauge are needed which were determined above. Using the area of the stream gauge’s watershed and the flow data gathered, the flows are divided by the area of the watershed giving a unit of flow per area, in this case cubic feet per second per square mile (cfs/m^2). This gives a unit that is capable of being used to interpolate data to account for the fact that the dam is down stream and accumulates more water from the subsequently larger watershed area. As such, these values are then multiplied by the area of the dam giving the approximate flows that run over the dam. In the case of the Oyster River Dam and USGS 01073000, a watershed area ratio scalar of 1.67 was used to modify the data from USGS 01073000.

Indicators of Hydrologic Alteration (IHA):

Using the modified flow data the Indicators of Hydrologic Alteration (IHA) method of stream flow analysis was used to examine the stream flow. The program, IHA 7 was used to run the data analysis of the stream flow data from USGS 01073000. This analysis produced monthly average flow rates, minimum and maximum flows for 1, 3, 7, 30 , 90 day periods, low/high pulse counts and durations, as well as the rise and fall rates of the river changes.

USGS/NHDOT Method:

Using watershed characteristics retrieved from the USGS Stream Stats this method the calculations can be conducted for different recurrence intervals. See appendix for calculations based on this method, also reference USGS article Estimation of Flood Discharges at Selected Recurrence Intervals for Streams in New Hampshire for calculation methodology.

Analysis Results

Stream Flow:

Utilization of the IHA program was primarily used to determine the average monthly flows that pass over the dam, however other useful information was garnered that would be helpful to understanding the stream flow regime at the dam's location. The overall average flow that passes over this dam throughout the year is approximately 20.1 cfs. For each individual month refer to Table 1. These values were used in calculations in reference to power generation for an Archimedes screw power generator.

Table 1: Power Generation

Parameter Group #1	Mean Guage	Coeff. of Var.	Mean Dam
October	8.668	1.289	14.47
November	18.57	0.7728	31.01
December	22.77	0.6308	38.02
January	19.12	0.6412	31.92
February	22.07	0.7096	36.85
March	48.38	0.4946	80.78
April	48.77	0.4869	81.43
May	25.63	0.673	42.79
June	13.39	0.9344	22.36
July	5.542	1.107	9.25
August	4.028	1.356	6.73
September	4.549	1.663	7.60

The minimum and maximum flows for the Oyster River at different time intervals in conjunction with high and low pulse information is important to understanding how the impoundment caused by the dam will react to extreme flow situations over periods of time. In defining the pulses which are flows that fall into the first and last quartiles of data when it is numerically ranked from lowest to highest. In this case the thresholds for high and low pulses are 88.68 cfs for high pulses and 5.01 cfs for low pulses. On average these pulses occur 6.67 times for low pulses and 8.14 for high with average durations of 19.37 days and 4.30 days respectively[1].

100 Year Flood:

USGS Stream Stats was used to estimate the 100 year flow to be 1800 cfs, at a prediction error of 39%. It was determined that further analysis should be conducted. Based on calculations from the USGS/NHDOT method the 100 year flood flow for the Oyster River dam was estimated to be 1750.14 cfs. Based on the flow values the maximum flow that has occurred happened April 16th, 2007 with a flow of 1572.83 which is 87.37% of the USGS stream stats and 89.87% of the calculated value. These 100 year floods are most likely conservative. Due to this a bulletin 17B can be utilized to produce a lower flow for the 100 year flood however the conservative values are recommended.

Sources of Error

The methods used produces approximate flows that could possibly occur at the Oyster River dam. Two main sources of error that could change the results are as follows. First, is that the watershed scaling used, makes the assumption that due to the size of scale, these watersheds are affecting all watersheds. Since this assumption was made it neglects that any tributaries that enter the Oyster River after the stream gauge may have an adverse effect on the actual flow regime at the dam. The second source of error for these data is caused by a canal that was not completed during 1800's that was supposed to connect the Oyster and Lamprey rivers. Though it was not completed the low-lying area that resulted during extreme storms could cause water from the Lamprey to flow into the Oyster River, therefore increasing the actual flow.

Conclusion

Including the sources of error mentioned these approximate flows determined are within tolerable bounds for the use of the hydrologic analysis. These values were also used in the analysis of hydropower generation and are also acceptable for the use of that analysis as well. If further investigation is determined to be required for the 100 year flood upon further analysis a bulletin 17B utilizing the watershed scaling should be utilized. The recommendation of the 100 year flood value to be used is 1750 cfs for continuing the design of the structural rehabilitation of the dam.

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[1] All IHA graphs and data in appendix

Hydropower

In addition to the proposed structural rehabilitation plans of the dam, a hydropower installation feasibility report has also been prepared. The initial capital costs as well as, the cost of labor, materials, equipment, and maintenance were assessed. The range of costs and benefits associated with the hydropower process and determination of the economic feasibility of installing hydropower was also assessed for the Oyster River Dam.

Several methods can be used to generate electricity using a river; many turbine designs are associated with these generation methods. The Oyster River Dam site is has a low head and medium flow rate; a "reaction turbine" was determined to be most suited for use. This type of turbine draws energy from the pressure drop of a fully immersed water turbine. Specifically an Archimedean screw, or Hydrodynamic Screw, hydro generator was chosen. Although this turbine is not considered a traditional reaction turbine due to its partial immersion, it still draws energy from the pressure drop between the higher and lower water levels flowing over the dam, and will continue to work at low flows.

The Archimedean Screw generator was chosen for the following reasons. The flow rate vs. mechanical efficiency of the Archimedean Screw has an efficiency of 90% at maximum flow rates, and holds this level of efficiency to flow rates 50% the maximum flow. This quality gives the Archimedean screw a large advantage due to the varying flow rate levels experienced by the Oyster River Dam. When flows drop below half the maximum flow, the efficiency can be retained using a braking control system that controls the speed of the screw. The system is also robust due to its slow operational speed, which lowers maintenance costs. The generator also has environmental benefits such being fish friendly because of the slow speed and wide blade placement; and that the open-air design oxygenates the downstream water. These benefits led to the decision to use the Archimedean Screw as hydroelectric generator on site.

Once the generator was selected, approximate yearly energy outputs were calculated. The equation used to calculate the potential power in a hydroelectric generator is:

$$P = HQg\eta$$

P = Power generated (kW)
H = Head of dam (m)
Q = Flow (m^3/s)
g = Gravitational acceleration (9.81 m^2/s)
η = Generator efficiency

In this case the head differential of the dam is difficult to determine due to the downstream's tidal nature. To compensate for this the generator was designed for the minimum net head of approximately 1.8 meters.

The flows were determined using data compiled and analyzed from USGS. The flow duration curve determined by the hydrologic analysis estimated an average flow over the dam to be about 0.77 m^3/s.

Before the design of the generator, the use of the generated power was needed to be determined. It was decided that two scenarios were possible; the powering devices on site (such as pond aerators) or sale of generated energy to PSNH.

In the first scenario, the screw is only used to power devices on-site, such as lights illuminating the spillway or water aeration devices in the pond to increase the dissolved oxygen concentration in Mill Pond. A relatively small screw would be best suited to the situation. The advantages of the smaller screw are a lower capital cost in conjunction with a capacity to operate at lower flows than a larger screw. This allows the screw to operate longer at a higher capacity than a larger screw. A conservative flow rate of 0.7 m^3/s was used to design the screw, which required a diameter of 1.2 meters in order to operate. This design supplies 1 kW of power approximately 75% of the year, and would cost about $170,000 for purchase and installation.

The second scenario with potential revenue generation from the energy sold required an in-depth financial analysis to examine the feasibility of selling the energy. In this case conservative design flows could also be used to design a smaller screw and reduce initial capital costs; however a smaller screw generates less power and consequently less revenue. Therefore a small screw based on a conservative design flow was not utilized.

Several tradeoffs must be considered when sizing the screw to generate the most energy. Mechanical efficiency screw is approximately 85% when the flow through the screw is low compared to the designed flow rate, when the flow rate is below about 30% of the designed flow rate the efficiency does drop significantly. This means that a smaller design will be more efficient when the flow over the dam is low, where a larger screw may not be able to produce energy. Alternatively, when the flow is higher than the designed flow, a generator cannot utilize the flow optimally. This means that larger screws have the advantage at higher flows, because it uses most of that potential power. A balance must be found in order to produce the most energy throughout the year.

Using MATLAB, it was determined that the design flow which produces the most energy throughout the year is 2.5 m^3/s, which is higher than the average flow over the dam. This design flow does not producing power 30% of the year, due to flows that are too low. This would be an issue if designed to power a household or building, however because only overall sales due to energy generation are considered this is irrelevant. A screw with this design flow would be 1.75 meters in diameter.

The financial feasibility analysis for this screw required two values taken from the MATLAB program; the rated power (maximum power) of the generator, and the total energy generated throughout the year (kWh). Then several assumptions were made for a 40 year life span to include an economic inflation rate of 3%, an electricity inflation rate of 5%, a discount rate of 6%, and a rate of $0.06 per kWh for selling energy to PSNH. Utilizing software that was programed should these values need to be altered the below computations can be easily recalculated.

For a copy of this programming code see appendix.

A 40 year Life Cycle Cost (LCC) analysis was run for the lifespan of the Archimedean screw. The initial capital cost of this screw would be $242,130. From this the program utilized determined a negative LCC of $184,412; meaning that over a 40 year period, the generator would accumulate net revenue of $184,412. The Simple Payback period, in which the generator would pay itself off, would be 36 years. Using this information it can be derived that a larger screw may not be the best investment, but would eventually make the town a profit.

In order to verify that the values above are the most optimal trial and error of other design flows was conducted finding that a screw designed using a flow of 1.6 m^3/s is the most cost efficient design. Over 40 years life cycle it was determined to have a negative LCC value of $230,100. This is better than the original design utilizing a flow 2.5 m^3/s financially because though the larger screw outputs more energy annually, it has a higher capital cost. The design flow of 1.6 m^3/s has the optimum balance of capital cost and overall revenue over forty years.

If a combination scenario was analyzed, in which the Town powered a pond aerator while selling the remaining energy. This would provide revenue from the surplus energy sold, however because power must be used for the aerator, the profit margin from the previous analysis is reduced. It was found that although the capital cost of the aerator is insignificant compared to that of the screw, the reduced surplus energy significantly reduces the revenue of the generator over 40 years. If the LCC analysis from before was performed including one aerator, over 40 years a system with a design flow of 1.6 m^3/s would profit $5,745, while a system with a design flow of 0.7 m^3/s costs $19,700. This makes a combination scenario infeasible and a situation to be avoided.

After performing these feasibility analyses, it is clear that an Archimedean screw hydroelectric generator on the Oyster River Dam is a financial risk when trying to sell the energy. Though the larger generator would eventually produce a profit, the simple payback period is close to the end of the lifespan of the screw. If weighing the decision to sell, the Town should attempt to take certain measures to mitigate the disadvantages of the project.

First, the Town should attempt to enter into a private agreement with PSNH if they expressed interest to sell. The rate of electricity sold was fairly low in this estimate—if the Town could barter a rate higher than $0.06 per kWh from PSNH energy sold, the revenue gained would be higher and would become more feasible. Additionally, financial incentives for those participating in renewable energy projects within New Hampshire exist. The Renewable Energy Grant given by the NH Public Utilities Commission, up to $1,000,000, for new hydroelectric projects is one such example. If the Town were to secure a grant such as this, feasibility of the project would not be a problem.

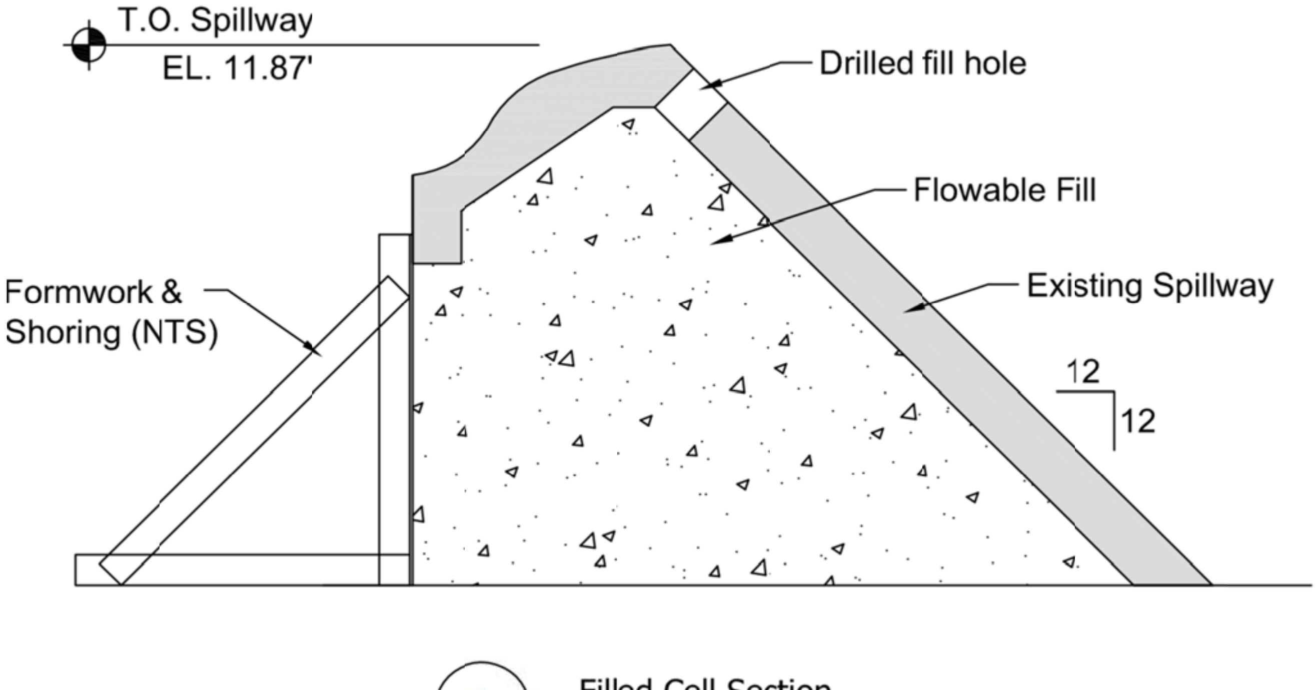
Other benefits to installing this Archimedean screw at the Oyster River site exist. Archimedean screw generators are uncommon in the United States and could become an attraction to the town, drawing positive attention to both the generator and the history of the Oyster River Dam. In doing so it would also become an educational site for UNH and other students. Environmental selling points such as it's the fish-friendly nature and the incorporation of the water aerators to increase the dissolved oxygen concentrations in Mill Pond also exist. Due to all of the benefits listed instillation of this system should be further considered and investigated by the town.

Structural Rehabilitation

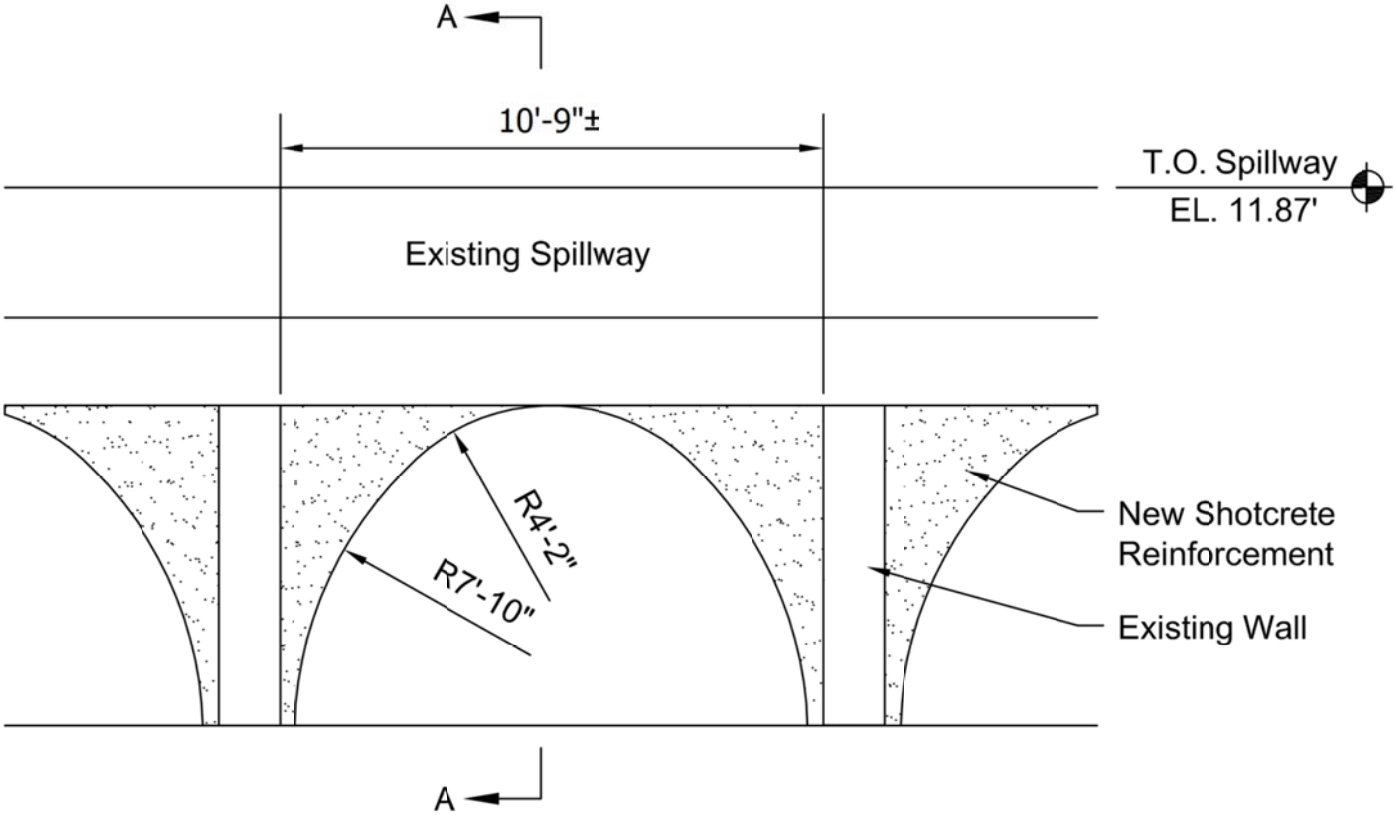
Structural rehabilitation of the Oyster River Dam was broken down into two areas of focus: the spillway and the gate structure. For reinforcing the spillway, there were three options up for consideration.
The first option was to reinforce with a topcoat over the existing spillway following surface preparation. This option requires the least amount of material with only 9 cubic yards required for a 2” topping coat. Surface preparation would be extensive to provide the best adhesion between the existing spillway and the new concrete. Delamination would be the biggest structural concern. Also, this new topcoat would raise the height of the dam. Concerns regarding the effect on abutters as well as 100 yr. flood overflow and permitting makes this course of action unfeasible.

The second option was filling the bays under the spillway completely with concrete. This would be accomplished by blocking the front of the cell and pumping in flowable fill through a hole drilled in the back of the spillway (Figure 1). The volume of each cell averages 32 cubic yards (found using AutoCAD model), and so would require a total of 256 cubic yards of concrete to fill. This is the largest volume of material required of the three options. Filling the cells completely with concrete, though effective, would eliminate the rib and cell construction that is one of the defining features of an Ambursen Dam.

The third option was to construct an arch reinforcing structure in each bay underneath the spillway. The arch would be constructed using shotcrete over a steel reinforcing cage built into each cell. The arch formed would follow a dual-radius arch for aesthetics. (Figures 2 and 3). The volume of shotcrete required is approximately 16 cubic yards per cell, for a total required volume of 128 cubic yards.

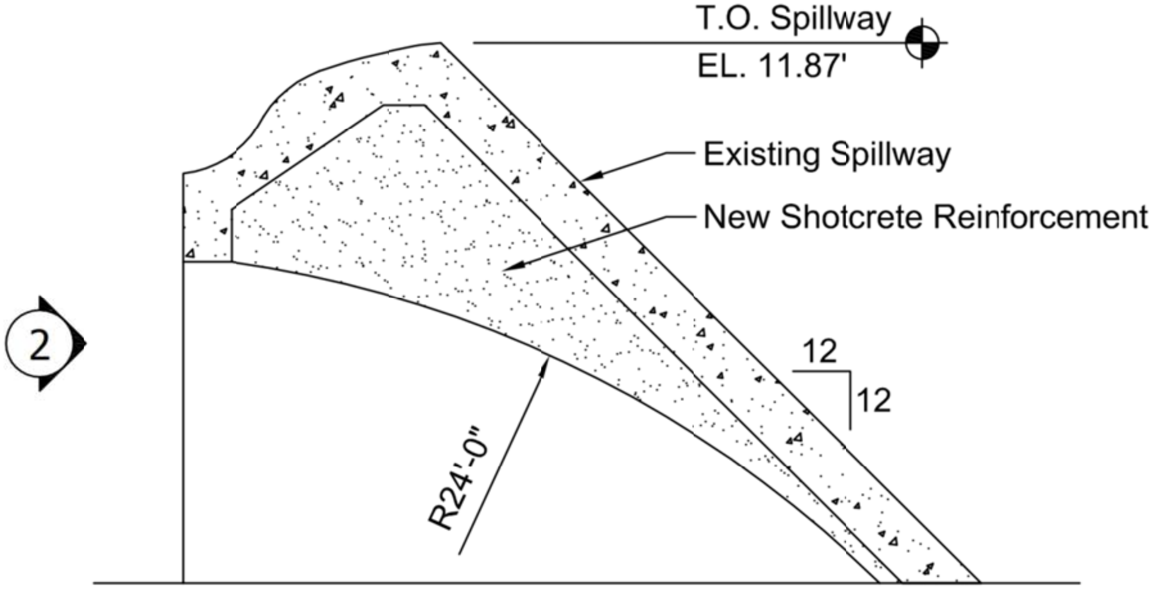


1 Filled Cell Section
Scale: 1/4" = 1'-0"



2 Elevation

Scale: 1/4" = 1'-0"



3 Section A-A

Scale: 1/4" = 1'-0"

In order to pick an option for recommendation, a design matrix was used. Considerations included feasibility, effectiveness of structural reinforcement, affects to the dam's aesthetics and cost of rehabilitation. The resulting matrix can be seen below in Table 2.

Table 2: Design Matrix

	Feasibility	Structural Reinforcement	Maintains Aesthetics	Cost	Total
New Top Coat on Spillway	1	2	3	2	8
Fill Bays w/ Concrete	3	3	1	1	8
Arch Reinforcement	3	3	3	3	12

1: Poor/Not Applicable
2: Fair
3: Good

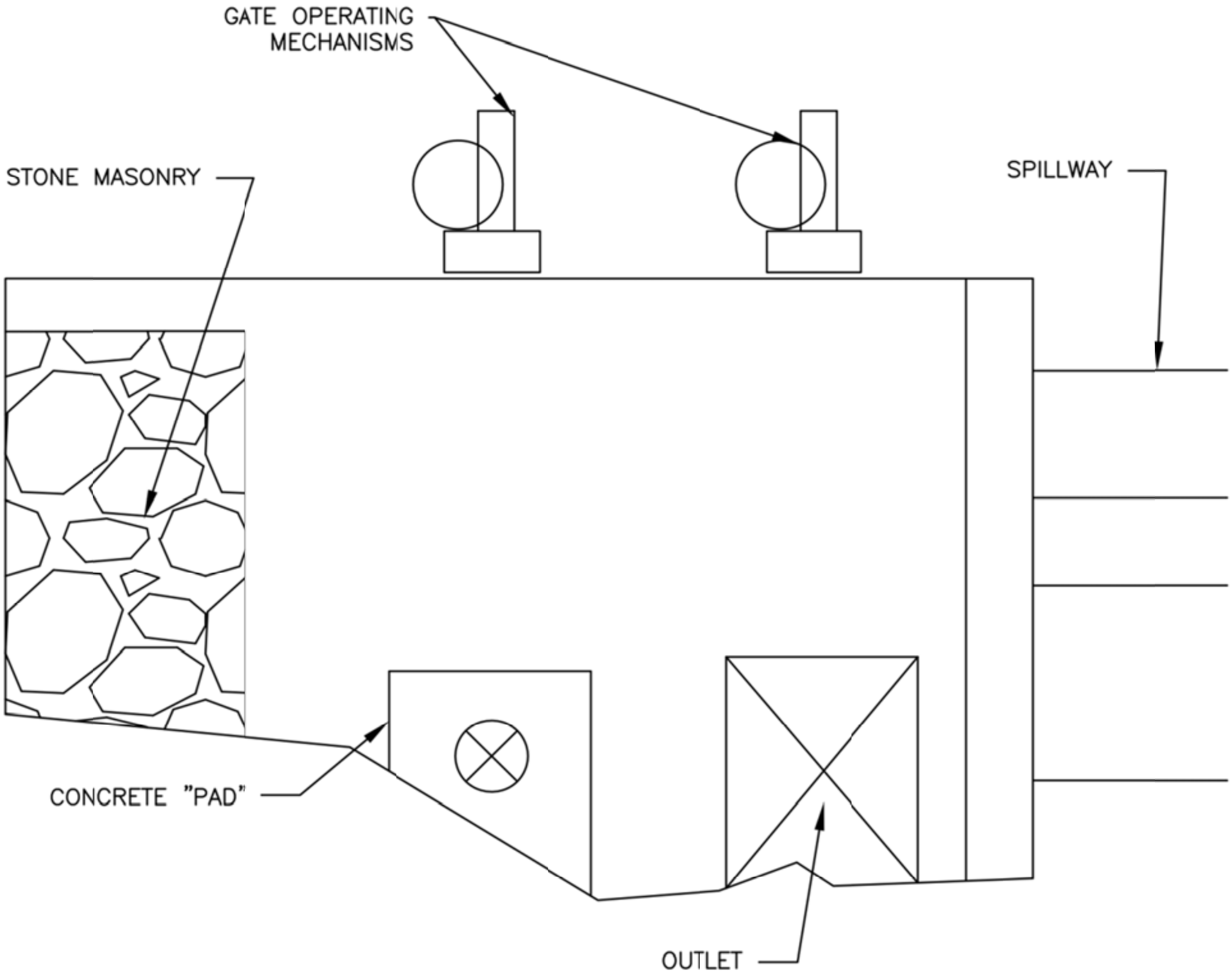
Thus, after considering all factors, it is recommended that the spillway be reinforced using the third option of an arch reinforcing structure.

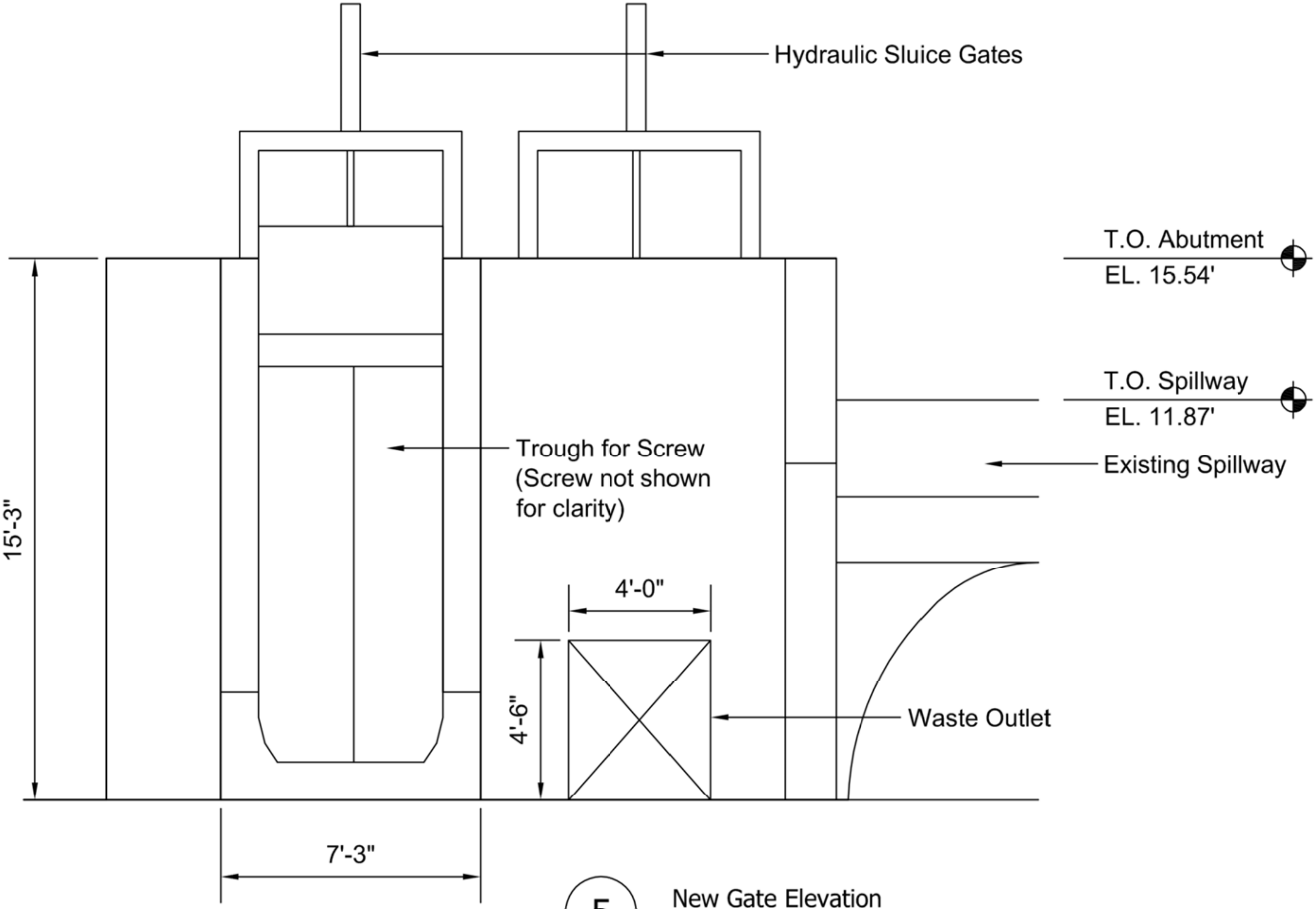
Gate Structure

The existing gate structure requires replacement. The existing gate structure houses two outlets, one 4ft wide by 4.5ft tall waste gate, and one 12 inch diameter corrugated metal pipe. These outlets are controlled using manually operated gates (Figure 4).

The new gate structure was designed to largely match the original, with the exception of a new trough added to house an Archimedean screw (Figure 5). In order to accommodate the flow from the 100yr flood, the right abutment/gate structure needed to be raised 1ft 10in. The outlet formed for the Archimedean screw will replace the pipe outlet in the existing gate structure. The supplemental waste outlet dimensions match the original. Two hydraulic sluice gates are used in place of the existing manual ones. One sluice gate is used to control the flow approaching the Archimedean screw generator, whereas the other one is used to operate the supplemental outlet.

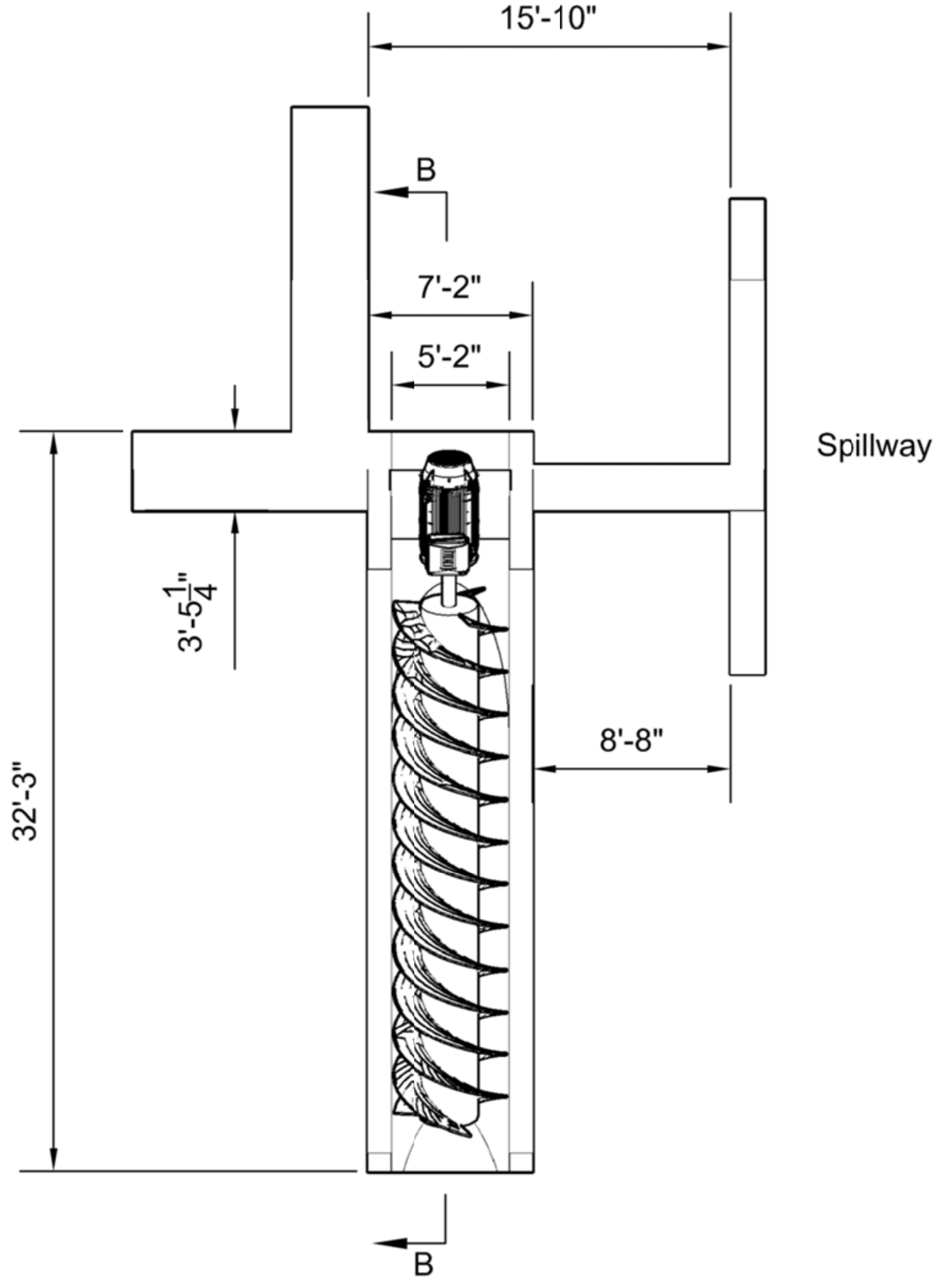
The additional structure required to house the Archimedean screw will be constructed using steel reinforced cast in place concrete. The trough in which the screw sits is to be formed at a 22 degree angle from horizontal as required for the screw generator. This new structure will have a footprint of 7ft 2in wide by 32ft 3in long (Figure 6).


GATE OPERATING MECHANISMS
STONE MASONRY
SPILLWAY
CONCRETE "PAD"
OUTLET



5 New Gate Elevation

Scale: 1/4" = 1'-0"



6 New Gate Plan
Scale: 1/4" = 1'-0"

Installation method

When the oyster river dam was first constructed in 1913, construction workers diverted water through the middle of the construction site and built the dam from the sides to the middle. Once concrete was set, water was then diverted over the spillway and the middle of the dam was finished. This method can be modified using sandbags to divert water around each cell. However, using the shotcrete is a very fast process. Construction workers will be moving from cell to cell at a relatively fast pace, faster than water diversion could be modified. Because of this, construction on the spillway must be done at once. If all water is first diverted over the spillway so that the gate structure can be removed and a temporary channel (wood/metal) can be installed to handle all flow, the spillway can be dried and construction on all the cells can be done at one time. This process must be done at an extremely low flow so that the temporary channel can handle all water, such as during dry summer months. After the shotcrete is set, water can be redirected back over the spillway and then construction on the Archimedean screw and gate structure can commence.

Permitting

In order to implement the generation of electric power at the Oyster River Dam site, consultation with the Federal Energy Commission (FERC), is necessary. The commission regulates the interstate transmission of electricity, hydropower and natural gas and oil amongst other things. The Oyster River dam site and our goal to implement a low head, hydropower generator falls within the guidelines of the small/low impact hydropower program of FERC. This program is intended for small projects that result in minor environmental effects. Minor environmental effects is defined by FERC as little changes to water flow and unlikely to affect threatened or endangered species.

The first step for licensing is to obtain a preliminary permit. This permit can be used up to three years and it grants priority to study conditions of the dam and changes in hydrologic conditions. With this permit, submission of reports containing activities and dates is required. Along with the preliminary permit, FERC requires consultation with federal, state, interstate and non-governmental agencies prior to construction or rehabilitation of any dam site, in order to address any adverse ecologic or hydrologic impacts that may affect the surrounding area.

The site falls under the 5 Mega-Watt exemptions that FERC offers for non-federal, pre 2005 dams that generate 5MW or less. In order to obtain the exemption, mandatory federal and state fish and wildlife conditions must be met. This requires consultation with US fish and wildlife services, national marine fisheries services and state wildlife agencies. Each agency must determine the prevention and or loss to damages to resources. Along with this, a license adhering to the federal reservation conditions under section 4(e) of the FPA must be obtained along with a license adhering to fish way prescriptions under section 18 of the FPA, 16 U.S.C. § 811. FERC recommends using the traditional licensing process (TLP) when consulting with outside agencies in order to complete the required criteria for the exemption. Project boundaries must also be included in a report submitted to FERC, which includes all associated lands and facilities, such as the powerhouse, dam, impoundment, transmission line, and any lands that fulfill a project purpose (*e.g.*, recreation, resource protection, and access roads). Implementing statutes must be followed when filing for the 5MW exemption under the Public Utility Regulatory Policies Act. Prerequisites include addressing the safety of the dam by the commission, provided opportunity for consultation with council on environmental quality and EPA.

The New Hampshire Department of Environmental Services must also be contacted prior to the rehabilitation of the Oyster River Dam. The applicability of the NHDES dam permit applies to non-permitted existing dams and the repair and reconstruction of dams. An application to reconstruct a dam, including an application relative to emergency measures described in Env-Wr 401.02(a)(2), must be filed by the owner(s) of the dam. An application to register the dam must be filed by the property owner(s) on which the proposed dam is located. A filing fee of $2,000 is also required along with the application. NHDES then inspects the site and structure to classify it as a low hazard structure, significant hazard or high hazard. Based on the classification, an annual registration fee is determined. This fee is aimed towards the protection and safety of residents downstream from the dam site if a failure were to happen. Once construction is approved, the project becomes contingent with the Wetlands Bureau.

Options for Controlling 100 Year Flood

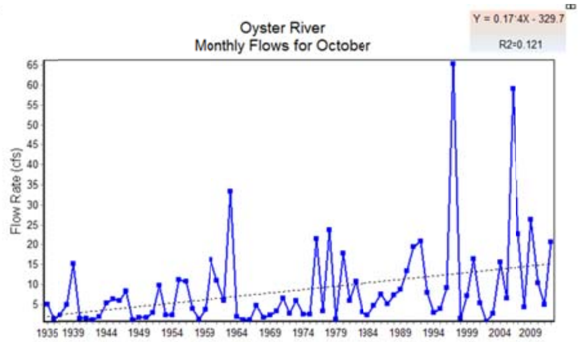
During the case of an extreme storm event, flooding occurs on the gate structure side of the dam and overflows into the adjacent yard. Necessary means must be considered to prevent flooding and to control and direct the river downstream without overflow. One option to consider would be to build an embankment or retaining wall. This is an advantageous method because the wall will only need to be 2 feet high and would be low in costs. Another option would be to install an underground drainage system, which would direct the excess water underground with the exit being on the downstream side of the dam. A more expensive option, but equally effective method to preventing flooding would be to install a hydraulic gate in the first bay of the dam. This could be achieved by removing the concrete spillway over the first bay and replacing it with a hydraulic gate. During the case of an extreme storm event, the gate would be able to open allowing for extra flow to move downstream, without overflowing into the adjacent property.

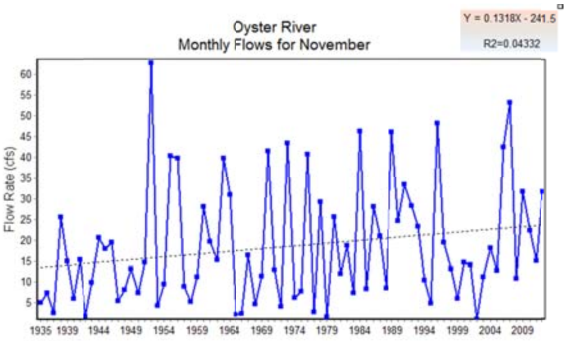
Conclusions and Recommendations

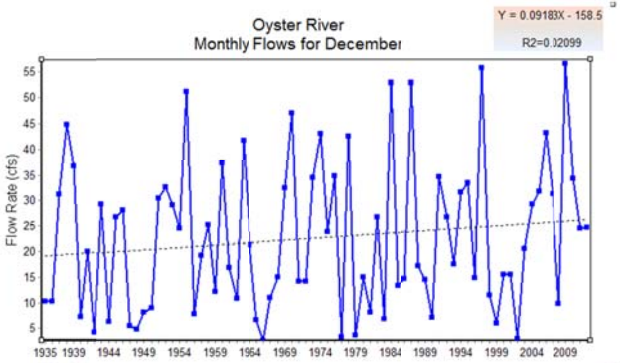
The Oyster River Dam is structurally deficient and the gate structure is structurally obsolete and must be replaced. Due to the concrete cracking on the underside of the spillway, a solution to reinforce the structure was necessary. In order to maintain the historical aspect of the structure, while adding structural support, it is recommended that an arch reinforcing structure be constructed under each bay. The arch would be constructed using shotcrete over a steel reinforcing cage and built into each cell. The arch formed would follow a dual-radius arch for aesthetics. (Figures 2 and 3). To implement this, it is recommended that the gate structure be taken out first, redirecting the flow away from the spillway. Upon completion of reinforcing the bays, the gate structure with the Archimedes screw will be installed, with flow being directed over the finished spillway. After completing a hydrologic analysis, and determining monthly average flows, it was concluded that the best option for the implementation of hydropower would be an Archimedes screw. This form of hydropower has relatively low maintenance costs, is environmentally friendly and is an efficient mechanical process. The Archimedes screw is not common in the United States and would provide an educational opportunity for UNH students as well as town's people. One method of conveying information to visitors would be to install a plaque or bulletin, detailed with images and text, explaining the historic significance of the dam, the rehabilitation process and also information on the Archimedes screw. With regards to power generation, it is recommended that the electricity be used on site for powering oxygen air diffusers within Mill pond and lighting the dam at night. Stephen Burns', the abutter to the site, owns the power rights and excess power could be redirected to his home. The Oyster River dam is a historic piece of engineering and ingenuity, representative of hard work and advances in technology in Durham and the surrounding area and should be preserved.

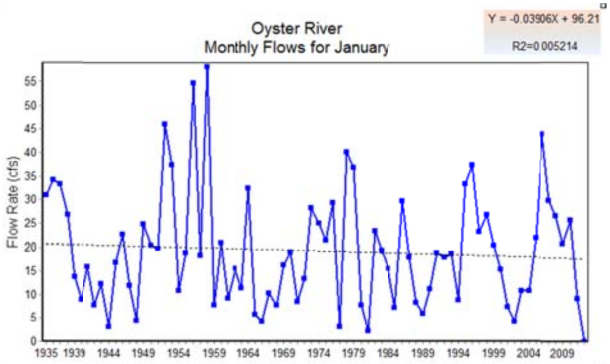
Appendix

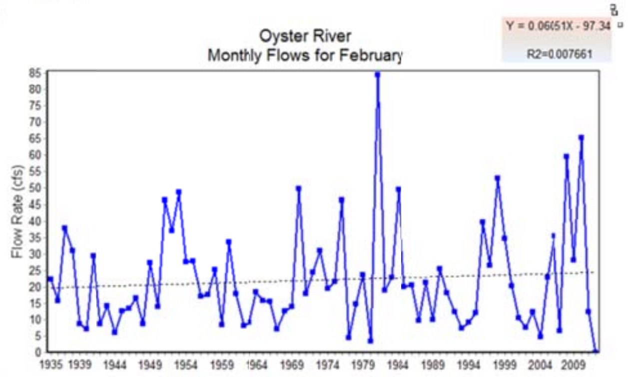
A.) IHA Graphs for USGS 01073000

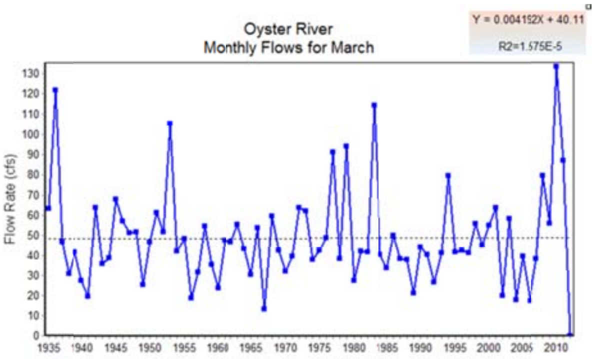


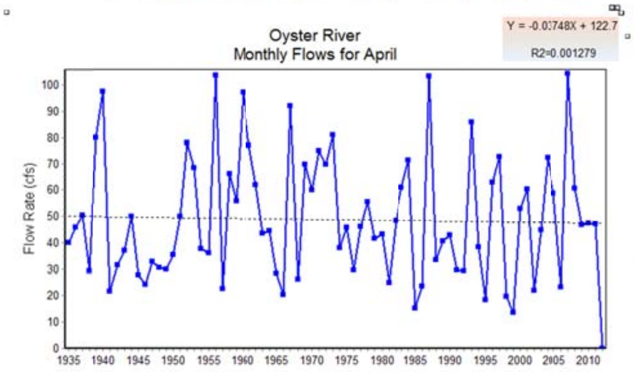


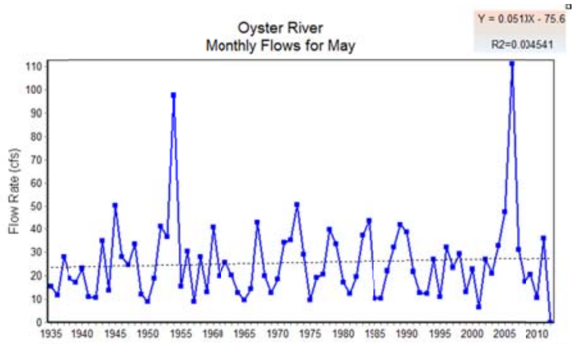


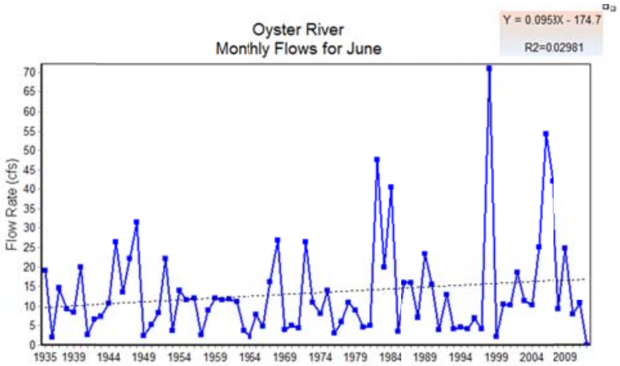


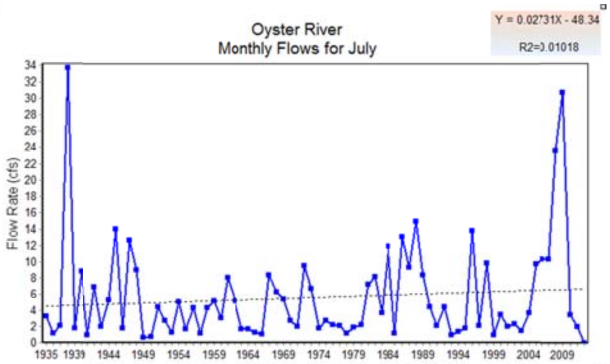


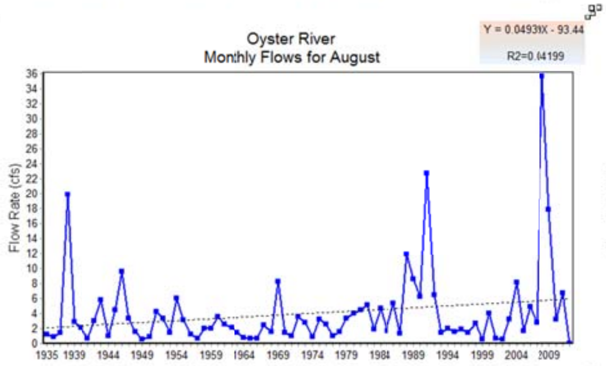


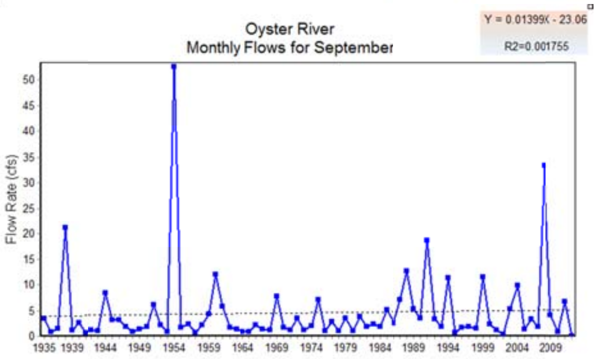


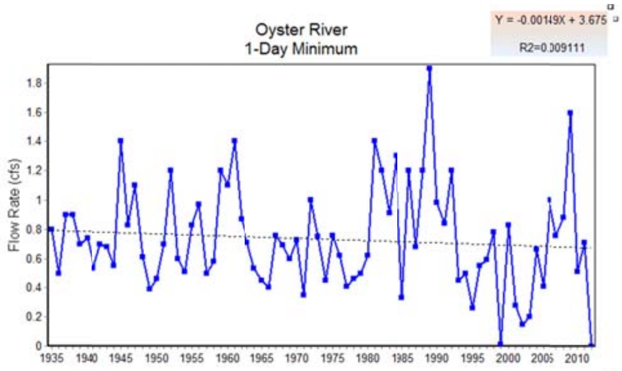


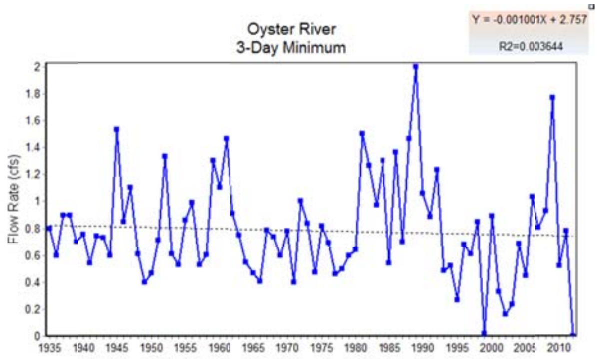

Oyster River
Monthly Flows for June
Y = 0.0953X - 174.7
R2=0.02981
Flow Rate (cfs)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

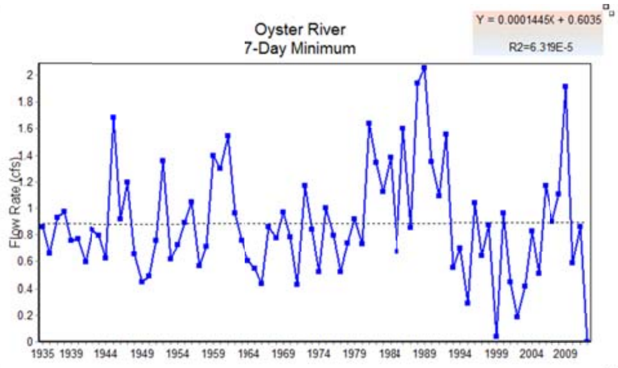

Oyster River
Monthly Flows for July
Y = 0.02731X - 48.34
R2=0.01018
Flow Rate (cfs)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

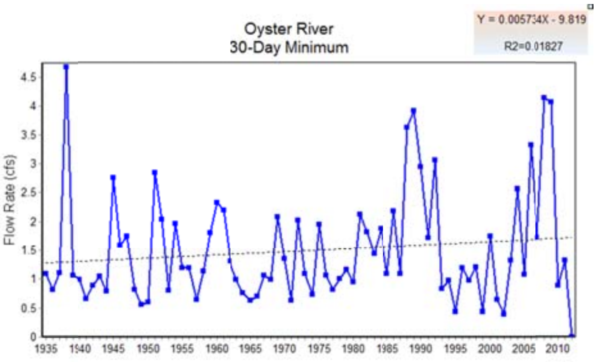

Oyster River
Monthly Flows for August
Y = 0.04931X - 93.44
R2=0.04199
Flow Rate (cfs)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

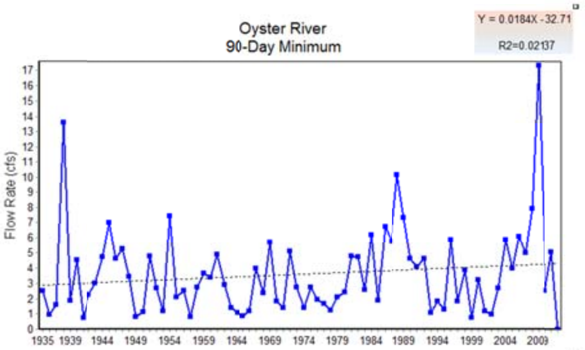

Oyster River
Monthly Flows for September
Y = 0.01399X - 23.06
R2=0.001755
Flow Rate (cfs)
0
5
10
15
20
25
30
35
40
45
50
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

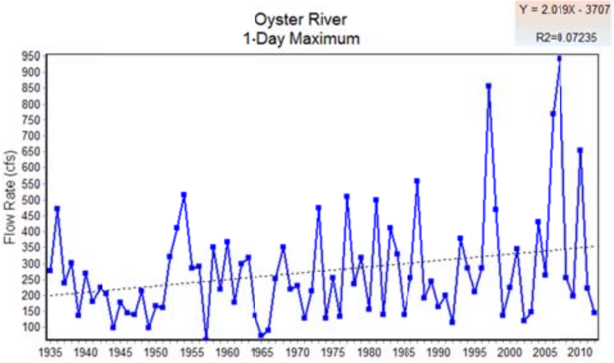

Oyster River
1-Day Minimum
Y = -0.00149X + 3.675
R2=0.009111
Flow Rate (cfs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

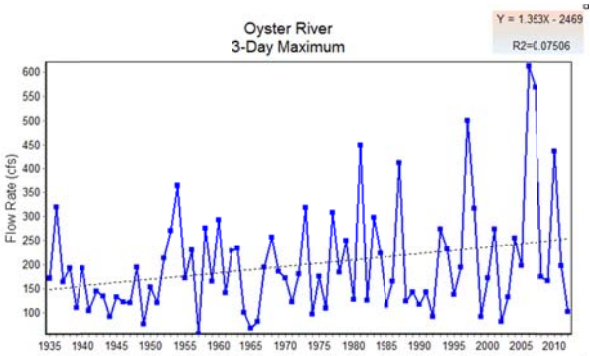

Oyster River
3-Day Minimum
Y = -0.001001X + 2.757
R2=0.003644
Flow Rate (cfs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

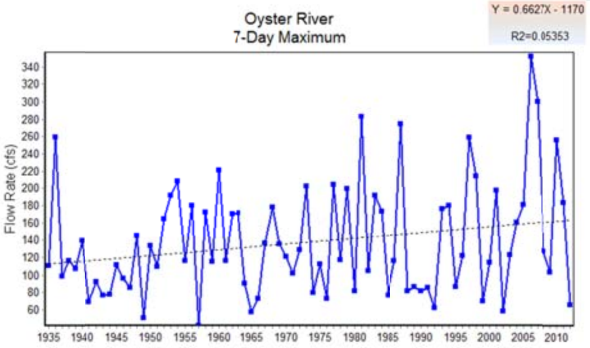

Oyster River
7-Day Minimum
Y = 0.0001445X + 0.6035
R2=6.319E-5
Flow Rate (cfs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

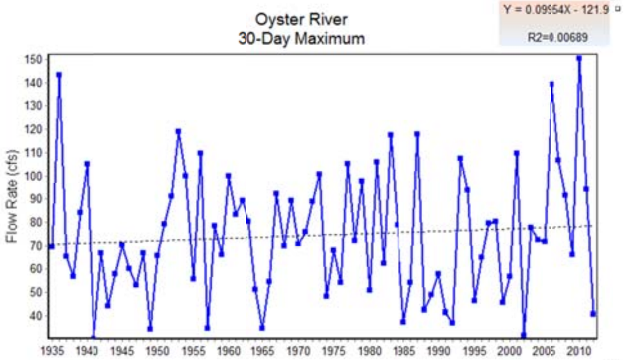

Oyster River
30-Day Minimum
Y = 0.005734X - 9.819
R2=0.01827
Flow Rate (cfs)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

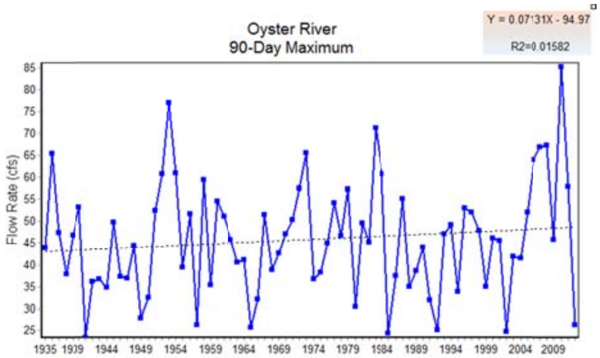

Oyster River
90-Day Minimum

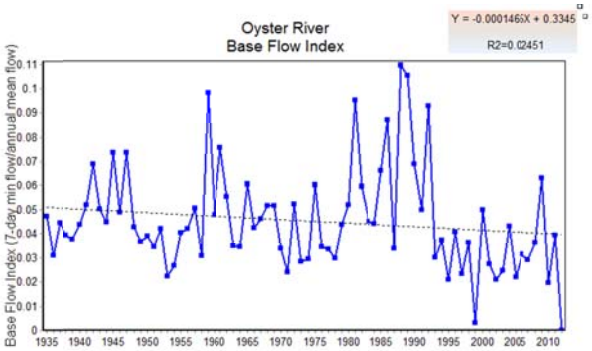

Oyster River
1-Day Maximum

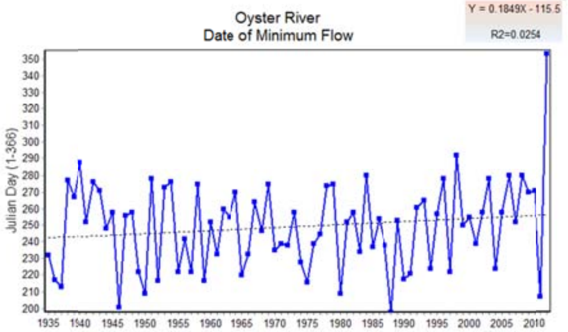

Oyster River
3-Day Maximum

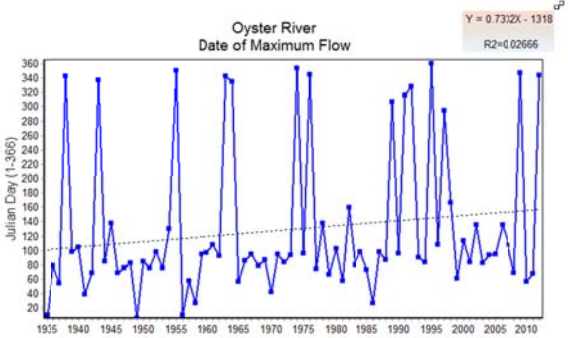

Oyster River
7-Day Maximum

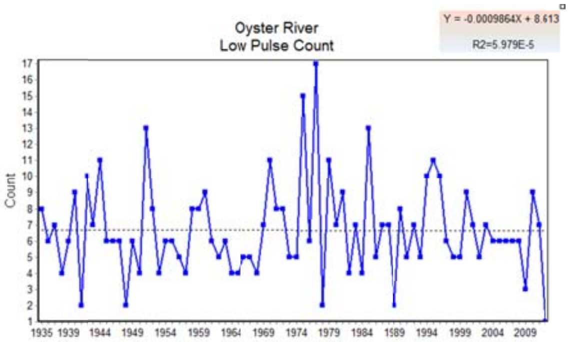

Oyster River
30-Day Maximum

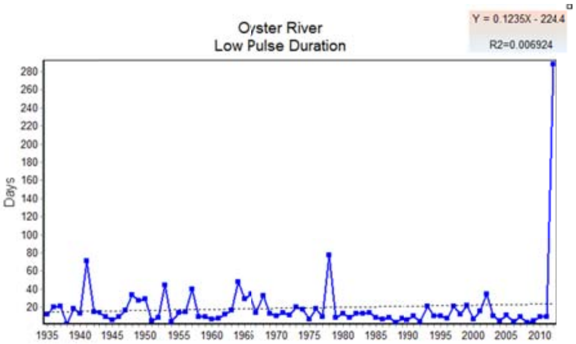

Oyster River
90-Day Maximum

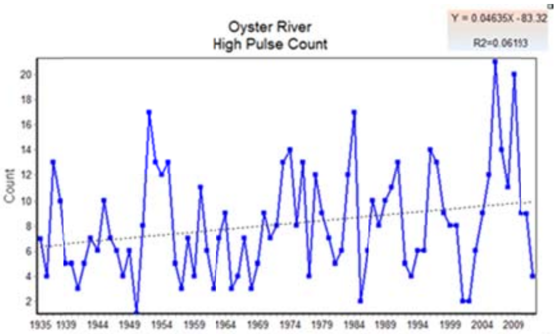

Oyster River
Base Flow Index

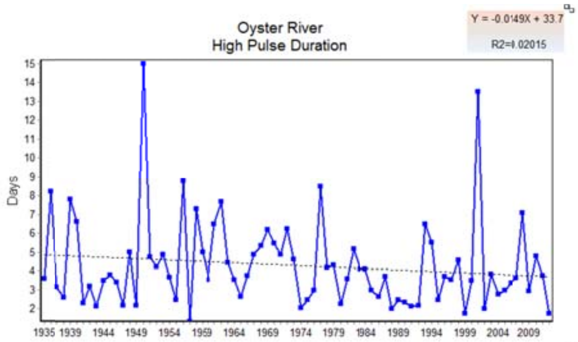

Oyster River
Date of Minimum Flow

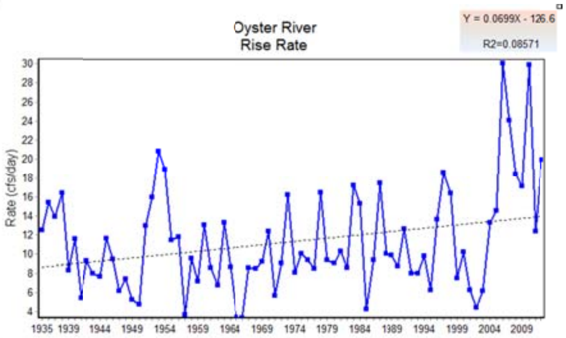

Oyster River
Date of Maximum Flow
Y = 0.7312X - 1318
R2=0.02666
Julian Day (1-366)
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

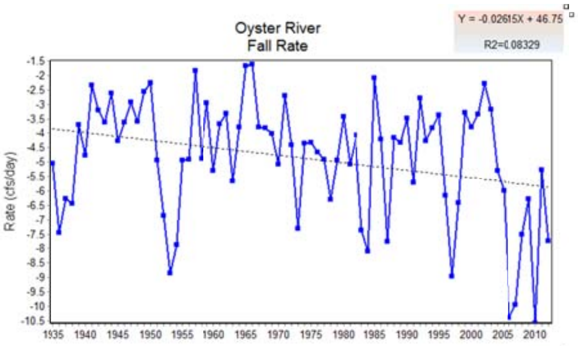

Oyster River
Low Pulse Count
Y = -0.0009864X + 8.613
R2=5.979E-5
Count
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

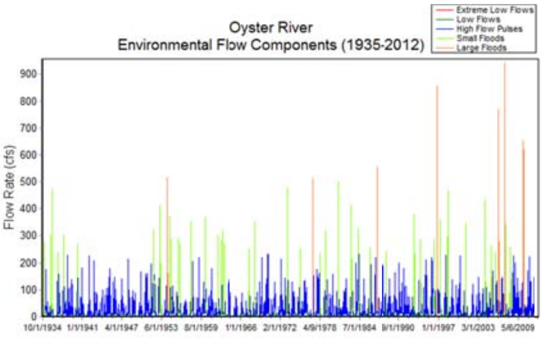

Oyster River
Low Pulse Duration
Y = 0.1235X - 224.4
R2=0.006924
Days
280
260
240
220
200
180
160
140
120
100
80
60
40
20
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Oyster River
High Pulse Count
Y = 0.04635X - 83.32
R2=0.06113
Count
20
18
16
14
12
10
8
6
4
2
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009


Oyster River
High Pulse Duration
Y = -0.0149X + 33.7
R2=0.02015
Days
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

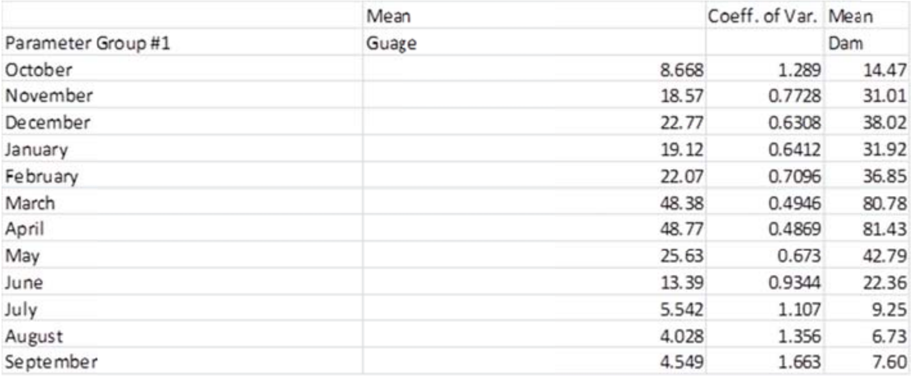

Oyster River
Rise Rate
Y = 0.0699X - 126.6
R2=0.08571
Rate (cfs/day)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
1935
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009


Oyster River
Fall Rate
Y = -0.02615X + 46.75
R2=0.08329
Rate (cfs/day)
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Oyster River
Environmental Flow Components (1935-2012)
Extreme Low Flows
Low Flows
High Flow Pulses
Small Floods
Large Floods
Flow Rate (cfs)
900
800
700
600
500
400
300
200
100
0
10/1/1934
1/1/1941
4/1/1947
6/1/1953
8/1/1959
1/1/1966
2/1/1972
4/9/1978
7/1/1984
9/1/1990
1/1/1997
3/1/2003
5/6/2009

B.) IHA Analysis

	Period of Analysis: 1935-2012 (78 years)
Watershed area	1
Mean annual flow	20.1
Mean flow/area	20.1
Annual C. V.	1.64
Flow predictability	0.33
Constancy/predictability	0.48
% of floods in 60d period	0.37
Flood-free season	7

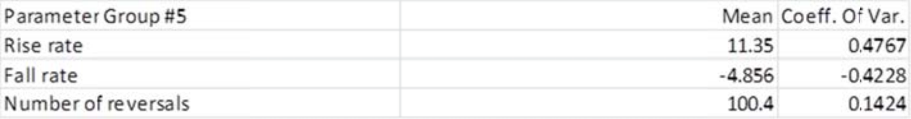


	Mean	Coeff. of Var.	Mean
Parameter Group #1	Guage		Dam
October	8.668	1.289	14.47
November	18.57	0.7728	31.01
December	22.77	0.6308	38.02
January	19.12	0.6412	31.92
February	22.07	0.7096	36.85
March	48.38	0.4946	80.78
April	48.77	0.4869	81.43
May	25.63	0.673	42.79
June	13.39	0.9344	22.36
July	5.542	1.107	9.25
August	4.028	1.356	6.73
September	4.549	1.663	7.60

Parameter Group #2	Guage Mean	Coeff. of Var.	Dam Mean
1-day minimum	0.7347	0.4814	1.23
3-day minimum	0.7818	0.4806	1.31
7-day minimum	0.8886	0.4636	1.48
30-day minimum	1.497	0.642	2.50
90-day minimum	3.601	0.7921	6.01
1-day maximum	277.4	0.6131	463.17
3-day maximum	200.2	0.5587	334.27
7-day maximum	138.2	0.4695	230.75
30-day maximum	74.51	0.3647	124.41
90-day maximum	45.76	0.2808	76.40
Number of zero days	3.692	8.832	
Base flow index	0.04529	0.4683	0.08

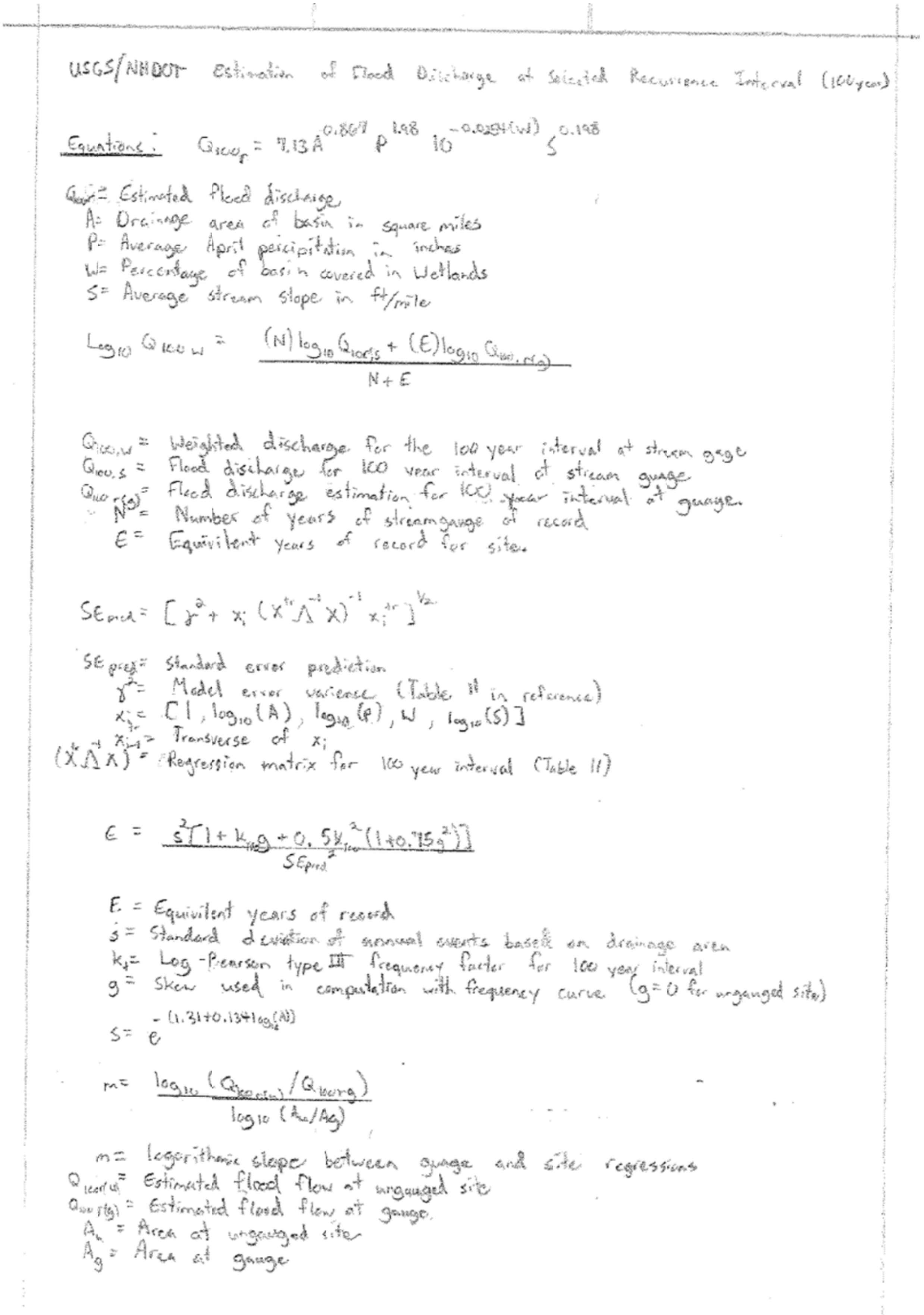
Parameter Group #3		
Date of minimum	249.3	0.07183
Date of maximum	63.26	0.1451

Parameter Group #4	Gauge	Coeff. Of Var.	Dam
Low pulse count	6.67	0.4336	
Low pulse duration	19.37	1.737	
High pulse count	8.14	0.5184	
High pulse duration	4.30	0.5534	
Low Pulse Threshold	3		5.01
High Pulse Threshold	53.11		88.68



Parameter Group #5	Mean	Coeff. Of Var.
Rise rate	11.35	0.4767
Fall rate	-4.856	-0.4228
Number of reversals	100.4	0.1424

C.) Hand Calculations



USGS/NHDOT Estimation of Flood Discharge at Selected Recurrence Interval (100 year)

Equations: $Q_{100_r} = 7.13 A^{0.867} P^{1.98} 10^{-0.0294(W)} S^{0.198}$

Q_{100r} = Estimated flood discharge
A = Drainage area of basin in square miles
P = Average April percipitation in inches
W = Percentage of basin covered in Wetlands
S = Average stream slope in ft/mile

$$\text{Log}_{10} Q_{100w} = \frac{(N)\log_{10} Q_{100,s} + (E)\log_{10} Q_{100,r(g)}}{N+E}$$

$Q_{100,w}$ = Weighted discharge for the 100 year interval at stream gage
$Q_{100,s}$ = Flood discharge for 100 year interval at stream guage
$Q_{100,r(g)}$ = Flood discharge estimation for 100 year interval at guage.
$N^{(s)}$ = Number of years of streamgauge of record
E = Equivilent years of record for site.

$$SE_{pred} = [\gamma^2 + x_i (X^{tr} \Lambda^{-1} X)^{-1} x_i^{tr}]^{1/2}$$

SE_{pred} = Standard error prediction
γ^2 = Model error veriense (Table 11 in reference)
x_i = $[1, \log_{10}(A), \log_{10}(P), W, \log_{10}(S)]$
$x_{i,tr}$ = Transverse of x_i
$(X^{tr} \Lambda^{-1} X)$ = Regression matrix for 100 year interval (Table 11)

$$E = \frac{s^2[1 + k_{100} g + 0.5 k_{100}^2 (1 + 0.75 g^2)]}{SE_{pred}^2}$$

E = Equivilent years of record
s = Standard deviation of annual events based on drainage area
k_t = Log-Pearson type III frequency factor for 100 year interval
g = Skew used in computation with frequency curve (g = 0 for unganged site)
$s = e^{-(1.31 + 0.134 \log_{10}(A))}$

$$m = \frac{\log_{10}(Q_{100 r(u)} / Q_{100 r(g)})}{\log_{10}(A_u / A_g)}$$

m = logorithmic slope between guage and site regressions
$Q_{100 r(u)}$ = Estimated flood flow at ungauged site
$Q_{100 r(g)}$ = Estimated flood flow at gauge
A_u = Area at ungauged site
A_g = Area at gauge

Equations continued:

$$c = m + \frac{\log_{10}(Q_{100r(g)}/Q_{100w})}{\log_{10}(a)}$$

C = Slope of logarithmic line at coordinates
a = percentage of drainage area = 1.5 when $A_u > A_g$

$$Q_{100u} = Q_{100w}\left[\frac{A_u}{A_g}\right]^{c}$$

Q_{100u} = Flood discharge for 100 year flood at site.

Data Given:

Gauge
$A = 12.20$ sq. mi.
$P = 4.18''$
$W = 9.60\%$
$S = 17.90$ ft/mi.

Site
$A = 20.37$ sq. mi.
$P = 4.16''$
$W = 7.59\%$
$S = 15.20$ ft/mi.

Miscellaneous 100 year Discharge Data
$K_g = 2.326$ (Bulletin 17B)
$\gamma^2 = 0.0235$ .. (Table 11)
$Q_{tg} = 1200$ cfs
$N = 72$ years
$a = 1.5$
$(X^T \Lambda^{-1} X)^{-1}$ = * See Table 11
$g = 0$

Calculations:

$$Q_{100r(u)} = 7.13\,(20.37\text{ sq. mi})^{0.867}\,(4.16'')^{1.98}\,(10)^{-0.0254(7.59\%)}\,(15.20\text{ ft/mi})^{0.198}$$

$\underline{Q_{100r(u)} = 1798.91\text{ cfs}}$

$$Q_{100r(g)} = 7.13\,(12.20\text{ sq. mi.})^{0.867}\,(4.18'')^{1.98}\,(10)^{-0.0254(9.60\%)}\,(17.90\text{ ft/mi})^{0.198}$$

$\underline{Q_{100r(g)} = 1069.34\text{ cfs}}$

$$x_i = [1,\ \log_{10}(12.20\text{ sq mi.}),\ \log_{10}(4.18''),\ 9.60,\ \log_{10}(17.90\text{ ft/mi})]$$

$\underline{x_i = [1,\ 1.086,\ 0.621,\ 9.60,\ 1.253]}$

$$SE_{pred} = \left[0.0235 + [1, 1.086, 0.621, 9.60, 1.253]' \cdot \begin{bmatrix} 0.06575E^{-1} & -0.51669E^{-2} & -0.50248E^{-1} & -0.59817E^{-3} & -0.10587E^{-1} \\ -0.51669E^{-2} & 0.13231E^{-2} & -0.13914E^{-2} & 0.10560E^{-3} & 0.19168E^{-2} \\ -0.50248E^{-1} & -0.013914E^{-2} & 0.10452 & -0.36357E^{-3} & -0.56145E^{-2} \\ -0.59817E^{-3} & 0.10560E^{-3} & -0.36357E^{-3} & 0.29263E^{-4} & 0.28972E^{-3} \\ -0.10587E^{-1} & 0.19168E^{-2} & -0.50146E^{-2} & 0.28979E^{-3} & 0.53550E^{-2} \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 1.086 \\ 0.621 \\ 9.60 \\ 1.253 \end{bmatrix}\right]^{1/2}$$

$\underline{SE_{pred} = 0.161}$

Calculations Continued:

$$S = e^{-(1.31 + 0.134\log_{10}(12.20\,\text{sq. mi}))}$$

$$\underline{S = 0.233}$$

$$E = \frac{0.233^2[1+0.5(2.326)(1+\cancel{0.25(0)^2})^0]}{0.161^2}$$

$$\underline{E = 7.81\text{ years}}$$

$$Q_{100w} = \frac{(72\text{ years})\log_{10}(1200\text{ cfs})+(7.81\text{ years})\log_{10}(1069.34\text{ cfs})}{72\text{ years}+7.81\text{ years}}$$

$$\underline{Q_{100w} = 1186.54\text{ cfs}}$$

$$m = \frac{\log_{10}(1798.91\text{ cfs}/1069.34\text{ cfs})}{\log_{10}(20.37\text{ sq mi}/12.20\text{ sq mi})}$$

$$\underline{m = 1.015}$$

$$c = 1.015 + \frac{\log_{10}(1069.34\text{ cfs}/1186.54\text{ cfs})}{\log_{10}(1.5)}$$

$$\underline{c = 0.758}$$

$$Q_{100u} = 1186.54\text{ cfs}\left[\frac{20.37\text{ sq. mi.}}{12.20\text{ sq. mi.}}\right]^{0.758}$$

$$\boxed{Q_{100u} = 1750.14\text{ cfs}}$$

D) Mat LAB

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%          Oyster River Dam Flow Efficiency Calculations           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all;
close all;
%Gross head minus maximum tidal flux:
H = 1.8;
g = 9.81;

%Flow Duration curve from nearby gage:
GageDur = [1.61 1.25 .95 .79 .71 .65 .59 .57 .54 .51 .48 .42 .28 .23 .18 .15 .14 .12 .1];
%Use Watershed Scaling to find Flow Duration at dam, and subtract .15 cms
%for reserve flow:
UseableFlowDur = (1.71*GageDur)-.15; %1.71, new: 1.6 ish

%Hours per each time period from Flow Duration points (adds to 1 year):
SegmentHours = (365.25/length(UseableFlowDur))*24;

%Percentiles for F.D. Curve (x axis):
DamPerc = 5:5:95;
plot(DamPerc,UseableFlowDur);
xlabel('Percent of Time');
ylabel('Flow Rate Q (meters cubed per second)');
title('Flow Duration Curve for Oyster River Dam');

%Eff of gearbox, inverter (because using variable speed screw), etc:
eEff = 0.75;
%Mechanical Eff Curve for Screw for percent of design flow (0% to 100%):
EffPerc = 0:5:100;
mEff = [0 0 .2 .45 .65 .75 .8 .82 .83 .84 .85 .86 .87 .87 .875 .88 .88 .885 .89 .895 .9];
figure
plot(EffPerc,mEff);
xlabel('Percent of Design Flow');
ylabel('Mechanical Efficiency');
title('Archimedean Screw Mechanical Efficiency Curve');

%%%%%%%    DESIGN FLOW RATE    %%%%%%
Qd = 1.6; %%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

TotEnergy = 0;
MaxPower = 0;
power(1:length(UseableFlowDur)) = zeros(1,length(UseableFlowDur));
energy(1:length(UseableFlowDur)) = zeros(1,length(UseableFlowDur));
SumEff = 0;
for i = 1:length(UseableFlowDur)
   %Ratio of flow rate to design flow:
   Qr = UseableFlowDur(i)/Qd;
   %If ratio is over Qd, sluice will automoatically restrict flow
   %to prevent damage to equipment.  Eff is also reduced (churning?):
   if Qr > 1
       %Eff reduced (bc of churning?) linearly if > 100%, zero at 500%:
       Eff = eEff*(1.125-(Qr*0.225));
       Q = Qd;
   else
       %Find the Mech Eff, multiply by Elec Eff for total Efficiency:
       percentile = ceil(Qr*21);
       Eff = eEff*mEff(percentile);
       Q = UseableFlowDur(i);
   end
   %Find average Eff:
   SumEff = SumEff+Eff;
   %Find output power and energy (during block of hours from year: whole
   %duration curve equals 1 year):
   power(i) = H*g*Q*Eff;
   energy(i) = power(i)*SegmentHours;
   %Find total energy in one year (using flow duration curve):
   TotEnergy = TotEnergy+energy(i);
```

```
   %Find max power:
   if power(i) > MaxPower
       MaxPower = power(i);
   end
end
%Find Capacity Factor:
CapFactor = TotEnergy/(MaxPower*24*365.25);
%Find Average Overall Efficiency:
AveEff = SumEff/length(UseableFlowDur);

figure
plot(DamPerc,power)
xlabel('Percent of Time (Flow)');
ylabel('Minimum Power for Time Percentile (kW)');
title('Power (from Flow Duration Curve)');


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  Financial Analysis (Oyster R Dam Archimedean Screw)  %%%
%%%          if Town sells power                          %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
close all;
clear all;

%LCC: Life Cycle Cost analysis: LCC = C + Mpw + Epw + Rpw + Spw
% Over amount of years:
years = 25; %Life cycle of screw?
%US general inflation rate:
r = 0.03;
%US discount rate:
d = 0.06;
%Amount of water aeration units (bubblers)?
a = 0;


%%%%%%   Find C (Capital Cost):   %%%%%%%%%%
%Price per kW (in pounds, three years ago):
PricePer5kW = [5500 4250 3500 3200 2900 2700 2500 2400 2250 2200];
%Price per kW (in dollars, now):
PricePer5kW = PricePer5kW*1.6058*((1+r)^3);
%Power intervals (in kW):
PowerBracket = 5:5:50;
%Input maximum power of screw:
MaxPower = 29.5;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Find screw cost:
if MaxPower > 50
    CScrew = MaxPower*PricePer5kW(10);
else
    CScrew = MaxPower*PricePer5kW(ceil(10*MaxPower/50));
end
%Find cost of bubblers:
CBub = a*2000;
%Assume cost of design, planning, permitting, installation, etc:
CAdditional = 100000;
%Find total capital cost C:
Cpw = CScrew+CBub+CAdditional;


%%%%%%   Find Mpw (Present Worth of O&M):   %%%%%%%%
%From Idaho National Laboratory:
OandMperkWh = 0.007; % 1990-1994: 0.7 cents per kWh
%Current O&M cost:
OandMperkWh = OandMperkWh*((1+r)^20);
TotEnergy = 70300; %kWh  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Mpw = 0;
for i = 1:years
    %Find cost of O&M in specific year:
    Mpwyear = TotEnergy*OandMperkWh*((1+r)^i)/((1+d)^i);
    %Sum together:
```

```
    Mpw = Mpw+Mpwyear;
end


%%%%%%   Find Epw (Present Worth of Future Energy Generation):   %%%%%
%Amount PSNH will pay for surplus energy:
PSNHsurplus = 0.06; %cents paid per kWh now
%Inflation of US electricity:
rE = 0.05;

%Find energy used from bubblers:
BubEnergy = a*24*365;
ESellpw = 0; % $ from selling to PSNH
for i = 1:years;
    %Find future value of energy for each year:
    ESellpwyear = -PSNHsurplus*(TotEnergy-BubEnergy)*((1+rE)^i);
    %Sum together:
    ESellpw = ESellpw+ESellpwyear;
end
%Find total present worth of energy:
Epw = ESellpw;


%%%%%%   Find Rpw (Present Worth of Replacements):   %%%%%%%%
%Assume lifespan of inverter of:
LifeInv = 7; % years
Rpw = 0;
%Find number of inverter replacements needed:
Rnumber = floor(years/LifeInv);
if Rnumber > 0
    for i = 1:Rnumber
        %Future replacement value (assume inverter now is approx $1/W):
        Rfw = MaxPower*1000*((1+r)^(i*LifeInv))/((1+d)^(i*LifeInv));
        %Sum together:
        Rpw = Rpw+Rfw;
    end
end

%%%%%%   Find Spw (Present Worth of Salvage):   %%%%%%%%
Spw = 0;

%%%%%%%%%%%%%%%%   FIND LCC   %%%%%%%%%%%%%%%%%%%%
LCC = Cpw+Mpw+Epw+Rpw+Spw;

%Doing nothing:
LCCnothing = -Cpw*((1+d)^years)/((1+r)^years);

%Net Present Value:
NPV = LCCnothing-LCC;
```

Citations:

Olson, Scott. "Estimation of Flood Discharges at Selected Recurrence Intervals for Streams in New Hampshire." *USGS Science for a Changing World*. 5206 (2008): 1-61. Print.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood-flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston,Va., 183 p., http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html.