River Modelling and Bank Protection Design for the Williamsburg Mill River Greenway

Created by

Fereshta Noori
Marcia Rojas
Laura Rosenbauer
Maya Sleiman

With the Support of Liaisons

Nick Dines
Carl Gustafson
Jim Hyslip
Gaby Immerman
Brett Towler

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Professor Susannah Howe
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Executive Summary

The Mill River Greenway is a proposed multipurpose pathway between the towns of Ashfield, MA and Northampton, MA along the Mill River, a tributary of the Connecticut River. The proposed Mill River Greenway at the Route 9 bend (hereafter referred to as the Bend) between Williamsburg and Haydenville is at risk of bank erosion. To address this concern, our Design Clinic team has collaborated with the Williamsburg Mill River Greenway Committee (WMRGC) this academic year to provide them with a recommendation for river bank-protection at the Bend and adjacent banks.

This report defines the twofold scope of our collaboration with WMRGC. First, it expands on the hydraulic model created by the team to assess two factors: a) The existing conditions of the river at the project site and b) the hydraulic effects of both implementing the considered bank-protection designs and of decommissioning the Brassworks Dam. To create these models, we collected bathymetric data in two main groups, the first defining the Bend area and the second defining the post-dam area. This data then fed into the base model simulating existing conditions. To understand the hydraulic effect of removing the dam, we simulated the dam as an inline structure for existing conditions and removed the structure to simulate the dam removal. Additionally, the team modelled the effect of bank-protection structures on channel location by shifting the channel by the same amount of structure intrusion into the river at bank-full.

Second, this report presents and discusses design selection criteria for bank-protection along different sections of the reach and presents WMRGC with our resulting recommendations for bank-protection. To achieve this, we divided the river reach at the Bend into three zones, each characterized by a range of velocities and bank slopes. We then identified the bank-protection components needed in each zone and a list of alternatives that would meet those needs. We then narrowed down the combinations into two optimum designs for each zone using the appropriate combination of these alternatives as guided by our criteria and the zone needs.

To test the validity of the optimum designs, we integrated them into the hydraulic base model and compared the resulting velocities with the allowable velocities of these alternatives. This

integration resulted in a total ofsix variations of the model covering existing conditions and considered bank-protection designs both with and without the Brassworks Dam.

Accordingly, we determined live staking and stream barbs to be most effective to redirect and reduce the high flows upstream of the Bend. Directly at the Bend and immediately downstream, we recommend a concrete vertical wall armored by riprap to shield the particularly high velocities and support the steep slope.

Acknowledgements

We would like to thank WMRGC members Gaby Immerman, Nick Dines and Jim Hyslip for bringing this project to the Smith campus. Our liaisons, the aforementioned WMRGC members, along with Brett Towler and Carl Gustafson, were essential in many aspects related to our understanding of both the social and technical facets of the project. Specifically, we would like to thank the following liaisons for their technical expertise and guidance.

Brett Towler, Hydraulic Engineer and Fish Passage Engineer with the U.S. Fish & Wildlife Service, was an instrumental part of our development of the HEC-RAS model. Having his perspective was crucial in capturing the essential features during our surveying and consequently developing our hydraulic model. We are also thankful for his work in obtaining water level data for high flow events in the past month. This was a critical piece for the calibration process of the hydraulic model.

The guidance from Carl Gustafson, retired USDA Natural Resources Conservation Service Engineer, was mainly on the bank protection designs, though not exclusively so. Because there was a shorter time to work on developing bank protection designs, Carl’s knowledge in this field allowed us to complete the production and assessment of designs in time.

Nick Dines, Professor Emeritus of UMass Landscape Architecture and Planning, possesses a rich understanding of the Greenway project as a whole and its individual technical components. We appreciate his star attendance at our meetings! His ability to weave in the different components of the project during the meeting was important in making sure that we were aware of the entirety of the project.

We would like to thank Jim Hyslip, Principal Engineer at HyGround Engineering, for his help regarding the technicalities of retaining walls. The retaining wall workshop he generously held supplied us with the needed information to understand how retaining walls fit in our project.

We thank Gaby Immerman, chair of the WMRGC and Landscape & Education Specialist with the Smith College Botanic Garden, for her mentorship in always supplying social context to our project and serving as link between our team and the bigger Williamsburg community. Her leadership in the Greenway project is inspiring!

We would also like to thank Matt Chase, the Associate Project Manager from VHB, and his interest in connecting our work with theirs by referring us to the surveying team from Hill Engineers. We would like to thank Tim Armstrong, Chief Land Surveyor from Hill Engineers, for introducing us to their surveying methods and collaborating with our team on connecting our bathymetry survey data to their land survey data along with technical help regarding error mitigation.

On the Smith College Campus, we received support from various sources, the first was of course Professor Susannah Howe, director of the Design Clinic Program, who set up the project and supported us throughout the year via internal coach meetings, course assignments, and extensive advice in general. Next in our timeline was Professor Bob Newton from the Geosciences Department, who helped us with his expertise on fieldwork instrumentation and lent us the necessary equipment for our site visits. From the Spatial Analysis Lab we would like to thank Jon Caris, Director of the Spatial Analysis Lab, and Tracy Tien, Post-Baccalaureate Spatial Analysis Fellow, for their technical support regarding GIS and GPS equipment and software, as well as lending us the needed equipment. We also thank Lizzie Sturtevant ‘18 for clarifying technical difficulties with the total station equipment. Finally we would like to thank our in-house safety experts Sue Froehlich and Paul Wetzel, without whom the second part of our data collection would not have been possible.

This project was an interdisciplinary effort, and communication between our liaisons, outside mentors, and industry partners provided an invaluable learning experience for developing the deliverables of our model and understanding of the engineering practice.

Contents	Page No.

X. Appendices

LIST OF TABLES

LIST OF FIGURES

I. Introduction & Project Overview

Williamsburg is a town in Hampshire County, Massachusetts, United States (Figure 1) that stretches over an area of 25.7 square miles. In addition to the main village of Williamsburg near the center of town, the town includes another village center, Haydenville. The Mill River flows southeast from Williamsburg village, where the East and West branches join, through Haydenville and eventually into the Connecticut River.

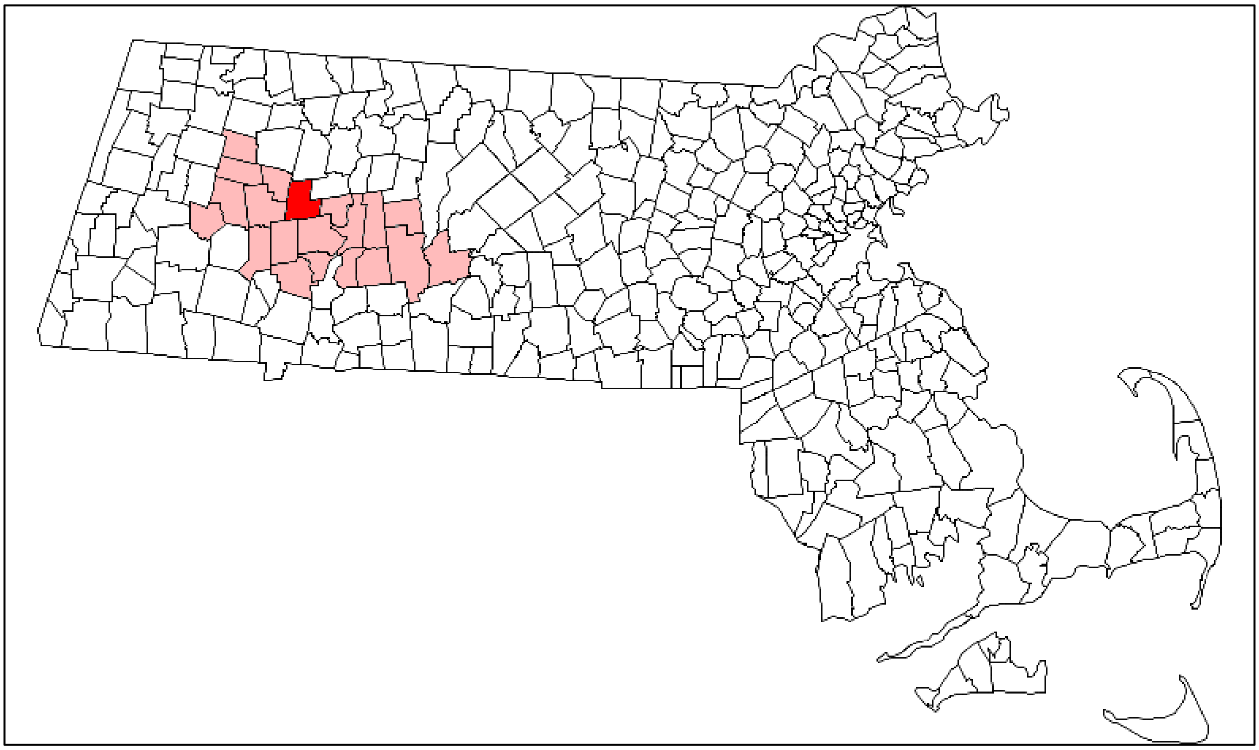


Figure 1. Town of Williamsburg (Red) and Hampshire County (Pink) in the State of Massachusetts

The Williamsburg Mill River Greenway Committee (WMRGC) - a subcommittee within the greater Mill River Greenway Initiative - focuses on creating a multi-use path that stretches along the 2.1 mile corridor connecting the villages of Williamsburg and Haydenville along Route 9 (Figure 2).

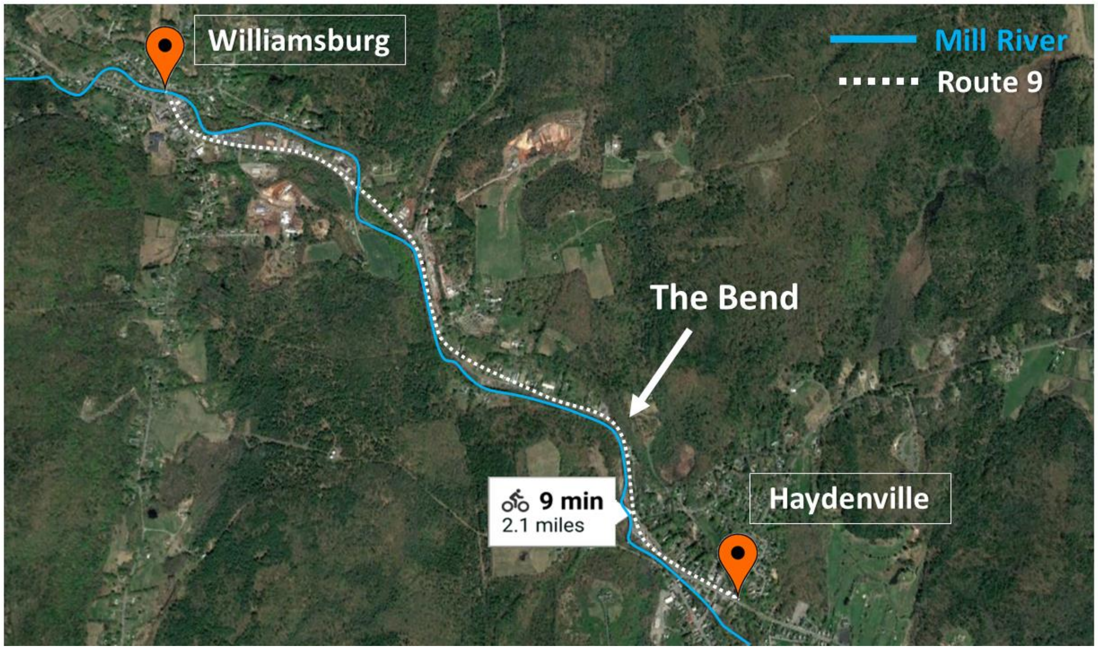


Figure 2. Path of Proposed Greenway

Along the Greenway's proposed path is a bend (hereafter referred to as the Bend) located between the Williamsburg Snack Bar and the Brassworks Building (Figure 3). The location and constraints posed by the road and slope of the Bend puts the proposed Greenway's bank at risk of erosion from the Mill River.

Figure 3. Aerial View of the Bend between the Snack Bar and the Brassworks Building

The scope of our project centers around creating a hydraulic model of the Mill River between the Williamsburg Snack Bar and the South Main St. Bridge. We started by modeling the existing conditions at our site, and then added bank protection designs intended to prevent future erosion from occurring. In our models, we also accounted for the Brassworks Dam, which is located midway between the Bend and the bridge. This dam has already been significantly deteriorated due to recent large storms. Whether it is a result of purposeful action by the town or of future storms, the dam will be rendered completely ineffective at some point. We accounted for this by running each of our models with and without the dam present. (Figure 4)

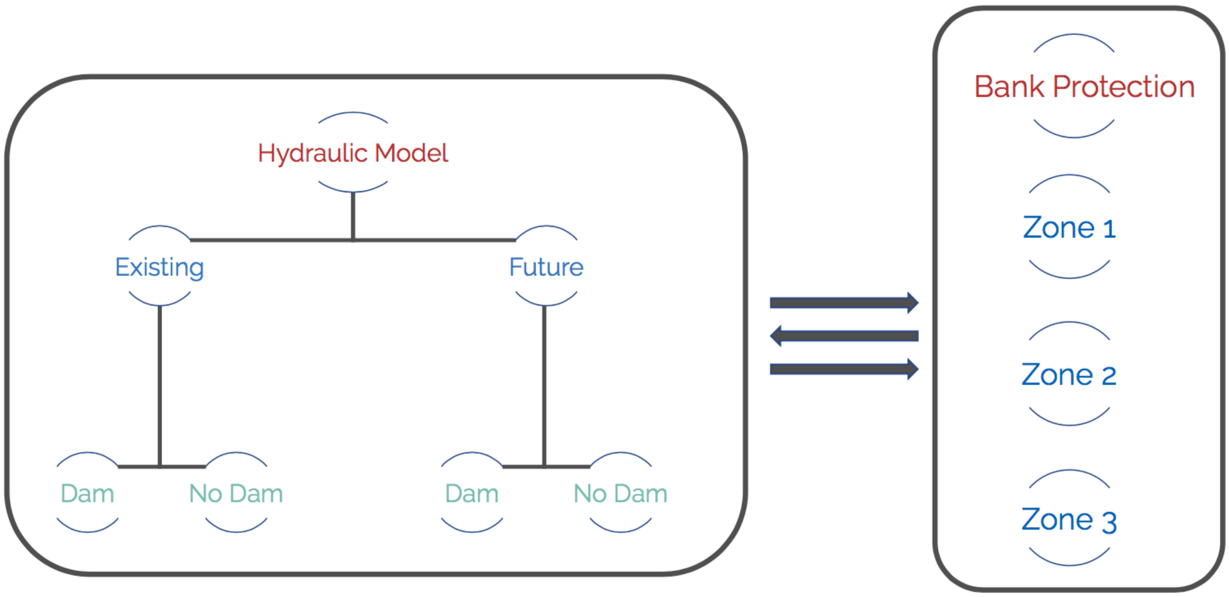


Figure 4. Diagram of Project Scope

Based on the results from our base model of existing conditions, we separated our preliminary designs into three regional zones according to their flow conditions and slopes at the bank. We then tested our preliminary bank protection designs in the model, and based on those outputs determined which designs were viable (Figure 4).

Our team's involvement with the project concluded in May of 2018, and construction by MassDOT is not expected to start for approximately 8 more years; therefore, we will not be involved in that part of the operation. This timeline does, however, allow for our work to feed into the design development study to be performed by the engineering firm contracted by the Town of Williamsburg, VHB. Our hydraulic model is of particular value to the upcoming project milestones, as it is expected to feed into the design work carried out by VHB.

Our team collaborated with members of WMRGC and other highly qualified community members, including Nick Dines, member of WMRGC and Professor Emeritus of UMass Landscape Architecture and Planning; Carl Gustafson, retired USDA Natural Resources Conservation Service Engineer; Jim Hyslip, member of WMRGC and Principal Engineer at HyGround Engineering; Gaby Immerman, chair of the WMRGC and Landscape & Education

Specialist with the Smith College Botanic Garden; and Brett Towler, Hydraulic Engineer and Fish Passage Engineer with the U.S. Fish & Wildlife Service.

II. Background and Motivation

In October of 2009, a group of local residents from the towns of Northampton and Williamsburg formed a group focused on exploring and reviving the ecological, cultural, economic, and recreational value of the Mill River. This group has since expanded to include residents from all nine towns along the Mill River and launched several projects, most recently the Williamsburg-Haydenville Mill River Greenway Project. This project aims to provide a shared use path for pedestrian and bicycle connections between the two town centers, as well as a connection to the Mass Central Trail at the Haydenville/Northampton Town Line in order to enhance walkability within the community (Mill River Greenway Mission Statement, 2017). Figure 5 displays a cross section schematic of the proposed design, and Figure 6 shows a sketch of the design.

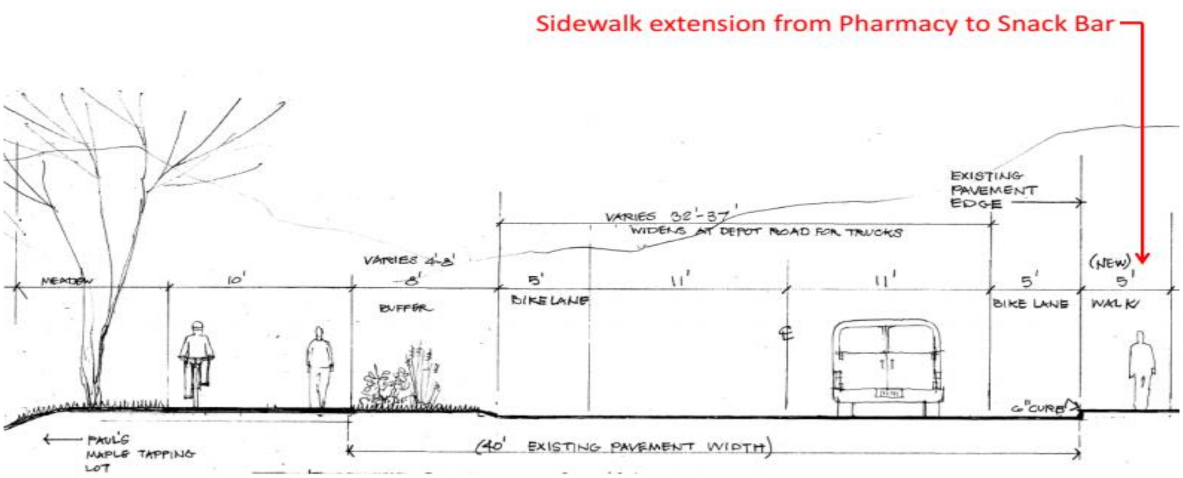


Figure 5. Cross-section of Greenway and Roadway (Dines, 2017)

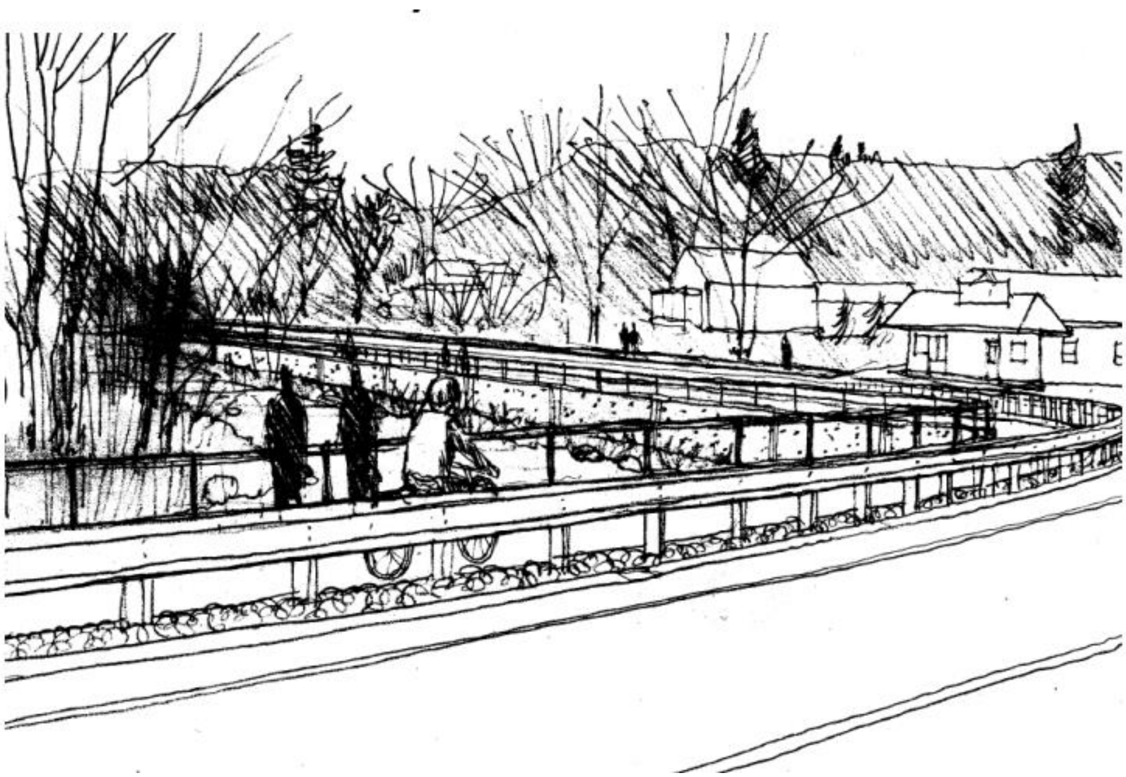


Figure 6. Sketch of Proposed Greenway at the Bend (Dines, 2017)

The process began in 2013 with a feasibility study (Dodson & Flinker, 2015), followed by the development of various route options over the next year. A single route was selected in 2016, and a Project Need Form was submitted.

In March 2017, the Massachusetts Department of Transportation (MassDOT) declared WMRGC's proposal eligible for state and federal transportation funding. As of October, the firm VHB has been selected to complete initial route survey work. VHB hired a subcontractor, Hill Engineers, who started their survey in late fall. In addition, VHB will produce a pre-construction design development study. The estimated construction start date is scheduled for approximately 2025. Because the Greenway is in its early stages, our work on this project fundamentally contributes to future work.

The Greenway project has several complex components, including its landscape design, roadway retaining walls, and several pedestrian bridges. Our project is the interface between the

Greenway and the Mill River, where Route 9 bends between the Williamsburg Snack Bar and the Brassworks Building. This location is of particular concern to the Greenway project, given that it is at risk of erosion by the river (Figure 7). This erosion could completely undermine the project if not addressed.

Figure 7. The Bend towards Snack Bar

As mentioned previously, another key component for this section of the greenway is the Brassworks Dam. The dam has been significantly damaged in recent years due to major hurricanes Irene (2011) and Sandy (2012). It is inevitable that the dam will eventually be rendered completely ineffective, whether it is a result of future natural disasters or of a decision on the town's part to remove it in a planned procedure. It is therefore a useful practice to model how the dam's absence will impact stream conditions.

Our project provides the Williamsburg Greenway Committee with a robust HEC-RAS model of the Mill River river-reach from the Route 9 bend to the South Main St. Bridge both with and without the Brassworks dam. This model will be used by the company VHB in their design work. In addition, we are providing a design set of feasible bank protection alternatives along the Bend area, considering both traditional and bioengineered methods. We started with the clientpreferred concrete retaining wall, and decided to also investigate bioengineered alternatives in order to produce a holistic set of options.

III. Site Documentation through GIS

Our team began by familiarizing ourselves with the project landscape, and formulating a common understanding through our initial site visit, input from liaisons, and background research about the Greenway Initiative, history of the area, and the significance of the Mill River to the local community. Additionally, we documented relevant site characteristics in the form of annotated GIS maps. These maps allowed us to document important features of our site that will likely influence decision making regarding the Greenway. All maps can be found in Appendix 1. Table 1 summarizes the list of relevant layers, each accompanied by its method of acquisition and a brief description.

Table 1. GIS Layers with Corresponding Sources

GIS Layer	Source	Description
Orthography	Professor Reid Bertone-Johnson's database, Landscape Studies Department, Smith College	Satellite imagery
Topography	Professor Reid Bertone-Johnson's database, Landscape Studies Department, Smith College	2 ft contour lines containing information on elevations
Mill River Polygon	Professor Reid Bertone-Johnson's database, Landscape Studies Department, Smith College	Visual representation of river
Roads	MassGIS Data: MassDOT roads	Route 9
Wetlands	Dodson & Flinker	Valley View Farm wetland delineation
Soils	MassGIS NRCS SSURGO-Certified Soils (Last updated 11/2012)	Soil composition
Land use	MassGIS Data: Land Use (Last updated 2005)	Example residential, wetlands, farmland, etc.

This information is especially critical in the case of retainment options that would cause a dramatic shift of the river channel. For example, the land on the South bank of the river is privately owned by Valley View Farms. If the river shifts, it will encroach on their land and WMRGC may wish to consult with the land owners about this prospect.

IV. Hydraulic Model

To better understand the hydraulic conditions of the river, assess the hydraulic effects of integrating certain bank protection designs, and understand the effect of decommissioning the Brassworks Dam, our team developed a hydraulic model of the Mill River. The function of the hydraulic model is to assist WMRGC in making more technically informed decisions. Using the different variations of this model, WMRGC may better understand the existing conditions of the river and the influence of considered bank protection designs on the river velocities and water surface levels. These models also simulate the effect of eliminating the Brassworks Dam. Understanding the role of the Brassworks Dam on the river velocities and water surface levels at the Bend can help WMRGC decide whether the dam removal will improve upstream hydraulic conditions. The model covers the reach extending between the Williamsburg Snack Bar on the upstream end and 30m downstream of the South Main St. Bridge on the downstream end, as seen in Figure 8 below.

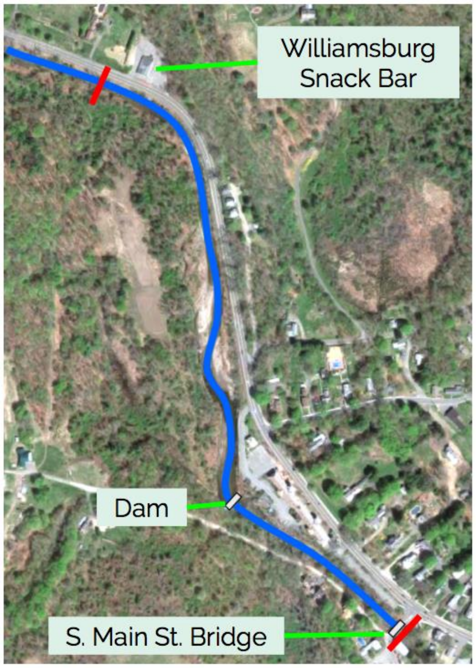


Figure 8. Aerial View Showing the Spatial Extents of our Hydraulic Model

Sections 4.1 through 4.7 below list the design requirements of these models, give background information about the program we chose for our modeling purposes, explain the process of their creation, and elaborate on their different versions.

4.1 Design Requirements for Hydraulic Model

We identified a number of design requirements to guide the development of the hydraulic model (Appendix 2). First, the model must be compatible with the industry standard for river modeling software, in this case HEC-RAS 1D, as confirmed by Brett Towler. The model must be run for the 2, 5, 10, 25, 50, and 100 year floods as guided by MassDOT standards and our client. The model must accurately predict water surface levels within 1ft of error, as advised by Brett Towler. Additionally, the model must allow for the quantification of the effect of the Brassworks Dam removal, and must thus include a version without the dam. Finally, the model must be compatible with future surveys of the project site. In particular, Hill Engineers should be able to locate the model's control points in their future surveys.

4.2 Introduction to HEC-RAS

We created the hydraulic model using the Hydrologic Engineering Center River Analysis System (HEC-RAS). HEC-RAS is an open source software developed by the Army Corps of Engineers and is widely used in the industry for river modeling purposes (Hydrologic Engineering Center, 2017). HEC-RAS allows for both 1D and 2D modeling, where 1D analysis uses river cross-sections as base-units for flow analysis while 2D uses grid or mesh based units for this purpose. 1D is sufficient for the analysis of primarily unidirectional flowing rivers where minimal splitting takes place, while 2D is more appropriate for shallow and splitting flows. For this reason, we have determined under the guidance of Brett Towler and Carl Gustafson that 1D modeling is sufficient for the purposes of our project.

HEC-RAS employs the one-dimensional energy equation as a basic computational procedure for steady flow analysis. Energy losses are accounted for through contraction / expansion and surface roughness frictional losses. The latter are specified through Manning's roughness coefficient, while expansion / contraction are specified through their corresponding coefficients.

In broad terms, the creation of a 1D steady-flow analysis in HEC-RAS requires the user to define an appropriate number of cross-sections in the studied reach, specify the downstream reach distance separating each cross-section from the consecutive one, define the extent of the left and right banks of each of the cross-sections, and specify the roughness of the banks and main channel. Additionally, the user has to feed into HEC-RAS the flow on which the analysis is to be performed. A detailed manual on how to create a steady flow model in HEC-RAS can be found in Appendix 3.

4.3 Spatial Scope of the Hydraulic Model

The hydraulic model covers the reach extending between just before the Williamsburg Snack Bar on the upstream end and 30m downstream of South Main Street Bridge on the downstream end, as seen in Figure 8 above. The choice of this reach was informed by two main factors:

- The presence of the Bend area, which constitutes our main area of concern in this project.
- The presence of the South Main St. Bridge in the reach, which allows for modeling the removal of the Brassworks Dam, since the bridge acts as the first major constriction downstream of the dam.

4.4 Model Development: Existing Conditions

The first step in developing our base model was collecting its input data (Figure 9). We surveyed the river's bathymetry in two main stages; the first covered the bend area and the second covered the area downstream of the Brassworks Dam. The first data set, which we collected during the fall, included seven cross-sections (XS13 through XS7).

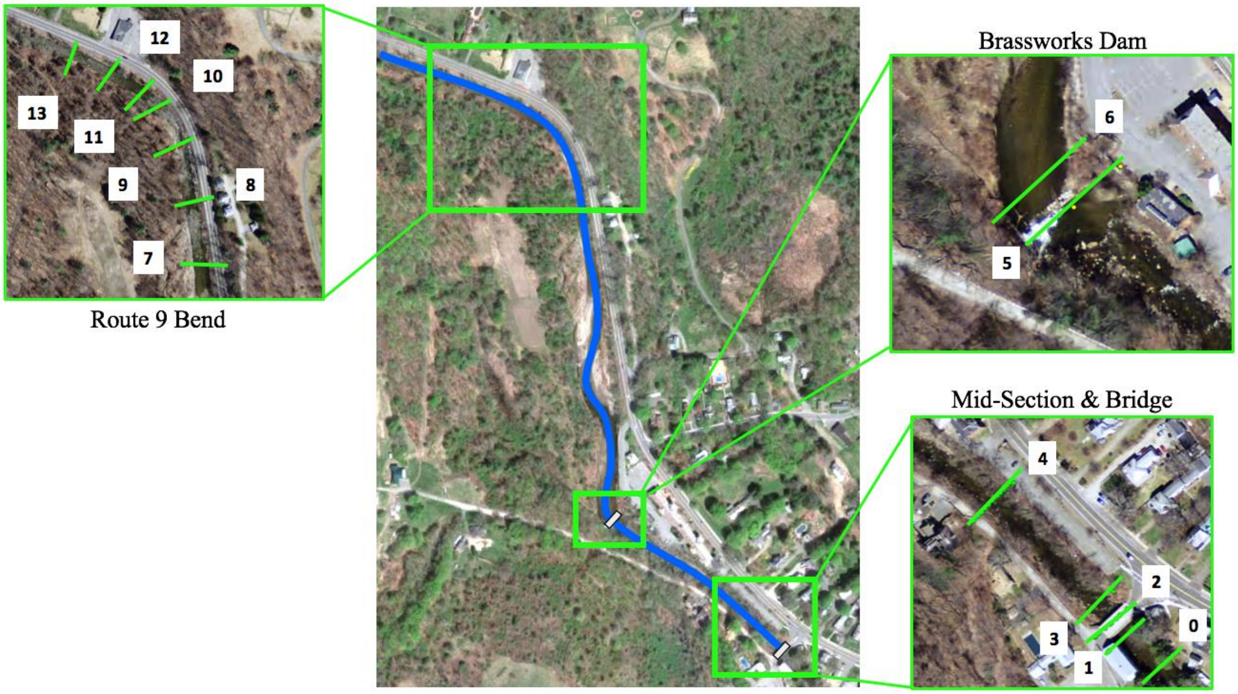


Figure 9. Aerial View (Google Maps) Showing the Two Groups of Cross Sections Surveyed: The First Defining the Bend Area and the Second Defining the Reach between the Dam and the Bridge.

Our choice of cross-section location in this first collection area was influenced by river accessibility and the need to capture important features of the Bend area (Figure 10).

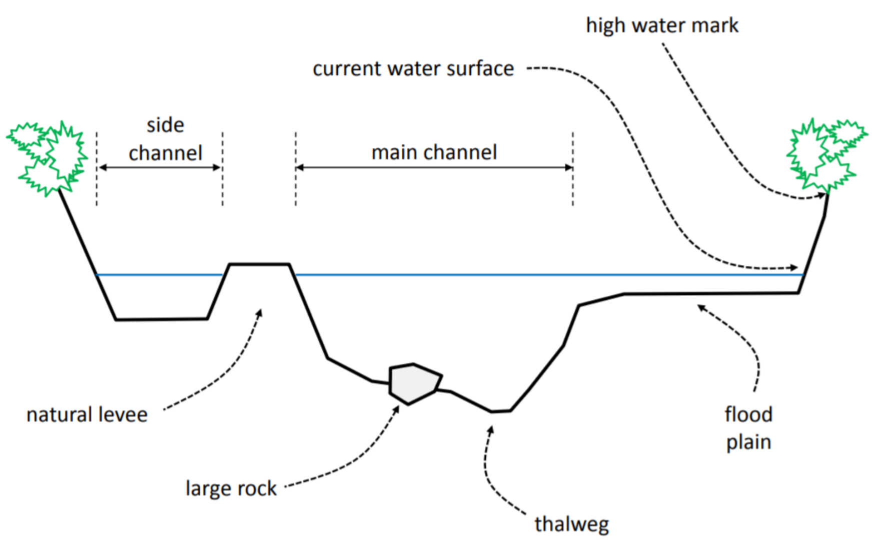


Figure 10. Labeled Section Diagram of River Features for Surveying (Brett Towler, 2017)

The second data set, which we completed in the winter, included three cross-sections downstream of the Brassworks Dam (XS4, XS2, XS1). The goal of surveying this reach was to allow for the omission of the dam in our model. For this purpose, we surveyed a cross-section midway between the dam and South Main St. Bridge (XS4) - with the purpose of characterizing the geometry of the channel connecting the dam with the bridge - and two cross-sections defining the bridge constriction (XS2 and XS1).

In addition to the above-surveyed cross-sections, we created four additional cross-sections using interpolation and photographic representation of XS6, XS5, XS3, and XS0. This amounted to a total of 14 cross sections that were refined to reduce error and used to create our base model. The creation and refinement of these cross-sections are fully detailed in Appendix 4.

The Brassworks Dam was modeled as an inline structure. We used current photos of the dam to define the shape of this inline structure in HEC-RAS (Figure 11).

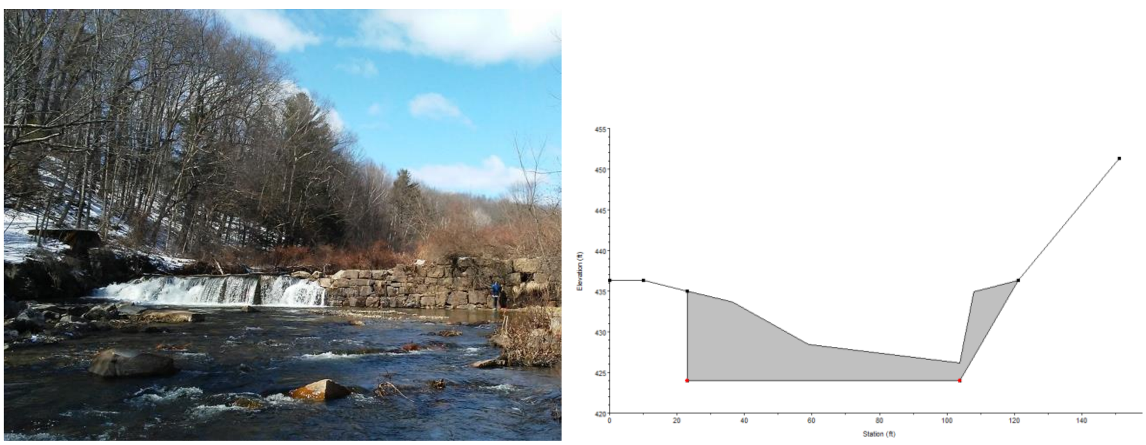


Figure 11. Photo of Brassworks Dam (Left) and HEC-RAS Screenshot Showing the Brassworks Dam Modeled as an Inline Structure (Right)

To have our model accommodate higher water levels during river flooding, we extended each cross-section by 25-30ft on both the right and left banks. Most of the cross-sections either extended to a road or flat field, in which case we assumed horizontal lines as extensions (Figure 12). In some other cases where the cross-section extended to a slope, we used a 2 ft contour GIS layer and site visit pictures to estimate the slope and extend the cross-section accordingly (Figure 13).

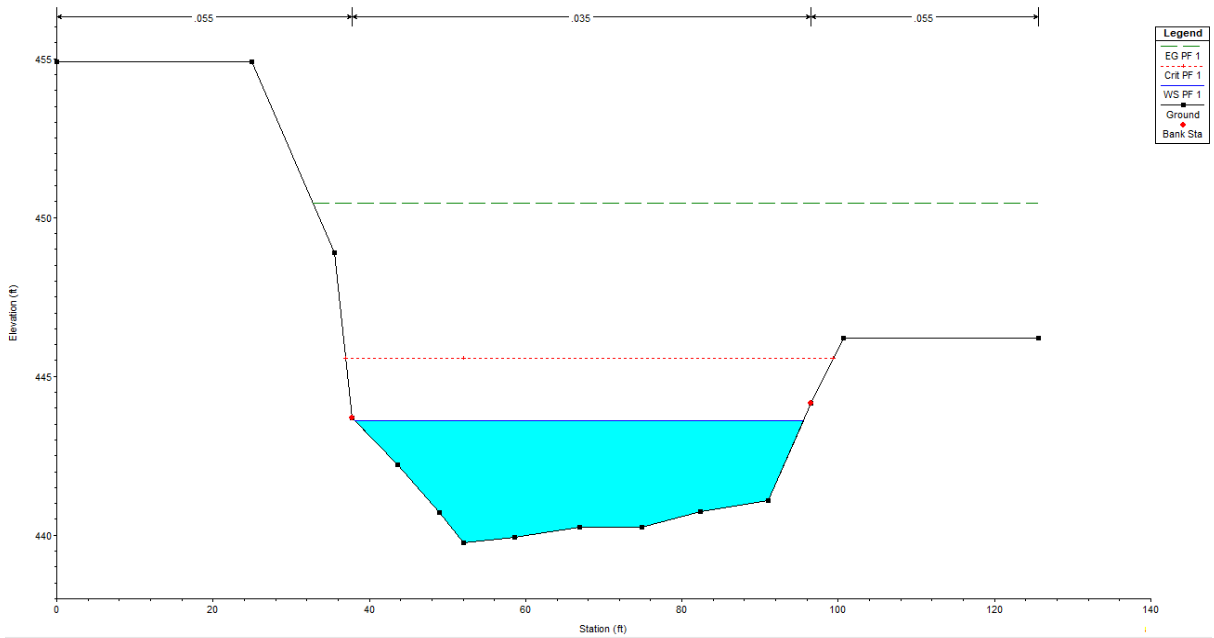


Figure 12. XS 12 with Flat Extensions: Flat Field on the Right of Bank and Route 9 on the Left of Bank

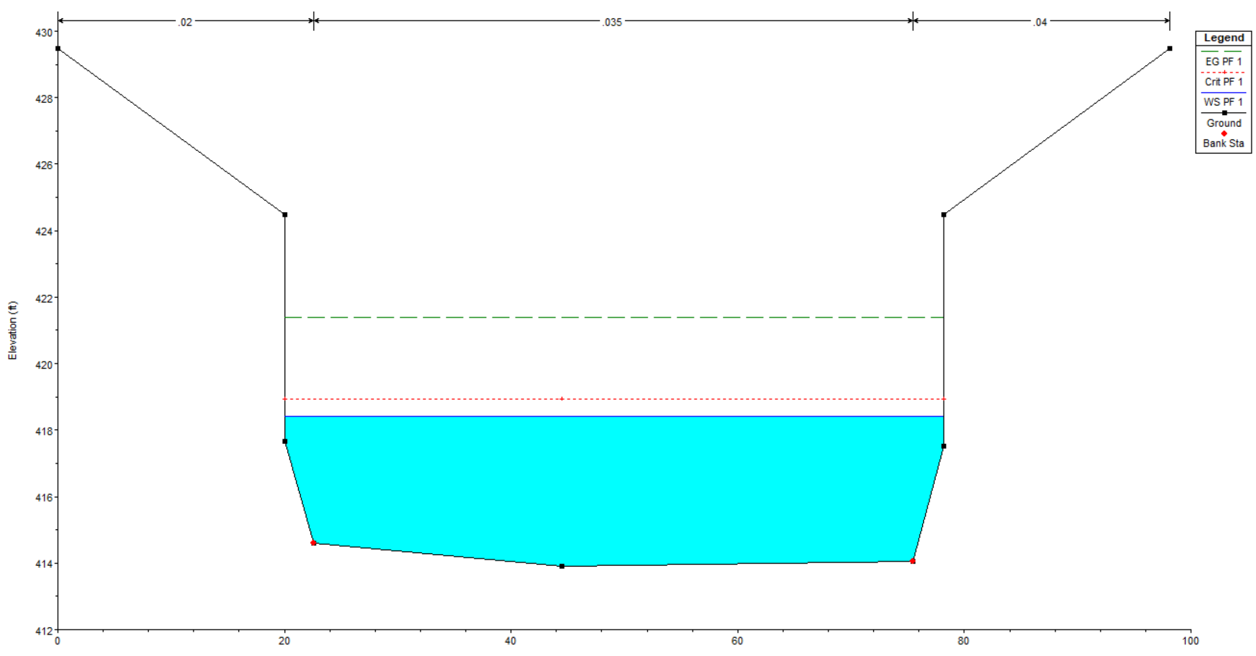


Figure 13. XS 0 with Sloped Extensions on Left and Right

We developed flow values used in the models using a Log-Pearson Analysis (Appendix 5) with input data from the Northampton USGS Gauge Station (USGS-01171500) prorated down to our site. We used the ratio of the Williamsburg watershed area at the Bend to the Northampton watershed at the USGS as shown in Equation 1:

$$Q_{WB} = Q_{Noho}\left(\frac{A_{WB}}{A_{Noho}}\right) \qquad \text{Equation 1}$$

where Q_{WB} is the approximated flow at the Williamsburg site, Q_{Noho} is the Northampton USGS flow, A_{WB} and A_{Noho} are the watershed areas of Williamsburg and Northampton respectively found through the USGS tool StreamStats (USGS, 2017).

To calibrate our model, one of our technical liaisons, Brett Towler, measured the water surface elevation of the river at the South Main St. Bridge and recorded the flow, prorated down from the Northampton gauge station as mentioned earlier. We then ran a HEC-RAS steady flow analysis of our model using the flow value recorded for the measurement time, and recorded the output for water surface level at the bridge. We then calculated the difference between the measured and the model-predicted water surface levels at the recorded flow.

The above process was repeated for five different flows ranging between 135 cfs and 545 cfs, and the highest discrepancy recorded was 0.32 ft (Table 2). The accuracy assessment process is explained in detail in Appendix 6.

Table 2. The Discrepancy between the Measured and Predicted Water Surface Levels at Five Different Flows Fell within the Required Margin of 1ft of Error

Flow (cfs)	Depth Measured (ft)	Depth Predicted (HEC-RAS) (ft)	Discrepancy (ft)
243	1.67	1.6	-0.07
297	1.83	2.1	0.27
323	1.89	1.7	-0.19
440	2.17	2.3	0.13
979	3.18	3.5	0.32

4.5 Verification of Design Requirements

Once our model was complete, we verified its design requirements as follows.

DR-01: The hydraulic modeling software used by the team is common throughout the professional field

Through our use of HEC-RAS 1D, we have guaranteed that we are employing a widely used software.

DR-02: The hydraulic model accounts for the 2, 10, 25, 50, and 100 year floods.

As seen in Figure 13 below, we have completed the steady flow analysis for the five flow values mentioned above. As mentioned earlier, we derived the flow (cfs) of these floods using a Log-Pearson analysis (Appendix 5).

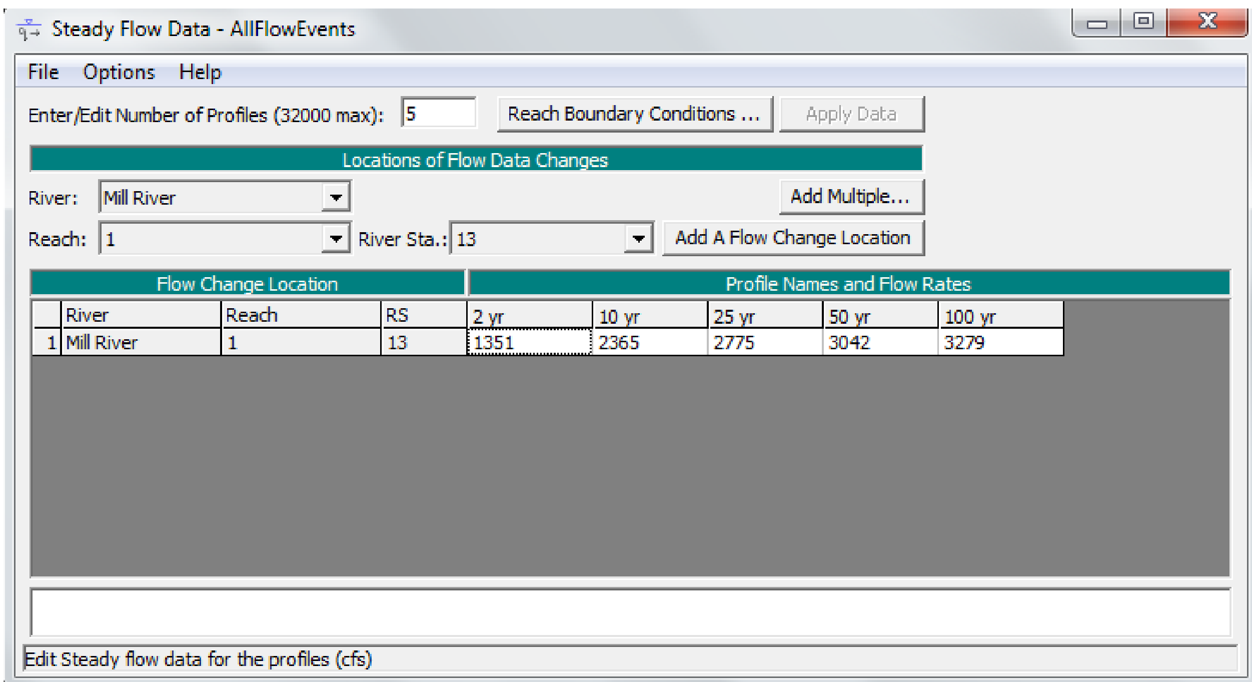


Figure 14. Screenshot from HEC-RAS Showing Flows of the 2, 10, 25, 50, 100 year floods

DR-03: Predicted values for water surface level must coincide with measured values by a margin of error of no more than 1ft.

Table 2 above confirms that for the five measurements taken at the Bridge for water surface level, the discrepancy between measured and model-predicted values never exceeded 0.32ft.

DR-04: The model must allow for the quantification of the effect of decommissioning the Brassworks Dam

Our modeling of the Brassworks Dam as an inline structure (Figure 14) allows us to model the river reach in the absence of the dam by simply removing the inline structure.

DR-05: Fixed points must be created and must be GPS-located along Route 9 and be clearly marked for visual recognition by on-ground surveying crew.

Our team has defined three control points along the Bend. We have located them on the guardrail of cross sections 12, 10, and 8. We have sprayed them and shared their GPS locations (Table 3) with Tim Armstrong, the project surveyor from Hill Engineers. Their location, along with photos locating them, is documented in detail in the Site Visit 11 Summary (Appendix 7).

Table 3. The GPS Location of the Three Control Points Along the Bend, Taken Using a Trimble GeoXH 2005 Series Pocket PC Set to Massachusetts State Plane Coordinate System.

	Northing	Easting	Elevation
XS 8 - CP	903982	100611.9	137.5
XS 10 - CP	904041.65	100572.95	136.4
XS 12 - CP	904079.4	100494.54	137.6

4.6 Model Development: Future Conditions

This base model was later adjusted to account for bank protection structure integration, consequent channel movement, and dam removal. After identifying the length and width dimensions of each of the considered bank protection designs elaborated on in the following section (Section 5), we measured their distance of intrusion into the water at full bank conditions, modeled as the 2-year flood in HEC-RAS. An example of such a measurement can be seen in Figure 15 below.

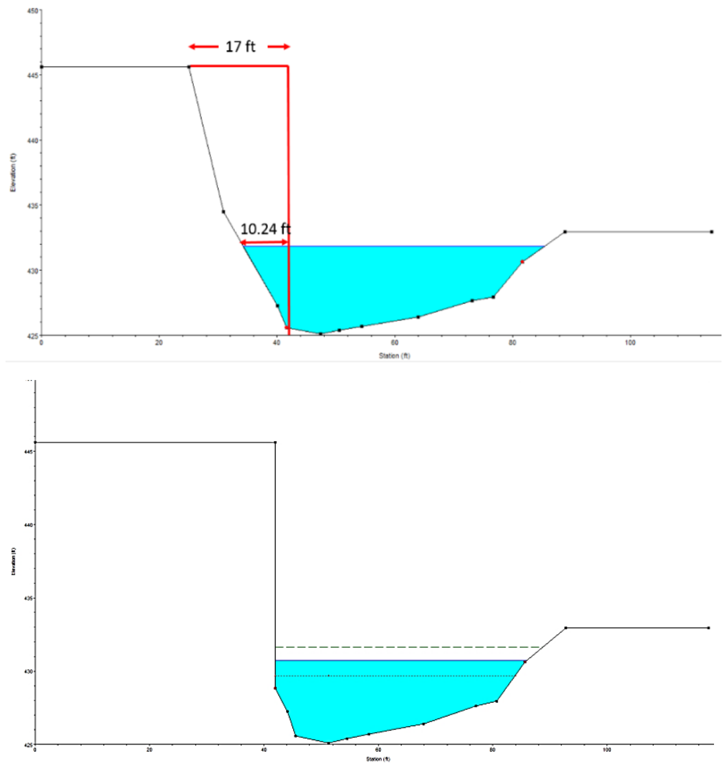


Figure 15. A 17ft Road Extension Intrudes a Total Distance of 10.24ft into the River at XS7 (Top) and the Riverbed is Shifted 10.24 away from Route 9 (Bottom)

We then shifted each cross-section away from Route 9 by the same distance of intrusion, also seen in Figure 15. Accordingly, cross-sections that did not include bank protection designs were not adjusted.

The Brassworks Dam was modeled using an inline structure. The cross-section adjacently upstream to the dam (XS6) was recreated to avoid counting the sediment as bathymetry. We simulated the possible removal of the dam by removing the inline structure. The process of modeling the dam area is explained in detail in Appendix 8.

We simulated 5 potential future conditions with the following models:

1. A model of the existing conditions of the river, without the Brassworks Dam
2. A model with a retaining wall bank protection at the bend, with the Brassworks Dam

3. A model with a retaining wall bank protection design at the bend, without the Brassworks Dam
4. A model with the considered bioengineered bank protection designs implemented at each of their corresponding zones, with the Brassworks Dam
5. A model with the considered bioengineered bank protection designs implemented at each of their corresponding zones, without the Brassworks Dam

4.7 Hydraulic Effect of Dam Removal

We compared the velocities and water surface elevations of the two models of the existing conditions both with and without the dam. This comparison was done for the 2, 10, 25, 50, and 100 year floods. The comparison shows that the removal of the dam has detectable effects only on XS8 through XS5, but not on the remaining cross-sections.

Generally, the removal of the dam decreases water surface levels and increases velocities upstream of the dam. These changes, however, are more pronounced near the dam. The results for the changes experienced by XS8 through XS5 for the 2 and 100 year floods are summarized in Table 4 below. Appendix 9 has these results for the 2, 10, 25, 50, and 100 year floods.

Table 4. Change of Hydraulic Conditions in XS8 – XS5 Due to Dam Removal

		Velocity (ft/s)			**Water Surface Elevation (ft)**		
XS	Flood (year)	Dam	No Dam	% change	Dam	No Dam	$\Delta Elevation$
8	2	6.06	6.13	1.16	431.85	431.79	0.06
	100	8.69	9.23	6.21	434.81	434.45	0.36
7	2	5.41	5.48	1.29	431.75	431.69	0.06
	100	7.94	8.42	6.05	434.71	434.33	0.38
6	2	2.16	8.14	276.85	431.58	426.04	5.54
	100	3.79	10.92	188.13	434.44	427.68	6.76
5	2	4.21	14.6	246.79	424.48	422.94	1.54
	100	4.76	18.49	288.45	426.67	423.59	3.08

V. Bank Protection Designs

The second main goal of our collaboration with WMRGC was recommending bank-stabilization designs and assessing their hydraulic effect on the river at the studied area. Developing the final design set was a two-part process. First, we developed the designs based on our stakeholder design requirements, the existing conditions as given by the HEC-RAS model velocities, and knowledge of the land type and bank slope grades from our in-person site visits. As mentioned earlier, we researched the client-suggested design of a concrete retaining wall, and we also explored bioengineered designs in order to consider a wider range of options. Second, we entered the best alternatives from the first process into HEC-RAS and assessed their effects on the river geometry and velocities. Additionally, we ensured that the resulting velocities and water levels meet the stakeholder design requirements.

5.1 Design Requirements

We defined several design requirements for the bank protection alternatives, as determined by WMRGC and local, state and federal regulatory agencies, as listed in the traceability matrix (Appendix 2). A major priority was to stabilize the bank by preventing erosion; this can be achieved by ensuring that the alternatives withstand velocities for the 100 year floods both with and without the dam. Additionally, the river level should not rise above the Greenway, which would result in flooding.

Any recommended alternative must also meet MassDOT vehicular and spatial standards by accommodating a minimum 5 ft shoulder and the 12 ft wide Greenway (MassDOT Healthy Transportation Policy Directive, 2013). In order to minimize the resulting intrusion into the river caused by the extension, the bank protection design should be able to accommodate steep slopes (Figure 16).

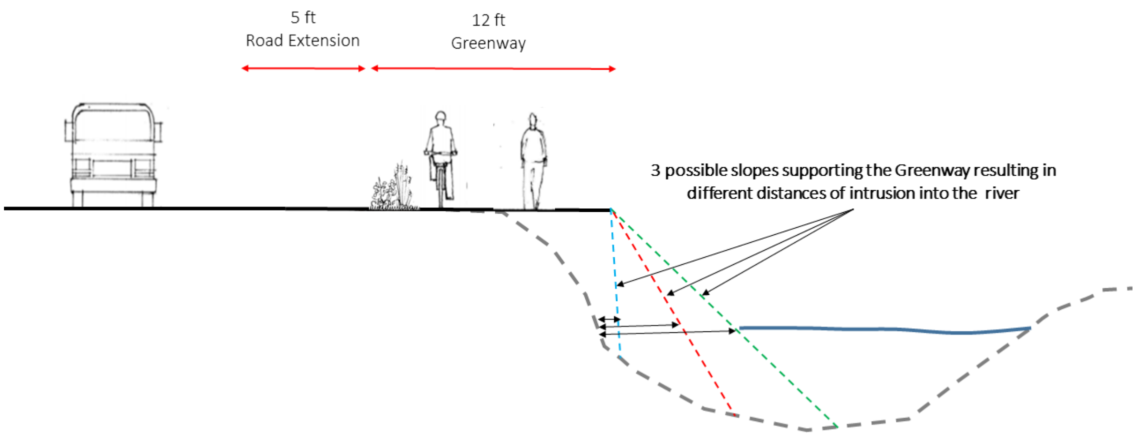


Figure 16. Proposed Solution for Road Extension and Added Greenway (Dines, 2017)

The purpose of the Greenway is in part to facilitate appreciation of nature, so we also added a design consideration that the bank protection minimize impact on water temperature and allow for vegetation and wildlife habitat. Further research into this consideration would involve working with the Massachusetts Department of Environmental Protection.

5.2 Bank Protection Alternatives Research

We generated an initial list of potential bank protection alternatives based on external literature review and input from our liaison Carl Gustafson, a former employee of the NRCS. In this research process, we focused exclusively on designs that had precedent. Based on the conditions specific to our site and other various constraints, we removed several alternatives from consideration in the early stages of our concept selection process. This initial list and our rationale for the decision-making process can be found in Appendix 10.

5.3 Existing Conditions

Before we could further narrow down potential alternatives, we needed to analyze the existing conditions in more detail and establish specific selection criteria. We divided the river reach into three distinct zones (Figure 17), based on three questions: what is the problem, what is the goal, and what are the needs. We then matched the alternatives with the functions that meet those needs to each zone.

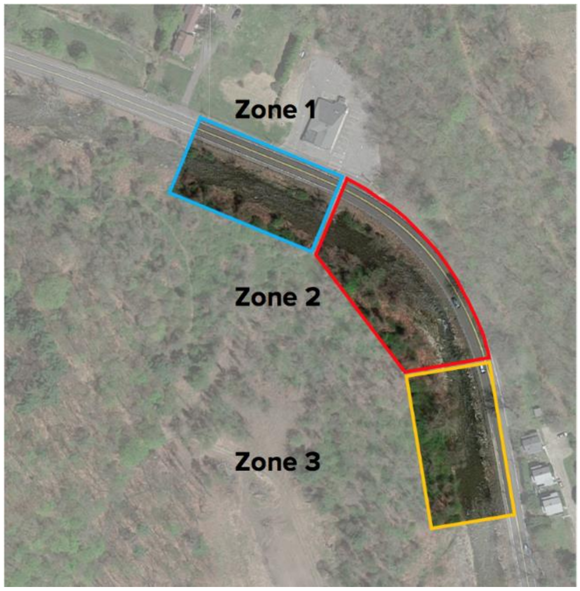


Figure 17. Zone Boundaries Along the Bend

Zone 1 consists of cross sections 12 and 13; Zone 2 cross sections 9, 10, and 11; and Zone 3 cross sections 7 and 8 (Figure 9). Zone 1 on its own is not an area of significant concern; there is a relatively gentle slope and very little curvature at this point. Additionally, the velocities at this zone are relatively low (7.12 – 12.1 ft/s). However, Zone 1 is crucial in serving as a preventative measure in anticipation of the high flows in the subsequent downstream sections. We chose vegetative alternatives to increase the roughness coefficient and redirective alternatives to move the flow away from the river bank.

At Zone 2, the river bank is in the most critical condition due to a combination of steep slopes and a nearly 120º bend resulting in high velocities (12.4 -25.8 ft/s). To address these concerns, we selected alternatives that provide toe armoring and sustain a vertical slope from the riverbed to the road level, in addition to vegetative and redirective components. Zone 3 has similarly high flows and even steeper slopes; however, this section is a straight-away so it does not require redirective alternatives.

5.4 Design Development

To leverage analysis of the existing conditions (Appendix 11), we created an assessment matrix for each zone (Figures 18-20). We generated the 10 criteria used in these matrices first by looking at our design requirements and conducting external research, then by consulting our liaison Carl Gustafson, who has prior experience on projects using these alternatives. We used a stoplight system in formatting the matrix, where green indicates the most favorable option; red indicates the least favorable option; and yellow falls in between. Where a certain criterion was not applicable to an alternative, we grayed out the cell. It is important to note that, although red represents the worst option, we did not rule out alternatives marked as red because the criteria had varying weights.

	Alternatives	A	B	C	D	E	F	G	H	I	J
Redirective	Stream barbs										
Vegetative	Wattle fences										
	Live fascines										
	Live siltation										
	Brush layers										
	Live staking										

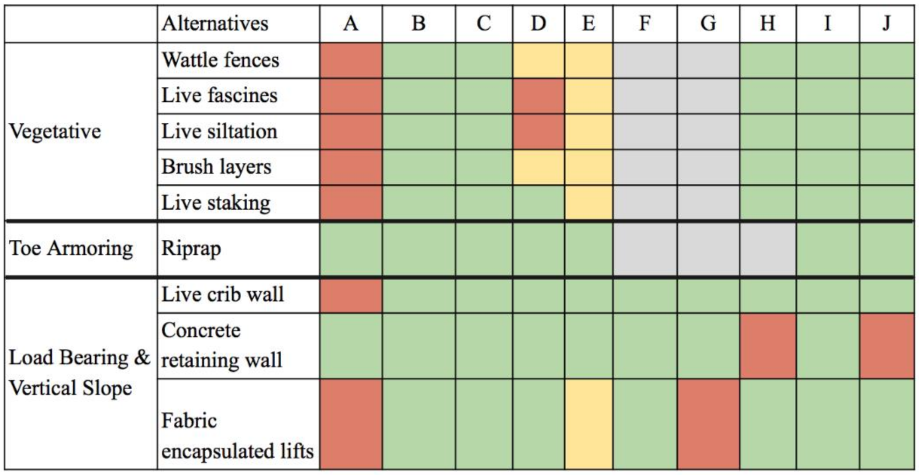
A	Tolerates high velocities
B	Meets town state and federal design regulations
C	Resistant to flooding
D	Service Life
E	Risk of failure within first 5 years
F	Supports steep slope for widening road
G	Load acceptance
H	Allows for bank vegetation
I	Precedent
J	Environmental Impact

Figure 18. Zone 1 Concepts Assessment Matrix

	Alternatives	A	B	C	D	E	F	G	H	I	J
Redirective	Stream barbs										
Vegetative	Wattle fences										
	Live fascines										
	Live siltation										
	Brush layers										
	Live staking										
Toe Armoring	Riprap										
Load Bearing & Vertical Slope	Live crib wall										
	Concrete retaining wall										
	Fabric encapsulated lifts										

A	Tolerates high velocities
B	Meets town state and federal design regulations
C	Resistant to flooding
D	Service Life
E	Risk of failure within first 5 years
F	Supports steep slope for widening road
G	Load acceptance
H	Allows for bank vegetation
I	Precedent
J	Environmental Impact

Figure 19. Zone 2 Concepts Assessment Matrix



A	Tolerates high velocities
B	Meets town state and federal design regulations
C	Resistant to flooding
D	Service Life
E	Risk of failure within first 5 years
F	Supports steep slope for widening road
G	Load acceptance
H	Allows for bank vegetation
I	Precedent
J	Environmental Impact

Figure 20. Zone 3 Concepts Assessment Matrix

Our goal was to create combinations of individual alternatives, which we will refer to as designs, for each zone in order to meet each need.

In cases where there were more than one alternative that performed the same function (e.g. “Vegetative”), we compared alternatives within their function groups. Where there was only a single option for a given function (e.g. riprap in “Toe Armoring”), we included it in each zone where the function was needed. We then examined how alternatives from different function groups complemented each other; for example, stream barbs pair well with the live crib wall because their red blocks are balanced by corresponding green blocks in the other (i.e. stream barbs do not provide load acceptance, but live crib walls do) (Appendix 12).

5.5 Modeling Selected Designs in HEC-RAS

Using the concepts assessment matrices for each zone (Figures 18-20) we selected three designs to model in HEC-RAS. For Zone 1, we chose live staking and stream barbs (Figure 21). For Zones 2 and 3, we modeled two different designs: the first consisted of live crib wall with riprap, stream barbs, live staking, and small retaining walls (Figure 22); the second consisted of concrete retaining wall with riprap.

Figure 21. Examples of Live Staking (left) and Stream Barbs (right) Used for River-Bank Restoration. (Cardno, 2018)

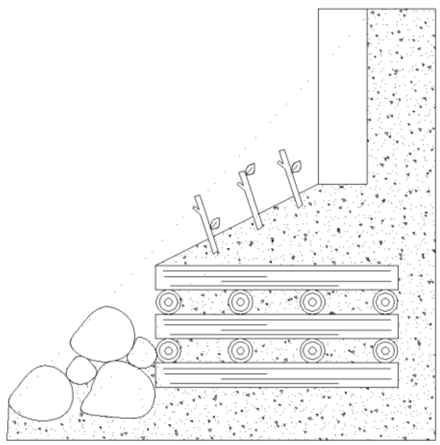


Figure 22. Crib Wall Design for Zone 3

For each of the recommended designs we compared their allowable velocities to those predicted by HEC-RAS. Through our research, we found that it is difficult to assign an exact number for the allowable velocity of each bioengineered design because these are largely determined empirically, and because they are relatively new alternatives with fewer data than traditional designs. The NRCS has compiled several of the empirical studies that have been completed on bioengineered alternatives, and derived ranges of allowable velocities (Table 5). As the vegetation in bioengineered designs has time to grow, the allowable velocities increase. For this reason, Table 5 also includes values once the alternative has had time to establish.

Table 5. Allowable Velocities for Streambank Soil Bioengineering Practices (NRCS, 2007)

Alternative	Allowable Velocity - Initial (ft/s)	Allowable Velocity - Established (ft/s)
Live Fascine	5 - 8	8 - 10+
Wattle Fence	1 - 2.5	3 - 10
Live Crib Wall	3 - 6	10 - 12
Brush Layer	2 - 4	10+
Live Staking	1 - 2.5	3 – 10

5.5.1 Zone 1

We did not change the slope of Zone 1 in our design-integrating model since the addition of live staking and stream barbs can be implemented with the existing slope. The extension of the roadway will require the channel to shift 17 ft towards the south bank to accommodate the Greenway and additional shoulder width. This existing slope will be maintained (Figure 23).

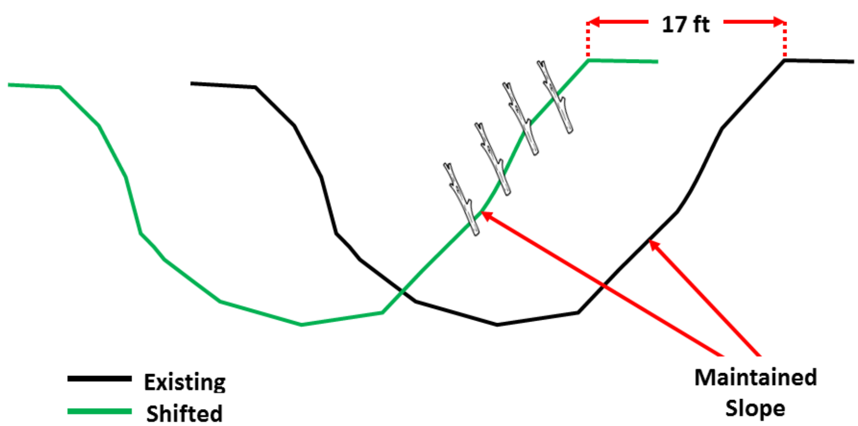


Figure 23. Suggested Shifting of a Cross-Section in Zone 1

Water level elevation and velocity results from HEC-RAS suggest that it is a viable design for this zone. At the Route 9 side of the river, the water level predicted by the model for the 100-year flood is roughly 10 ft below the Route 9 level elevation, so no flooding is expected.

Under these conditions, the highest velocity predicted by the model is estimated to be 12.1 ft/s. The highest velocity that live staking can withstand is 10 ft/s, and the addition of stream barbs will reduce velocities, likely making this a suitable velocity tolerance for this zone. Although stream barbs were not modeled in HEC-RAS, they are included in this design package, as they are the only alternative to address redirective protection. An important reason that we did not model stream barbs is that HEC-RAS gives average velocities for a given cross-section and does not show local velocities that would result from the addition of stream barbs.

5.5.2 Zones 2 & 3

For each of these two zones, we modeled two designs: a bioengineered and a traditional engineering approach.

The bioengineered approach is a combination of live crib wall with riprap, stream barbs, live staking, and concrete vertical wall. Note that again, stream barbs were not integrated into our model. Constructing a live crib wall for the entire height of the bank is impractical because live crib walls have a recommended maximum height of 7 ft (NRCS, 2007). To address this constraint, we designed the crib wall to only the 50-year flood height and accounted for the remaining elevation using earth slopes with live staking followed by a concrete vertical wall (Figure 22).

Modeling the bioengineered design in Zones 2 and 3 for the 100-year flood confirmed that these two zones will not experience flooding. On the other hand, the predicted velocities are much higher than what this bioengineered design can withstand. The highest velocity that a live crib wall can take is approximately 12 ft/s while the highest estimated velocity under these conditions is 24.1 ft/s. The highest predicted velocity for the 50-year flood event was not very different from 100-year flood. We therefore rejected the bioengineered design for Zones 2 and 3.

The traditional design approach for Zones 2 and 3 is a combination of concrete retaining wall and riprap. This solution is structurally robust, and it can withstand high velocities. Modeling for the second design confirmed that for the 100-year flood event, flooding on Route 9 is not expected. Since a concrete retaining wall in combination with riprap is a retaining solution designed specifically for high velocities, we recommend it as a viable design. We also recommend the addition of stream barbs to the left bank of Zone 2 to move higher velocities away from the bank, a need that is not required for Zone 3 because it is a straightaway.

5.6 Design Verification

After we finalized the HEC-RAS model for all existing and future conditions, we were able to verify whether or not the proposed design alternatives met the design requirements established at the beginning of the project (Appendix 13).

DR-01: Alternative must withstand velocities predicted by the HEC-RAS model with the dam

Based on the above comparison between HEC-RAS predicted velocities and allowable velocities of our bioengineered alternatives (Section 5.5.1), this design does not appear to be able to withstand the maximum velocities predicted by the HEC-RAS model. The remaining alternatives, concrete retaining wall and riprap, are able to withstand very high velocities. Riprap can withstand approximately a maximum of 26 ft/s and concrete lining approximately 33 ft/s (NRCS, 2007).

DR-02: Alternative must withstand velocities predicted by the HEC-RAS model without the dam

At the Bend, velocities without the dam proved to be nearly identical to the values calculated with the dam present, most likely due to the fact that the dam was already significantly deteriorated.

DR-03: River level must not rise above the Greenway bank level

Looking at the HEC-RAS model visual outputs, we can confirm that the water level does not rise above the bank for the 100-yr flood.

DR-04: Minimum shoulder width and bikeway width are accommodated

The concrete wall and riprap design will allow for the minimum 17 ft required for the Greenway and shoulder width addition, and we are expecting to move the slope in Zone 1 to accommodate this as well.

Considerations

In addition to our design requirements we added a consideration to minimize the environmental impact of the bank protection design. This was a consideration rather than a requirement because having the most robust bank alternative to protect against extreme events at this point on the route supersedes the environmental concerns. In Zone 1 we do meet this consideration with the purely environmental bank protection alternatives. Live stakes consist entirely of natural materials, which will eventually root and sprout. They assist in quickly reestablishing the riparian vegetation, and over time they add to the roughness of the streambank to slow down velocities (NRCS, 2007). The stream barbs push the deeper and faster flows away from the bank, leaving a slower velocity area for habitat sustainment. In Zones 2 and 3, the retaining wall does have negative environmental impacts (e.g. increases water temperatures and velocities, shifts erosive energy downstream, removes existing vegetative habitats); methods for mitigating this impact should be further researched.

VI. Final Deliverables

Revisiting the scope diagram (Figure 24), our deliverables are highlighted by the two outlined boxes, one for the hydraulic model and the other for bank protection designs. The HEC-RAS model we have provided holds a significant value for future permitting and design work. It is easy to modify and so can be used by VHB if they choose to refine certain parameters or alter features to reflect their design work. The bank protection alternatives we are recommending provide an initial look into what type of alternatives would work respective to the critical bend region. Additionally, we are providing documentation of all the alternatives that we eliminated and the rationale behind doing so, giving WMRGC insight into which alternatives are not viable, and which alternatives should be further developed.

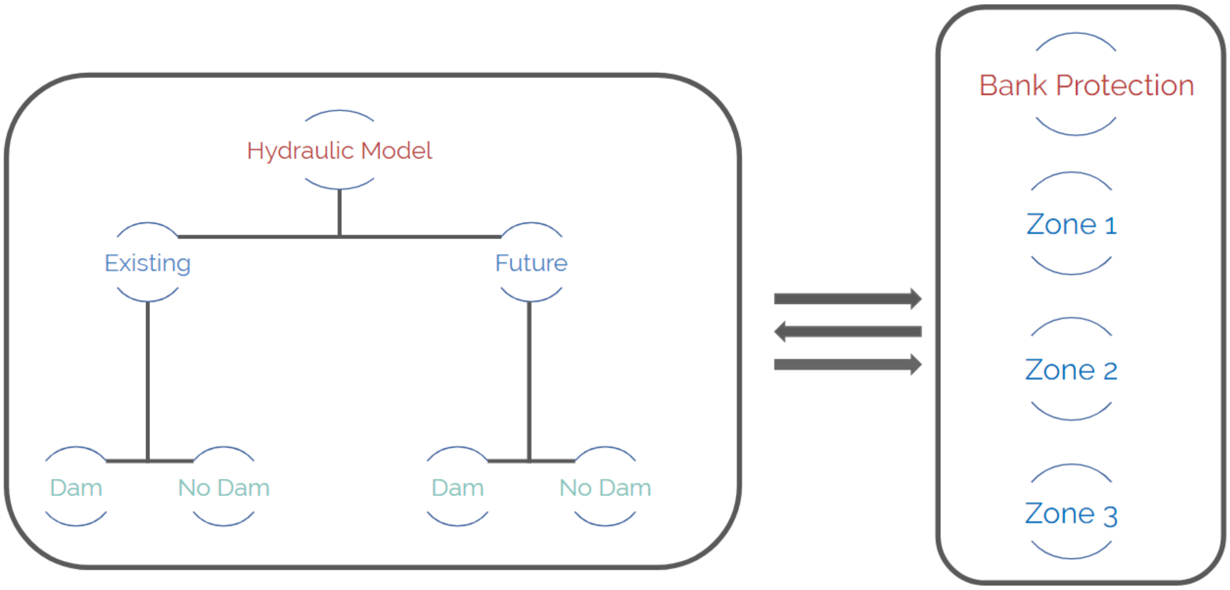


Figure 24. Diagram of Project Scope

VII. Next Steps & Future Work

There is still a significant amount of work to be done before the Greenway is fully constructed and ready for use. Our main contributions to the project have been the development of a hydraulic model and an initial set of bank protection recommendations. It is standard practice to present a hydraulic model to appropriate governmental agencies (i.e. U.S. Army Corps of Engineers) for projects constructed near a river. After being reviewed internally by engineers working with WMRGC, our model will satisfy this requirement for our client. The model's outputs can be used to predict how any changes or additions to the river will affect existing conditions. As previously mentioned, the model is able to be modified easily by future collaborators, which may be appropriate given climate change uncertainty.

The survey data we collected has inherent error associated with it. While this does not significantly impact our hydraulic model, which relies on relative values rather than the location of points in space, future collaborators may desire to more precisely locate our existing reference points in space. Hill Engineers has tools with far greater accuracy, and they will be able to compare where our points overlap with their survey work on the banks of the river. We have provided control points from our survey data set for the purpose of connecting these two data sets (Site Visit 11 in Appendix 7).

Our preliminary bank protection design recommendations will need to be reviewed and assessed by professional engineers at VHB. Any designs that they move forward with will need additional data to inform their implementation. For example, a geotechnical report will need to be completed on soils in the area, including borings to determine soil types at various depths. Additional soil data can also be used to improve some of our designs; in Zone 1, the soil type used for infill can be selected to increase the angle of repose, and thereby decrease the design's intrusion into the river.

Overall, we have provided a solid foundation for WMRGC and their future collaborators on which to build over the coming years. Accordingly, we have included extensive documentation of our processes and deliverables with this in mind, and expect that this report will also support future additions to our work.

VIII. Summary

This project was part of the bigger Mill River Greenway Project, which is going to create a connector between Haydenville and Williamsburg. We worked with WMRGC to aid in decision making on protecting the portion of the proposed Greenway along the Bend from bank erosion caused by the Mill River. Our scope of work featured an interplay between the GIS layer documentation at the site, development of a hydraulic model of the river reach upstream and downstream of the Bend, and our proposed design alternatives for bank protection. The GIS layer serves the purpose of documenting important features of the site that can influence decision making regarding the Greenway or the potential shifting of the river. These features include roads, wetlands, soil types, and land use. The HEC-RAS model consists of several different configurations: the existing river conditions and our recommended bank protection designs both with and without the Brassworks Dam. The bank protection deliverable presents our top option for bank protection for the three different zones we defined at the Route 9 bend: stream barbs and live staking in Zone 1, a combination of concrete wall, stream barbs, and riprap in Zone 2, and a concrete wall with riprap for Zone 3.

This project is still in its early stages and our work is only one of many components feeding into the final design. We look forward to the future development and construction of the Greenway over the next decade.

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Appendix 1 - GIS Documentation

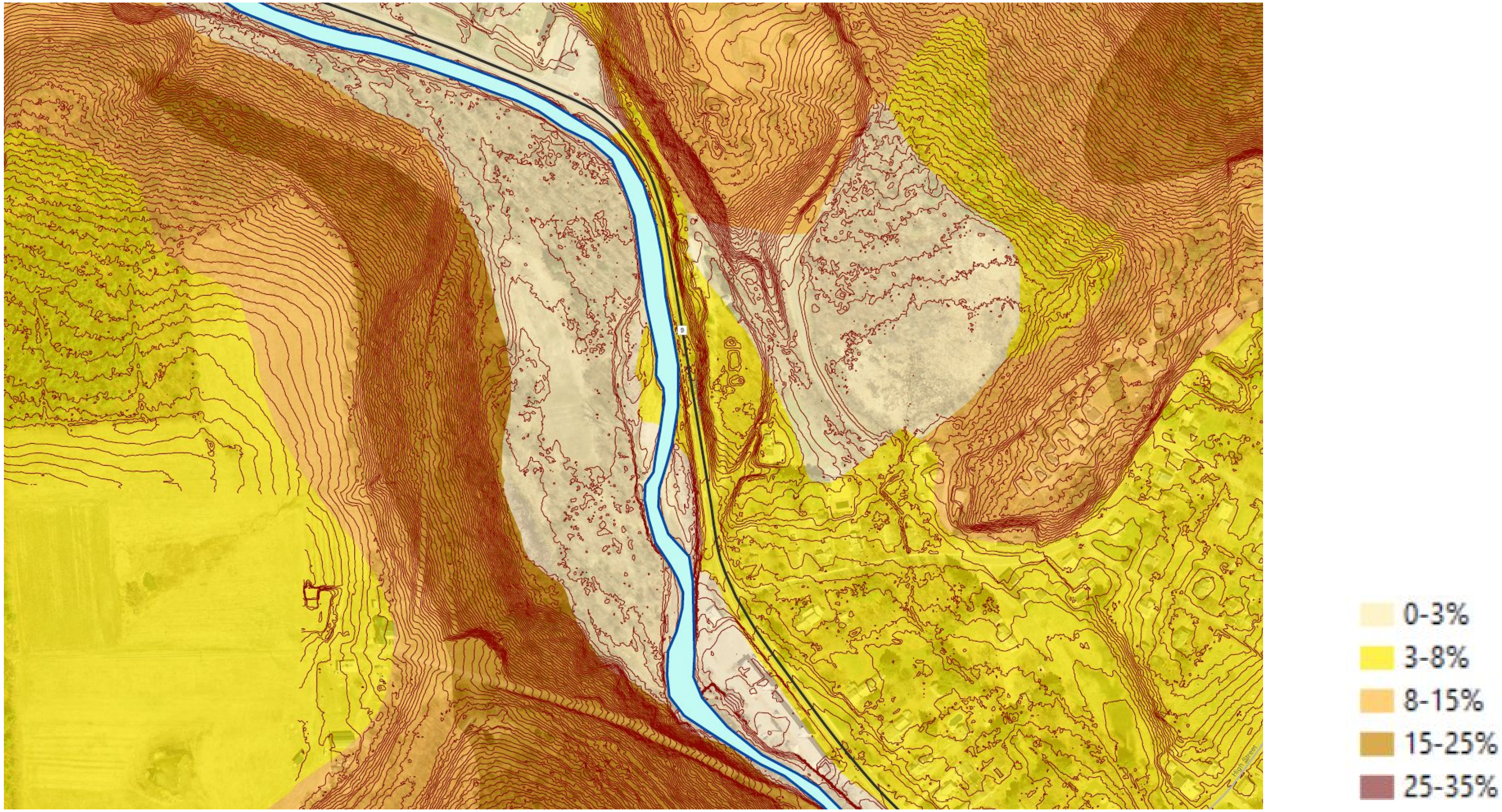
Our GIS documentation consists of five different maps, with a total of 7 layers. These maps help us to characterize the soil slopes, topography, farmland types, boundaries of various land uses, property ownership, and rock types.

<u>SOIL SLOPE</u>

This layer consists of two overlain layers:

Area by soil slope, sourced from MassGIS NRCS SSURGO-Certified Soils database. This layer divides the landscape into 5 areas of varying slope-ranges shown in the legend below. (MassGIS, November 2012)

2-ft contour lines, supplied by Reid Bertone-Johnson, Smith College Landscape Studies Department. Given its large scale, this layer provides a more accurate characterization of the landscape.



(MassGIS November 2012)

PRIME FARMLAND

This layer consists of three farmland categories: prime farmland, farmland of unique importance, and farmland of statewide importance. The land immediately on either side of the river is prime farmland, and as such should be protected from excess flooding. It should be noted that because the river has changed over time, there is a noticeable line of blank space where the river flowed at the time of data collection for this layer. This does *not* indicate a lack of forest here; rather, it can be assumed that prime farmland has taken its place.

Prime Farmland

"Land that has the best combination of physical and chemical characteristics for economically producing sustained high yields of food, feed, forage, fiber, and oilseed crops, when treated and managed according to acceptable farming methods." (MassGIS, November 2012)

Farmland of Unique Importance

"Land other than prime farmland or farmland of statewide importance that might be used for the production of specific high value food and fiber crops. (ei. Tree nuts, cranberries fruit and vegetables)" (MassGIS, November 2012)

Farmland of Statewide Importance

This land has the basic definition of prime farmland, and are "... *nearly* prime farmlands that economically produce high yields of crops when treated and managed according to acceptable farming methods." (MassGIS, November 2012)

(MassGIS November 2012)

All Areas are Prime Farmland

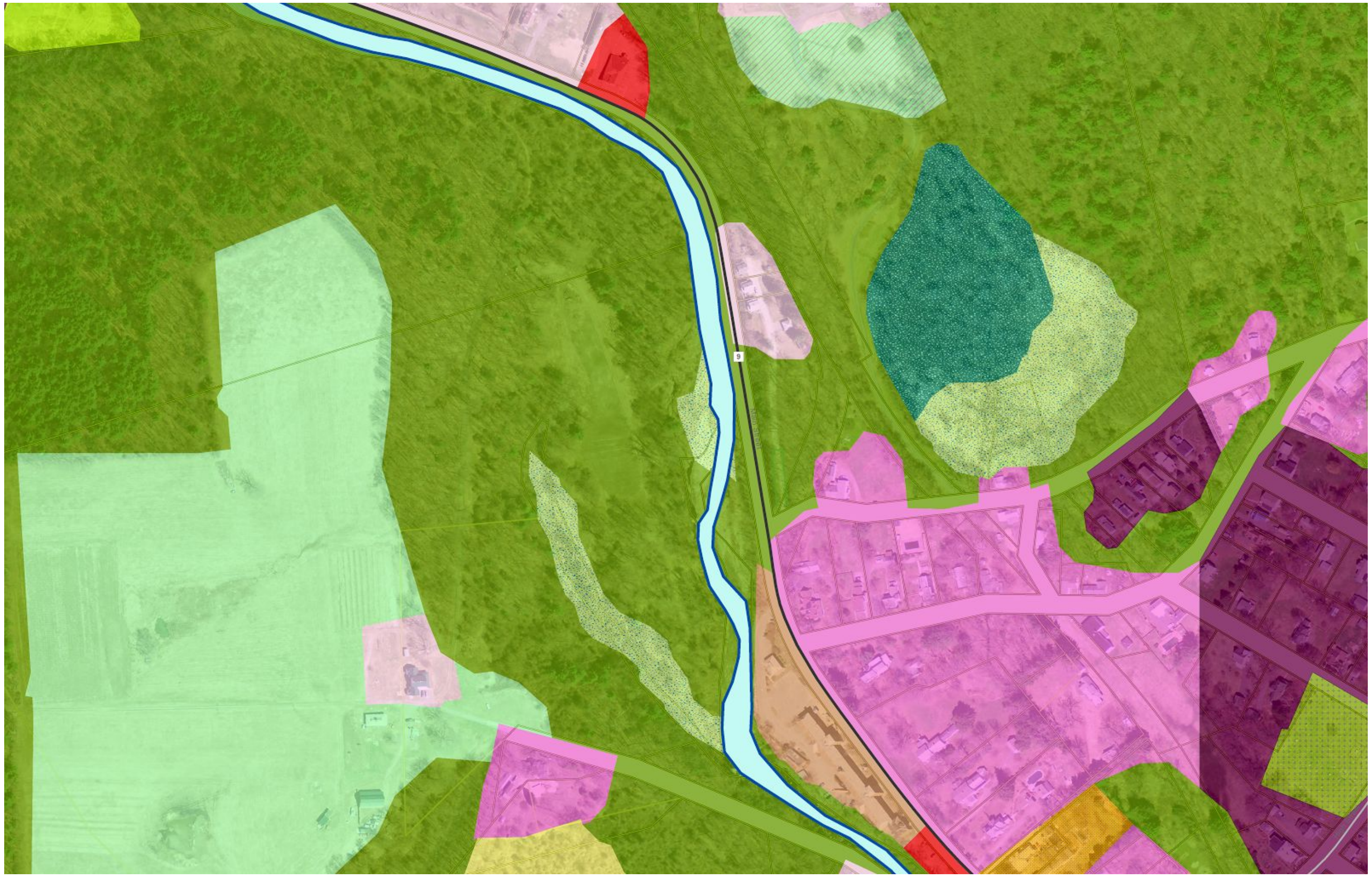
Farmland of Statewide Importance

Farmland of Unique Importance

<u>LAND USE</u>

This layer includes a range of uses for land; of most importance here are the following: Forest, Non-Forested Wetland, Urban Public/Institutional, Low Density Residential, and Very Low Density Residential.

A majority of the land immediately surrounding the river is forested, but there is also a portion of Non-Forested Wetland very near to the water's edge, just downstream of the bend on the farmland side of the highway. There is also a small area of wetland between the river and the highway; according to the land use data (last updated in 2009), the wetland is roughly 11 meters away from the road. Because the layer may be outdated, we plan to confirm numbers on-site.



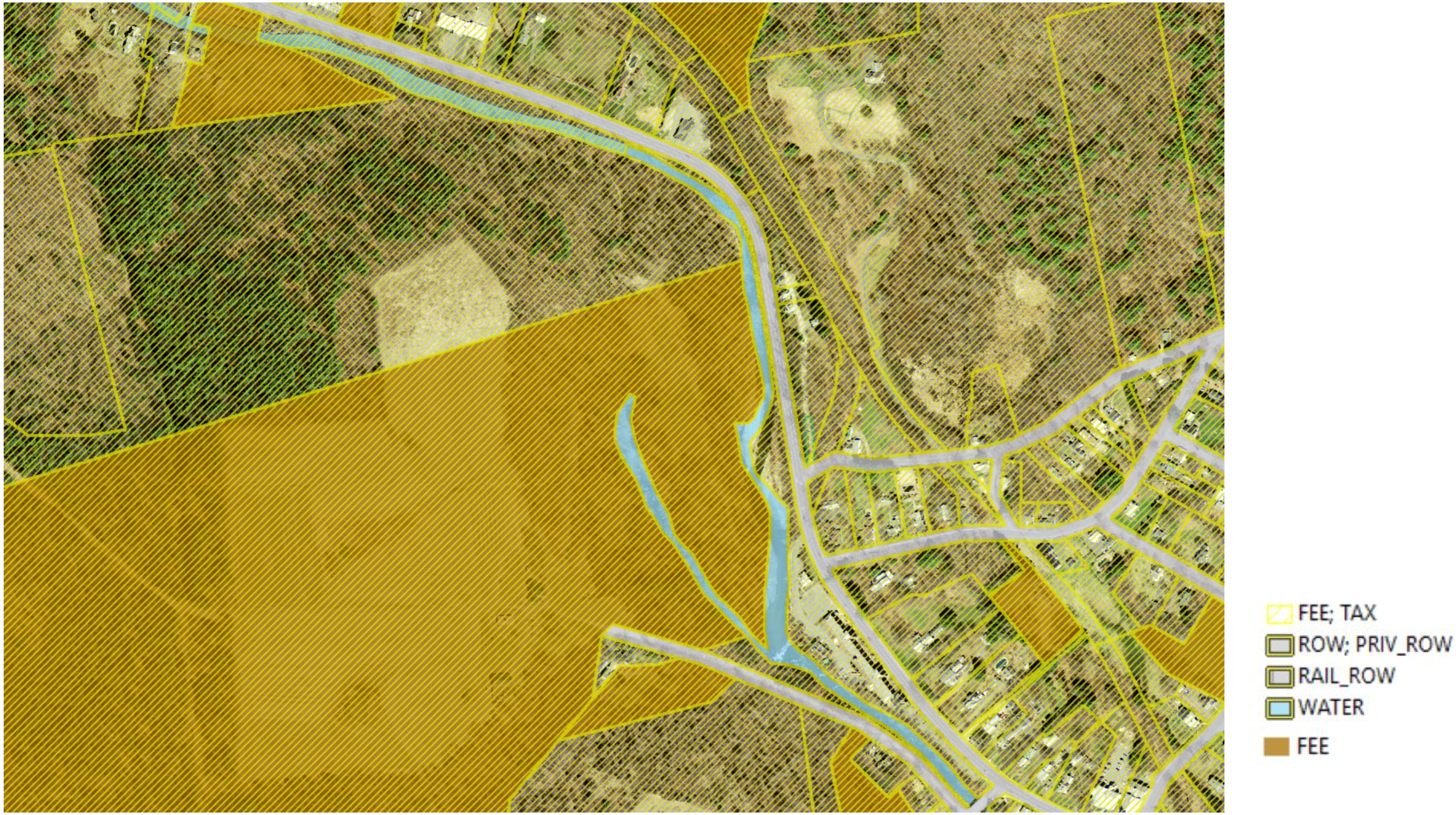
As defined by the Massachusetts Association of Conservation Commissions, wetlands are "land areas that contain surface water all or part of the time, as well as some adjacent land areas." It is important to ensure that the process of construction of the Greenway does not destroy or alter the wetland in accordance with the Massachusetts Wetlands Protection Act, enforced by the Williamsburg Conservation Commission.

(MassGIS June 2009)

PARCELS

It will be helpful for the project and the town members to know which lands, and maybe as a result, which landowners, may be influenced by the construction performed at this site.

This layer contains: “polygons or multi-part polygons, each of which links to one or more assessor tax records (unless it is a feature for which a tax record has not been established, i.e. public right-of-way, most water, etc…)” (MassGIS October 2017). Since most of the lands around the Mill River at the bend (with the exception of the road) are defined with this layer, it means that a majority are private properties. This map allows for a greater understanding of the legal aspects involved in constructing the Greenway at this section. (MassGIS Data - Level 3 Assessors’ Parcel Mapping)



(MassGIS October 2017)

SURFICIAL GEOLOGY

This data layer is “a compilation of surficial geologic materials, defining the areas of exposed bedrock, and the boundaries between glacial till, glacial stratified deposits, and overlying early-postglacial and postglacial deposits.” (MassGIS Data - Surficial Geology)

The geologic features overlap in many places, with the order corresponding to the order of rock layers. Thin Till Bedrock is the general underlying layer throughout the site, with Alluvium Postglacial Deposits the topmost layer immediately surrounding the river. Coarse Glacial Stratified deposits are found East of Route 9, covered by Stream-Terrace deposits over the same area.

(MassGIS, August 2015)

Map and Description Sources

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TRACEABILITY MATRIX

HEC-RAS Model at Mill River Greenway on Bend of Route 9

Fereshta Noori, Maya Sleiman, Marcia Rojas, Laura Rosenbauer

Date: (5/7/2018)

Revision: C7

This project aims to assess different bank-retaining alternatives for a greenway project connecting the towns of Haydenville and Williamsburg. The suggested alternatives will be informed by a HEC-RAS hydraulic model of the Mill River along with GIS mapping of the Mill River area.

DESIGN INPUTS								DESIGN OUTPUTS		
Stakeholder Needs (SNs)			Design Requirements (DRs)					Design Verification		
SN ID	Stakeholder Need Statement	Stakeholder Need Source	DR ID	Design Requirement Statement	Design Requirement Specification	Design Requirement Source	Verification Protocol for DR	Design Verification Result	Design Verification Date	Design Verification Documentation
SN-01	Hydraulic model compatibility	WMRGC	DR-01	Runs on software that is common throughout the professional field	use of HEC-RAS 1D, as standard hydraulic modeling software	WMRGC Meeting Minutes 11/08/2017	Confirm the use of HEC-RAS 1D by retrieving analysis output	Pass	4/9/2018	Figure 13 in Final Report
SN-02	Accounts for major flood events	WMRGC & MassDOT	DR-02	Accounts for the 2, 10, 25, 50 and 100 year floods	flow values input into HEC-RAS should include flow values of the 2, 5, 10, 25 and 100 year floods	WMRGC Meeting Minutes 11/08/2017	Test flood flow values in HEC-RAS model	Pass	5/4/2018	Figure 13 in Final Report
SN-03	Accurately predicts river velocities for storm events	WMRGC & MassDOT	DR-03	Predicts values within 1 ft of measured water level data	|Predicted WSE - Measured WSE| < 1ft	Brett Towler Meeting Minutes 2/22/2018	Calculate the error from the predicted and actual water surface level to be no greater than 1ft in difference(predicted by Brett-Towler or other source)	Pass	5/4/2018	Appendix 6: Accuracy Calculations for HEC-RAS Model
SN-04	Considers the effects of the Brassworks dam on the stability of the greenway	WMRGC & MassDOT	DR-04	Quantifies the effect of the Brassworks dam on the river hydraulics	model includes situation with and without dam	WMRGC Meeting Minutes 9/15/2017	Test HEC-RAS models with and without the Dam	Pass	5/4/2018	Figure 14 from Final Report
SN-05	Data collected must be compatible with future surveys	VHB	DR-05	includes control points in data collection	GPS-located fixed points along Route 9 must be clearly marked for visual recognition by on-ground surverying crew.	WMRGC Meeting Minutes 10/18/2018	Email Hill Engineers control points and ask whether they are physically able to locate our control points and that upon sending them electronically, they are able to apply the points into their master AutoCAD file.	Pass	4/9/2018	Hill Engineers Email Confirmation

TRACEABILITY MATRIX

Bank Protection at Mill River Greenway on Bend of Route 9

Fereshta Noori, Maya Sleiman, Marcia Rojas, Laura Rosenbauer

Date: (5/7/2018)

Revision: C7

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Stakeholder Needs (SNs)			Design Requirements (DRs)					Design Verification		
SN ID	Stakeholder Need Statement	Stakeholder Need Source	DR ID	Design Requirement Statement	Design Requirement Specification	Design Requirement Source	Verification Protocol for DR	Design Verification Result	Design Verification Date	Design Verification Documentation
SN-01	protect riverbank at route 9 bend from erosion with the dam	WMRGC & MassDOT	DR-01	withstand velocities predicted by the HEC-RAS model with the dam	Allowable velocity of design > Predicted velocities for the 100 year floods (modelled with the dam)	WMRGC Meeting Minutes 11/08/2017	Use the table TS14I–4 from NCRS Technical Supplement 14I and Figure 8–25 from NRCS Part 654 Restoration Design National Engineering Handbook to compare these values to those of the HEC-RAS design model velocities	Pass	5/4/2018	NCRS Technical Supplement 14I: Streambank Soil Bioengineering – *Table TS14I–4* , NRCS Part 654 Restoration Design National Engineering Handbook: Chapter 8 Threshold Channel Design – Figure 8–25, HEC-RAS Alternatives Model Velocity Outputs (With and Without Dam) - Refer to Appendix 13
SN-02	protect riverbank at route 9 bend from erosion without the dam	WMRGC & MassDOT	DR-02	withstand velocities predicted by the HEC-RAS model without the dam	Allowable velocity of design > Predicted velocities for the 100 year floods (modelled without the dam)	WMRGC Meeting Minutes 11/08/2017	Use the table Table TS14I–4 from NCRS Technical Supplement 14I and Figure 8–25 from NRCS Part 654 Restoration Design National Engineering Handbook to compare these values to those of the HEC-RAS design model velocities	Pass	5/4/2018	NCRS Technical Supplement 14I: Streambank Soil Bioengineering – *Table TS14I–4* , NRCS Part 654 Restoration Design National Engineering Handbook: Chapter 8 Threshold Channel Design – Figure 8–25, HEC-RAS Alternatives Model Velocity Outputs (With and Without Dam) - Refer to Appendix 13
SN-03	protect greenway from possible flooding	WMRGC & MassDOT	DR-03	Prevents river water level from rising above the Greenway bank level	Water surface elecation of the 100 year flood < Elevation of top of design	WMRGC Meeting Minutes 11/18/2017	Run the HEC-RAS model with the alternatives and ensure that at the 100 year flood, the top water level does not exceed the road-level	Pass	4/26/2018	HEC-RAS Cross Sections - Refer to Appendix 13
SN-04	Must meet vehicular spatial standards	MassDOT	DR-04	minimum shoulder width and bikeway width are accommodated	With designs: Threshold: shoulder = 4' Objective: shoulders = 5' Greenway width = 12'	WMRGC Meeting Minutes 3/28/2018	Confirm in HEC-RAS cross section whether or not top width of the road to the river is at least 16'	Pass	4/26/2018	Figure 15 from Final Report

Consideration

SN-05	Must minimize impact on the various aquatic species in the Mill River, and their habitat, after implementation	Williamsburg Conservation Committee	DC-01	minimizes impact on water temperature, allows for vegetation and habitat	creates shade, low velocity areas, and interlocking vegetation

Appendix 3: HEC-RAS Manual

This manual gives an overview of the steps needed to create a steady-flow hydraulic analysis in HEC-RAS. It explains the steps of creating a project folder, a geometry file, and a steady flow file in addition to the input data needed for each of them. It then states the steps to be followed to run a steady flow analysis using the created files

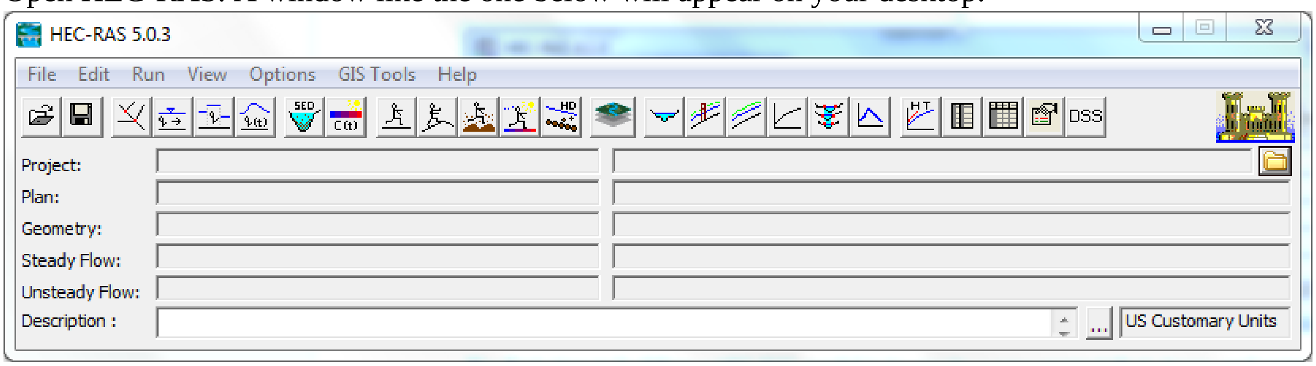
Manual for Creating a Base Hydraulic Model in HEC-RAS and Running a Steady Flow Analysis

Created by: Maya Sleiman
Created on: 04/07/2018

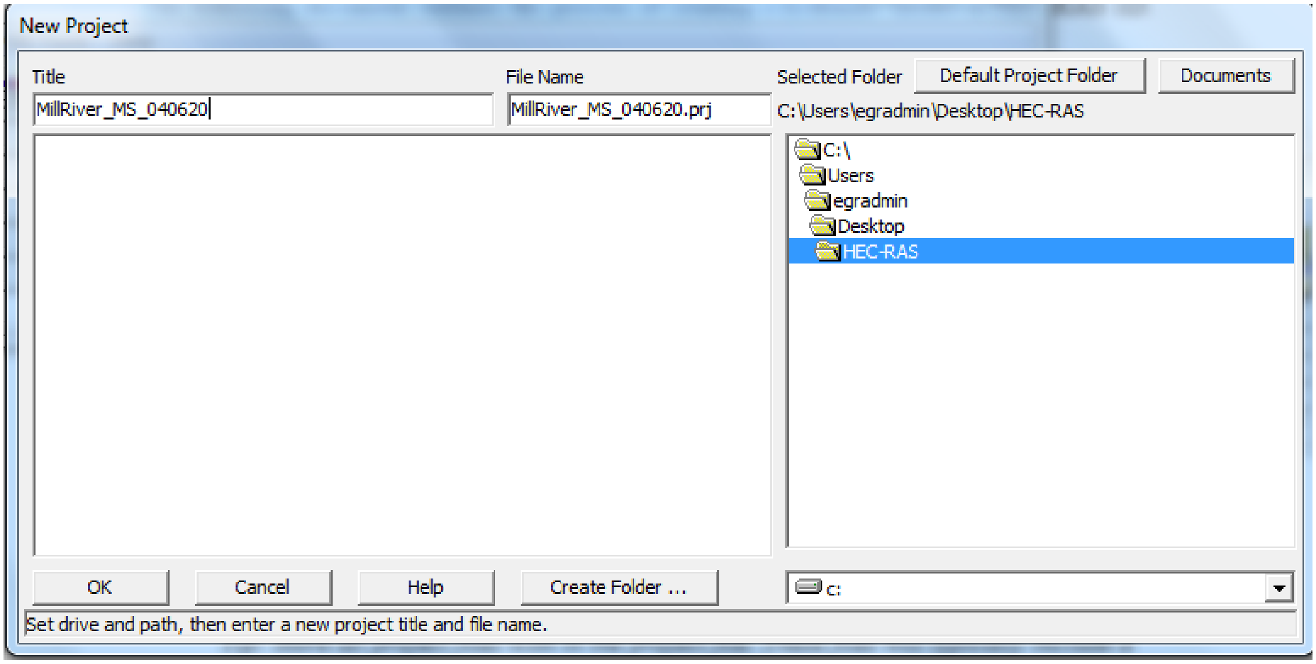
The following document outlines the process of creating a hydraulic model in HEC-RAS 1D and running a Steady Flow Analysis on it. This document only covers tools of HEC-RAS that were utilized in our project.

HEC-RAS is an open-source program created by the Hydrologic Engineering Center of the Army Corps of Engineers. You can download it at http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx .

1. Open HEC-RAS. A window like the one below will appear on your desktop.

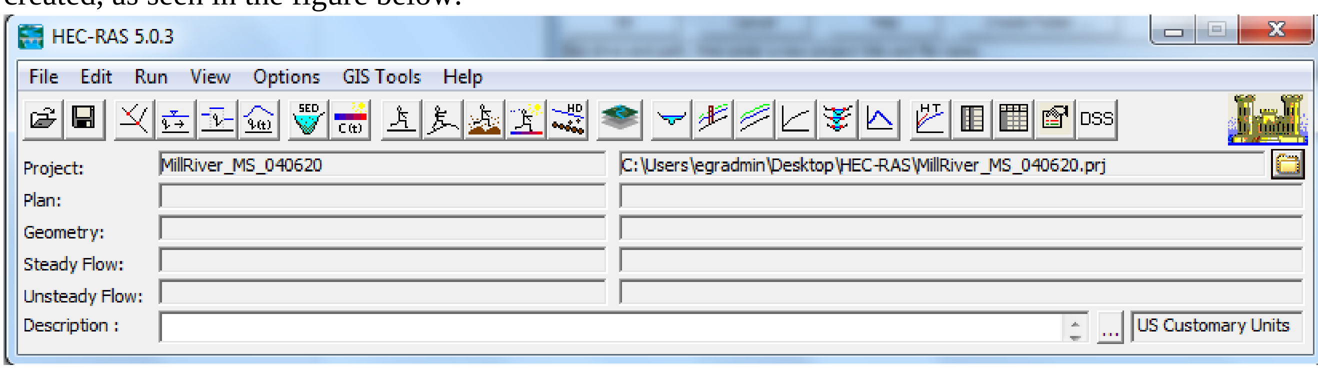


2. To create a new project, go to ***File > New Project.*** Navigate to the folder in which you want to store your project. Give your project a name and click the ***ok*** button on the bottom left. .
   In the example below, I navigated to *Desktop>HEC-RAS* and created a project *MillRiver_MS_040620.*

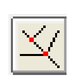


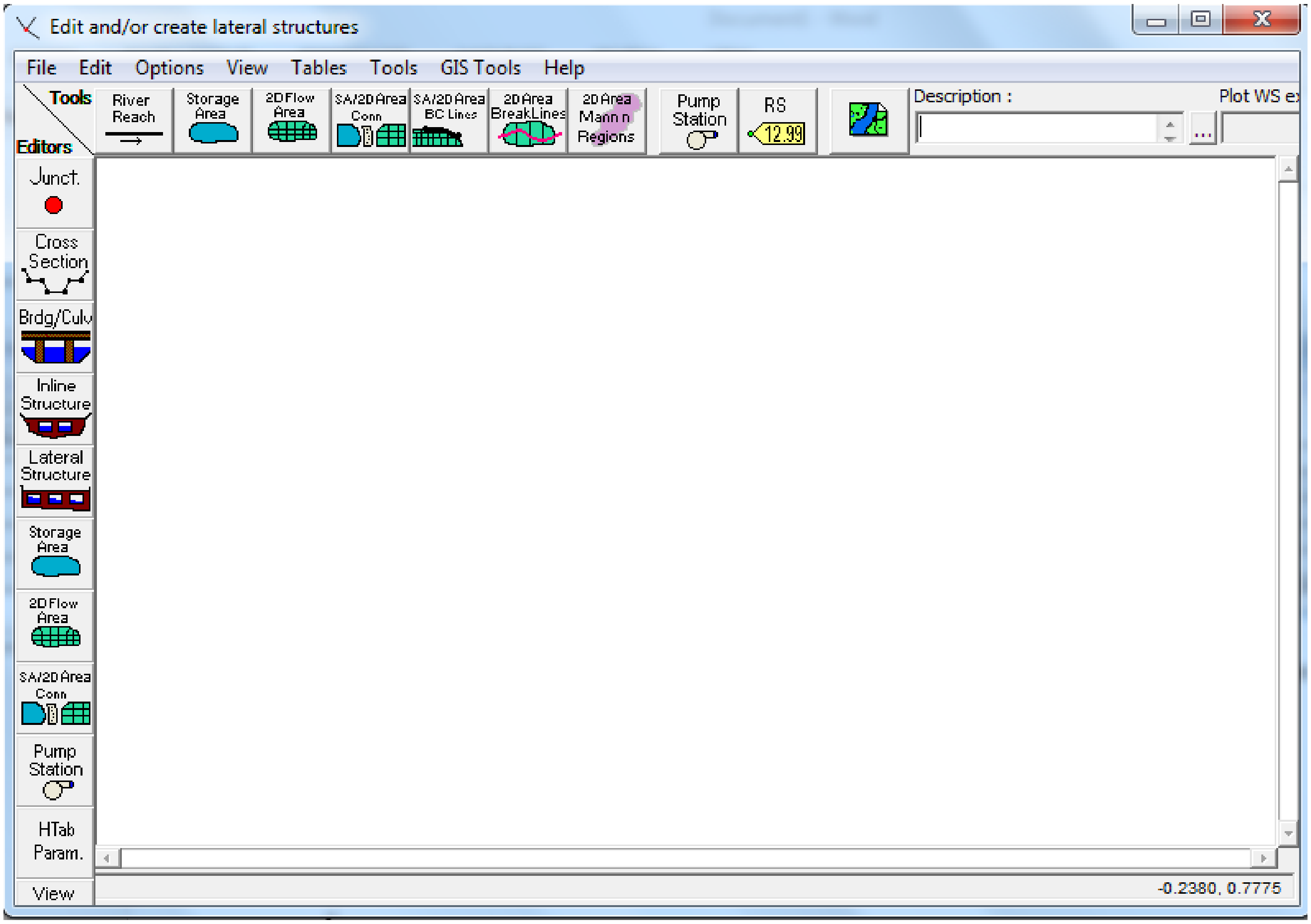
Tip: Store all project files with in the project file. These files will typically include a project, plan, geometry, and steady or unsteady flow.

The HEC-RAS main window should automatically update its *project* path to the name you just created, as seen in the figure below.



The units are automatically set to US Customary Units but can be changed under ***Options > Unit System (US Customary/SI)***

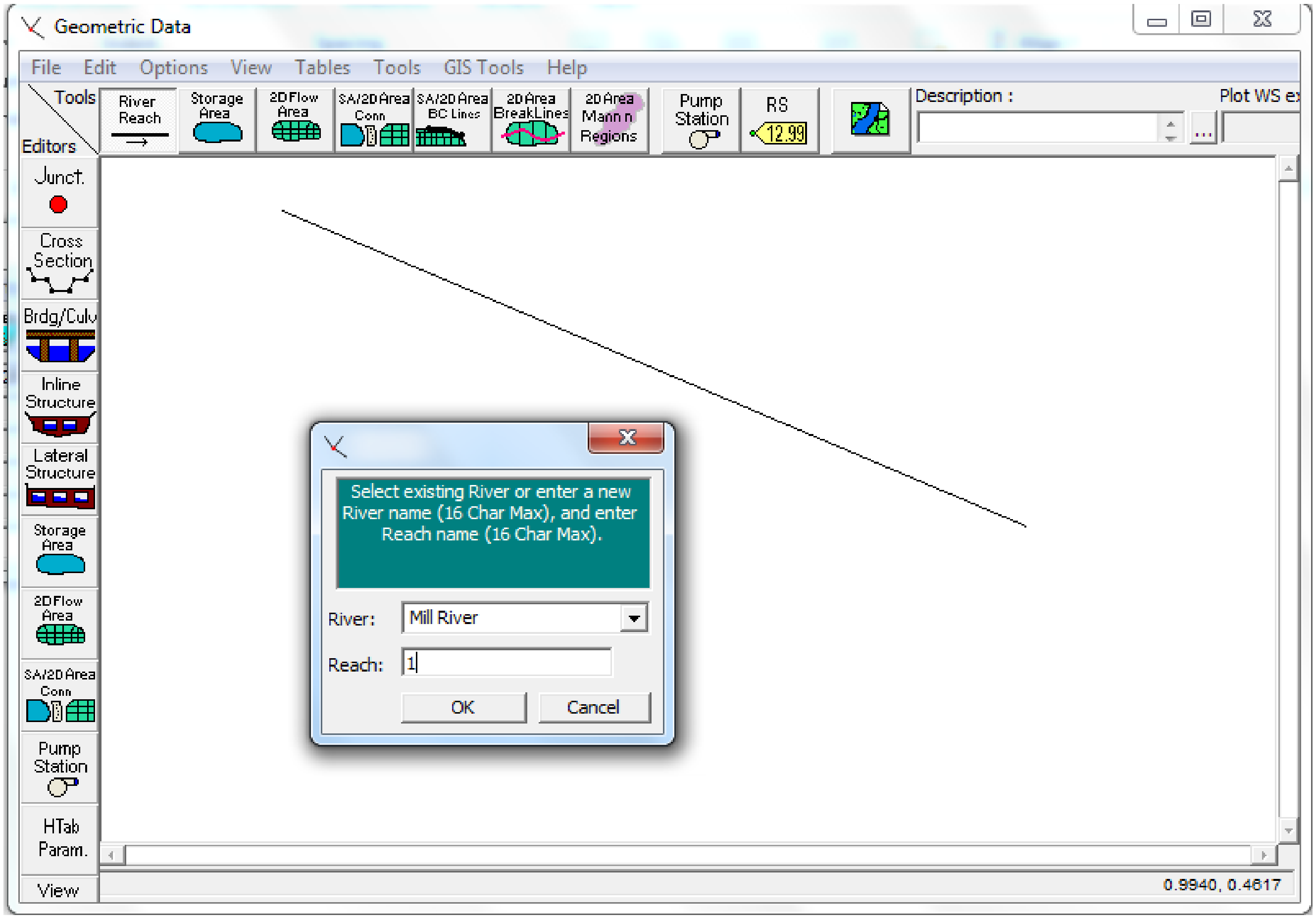
3. To create the plan of your project, click on the ***View/Edit Geometry Data***  . The Geometry Data window shown below will appear.



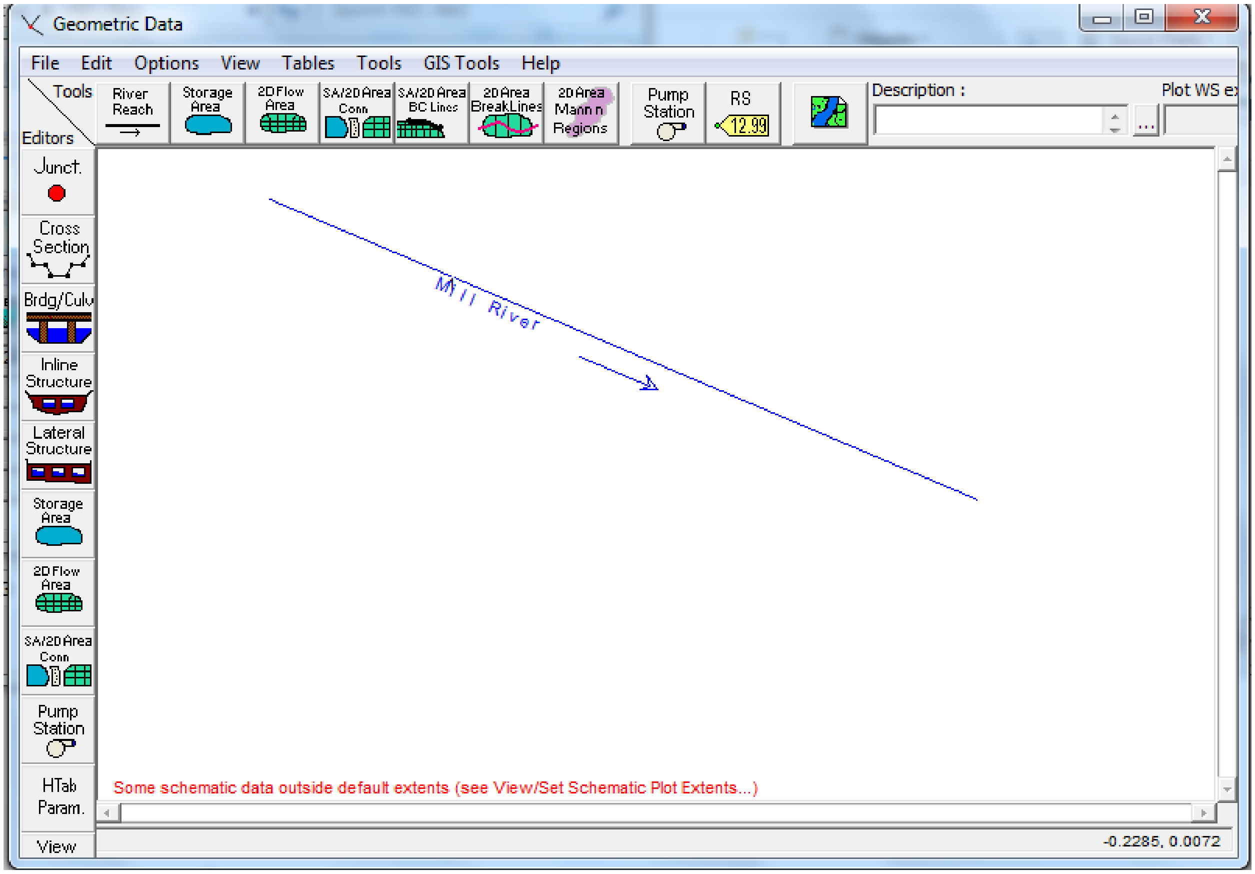
To create your river reach, click on the River Reach button 

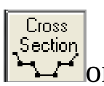
.

You will be prompted to draw a river reach in the white space of the Geometry Data window. Click in the space to establish your upstream point end of the reach, and double click somewhere else on the space to establish the downstream end of your reach.

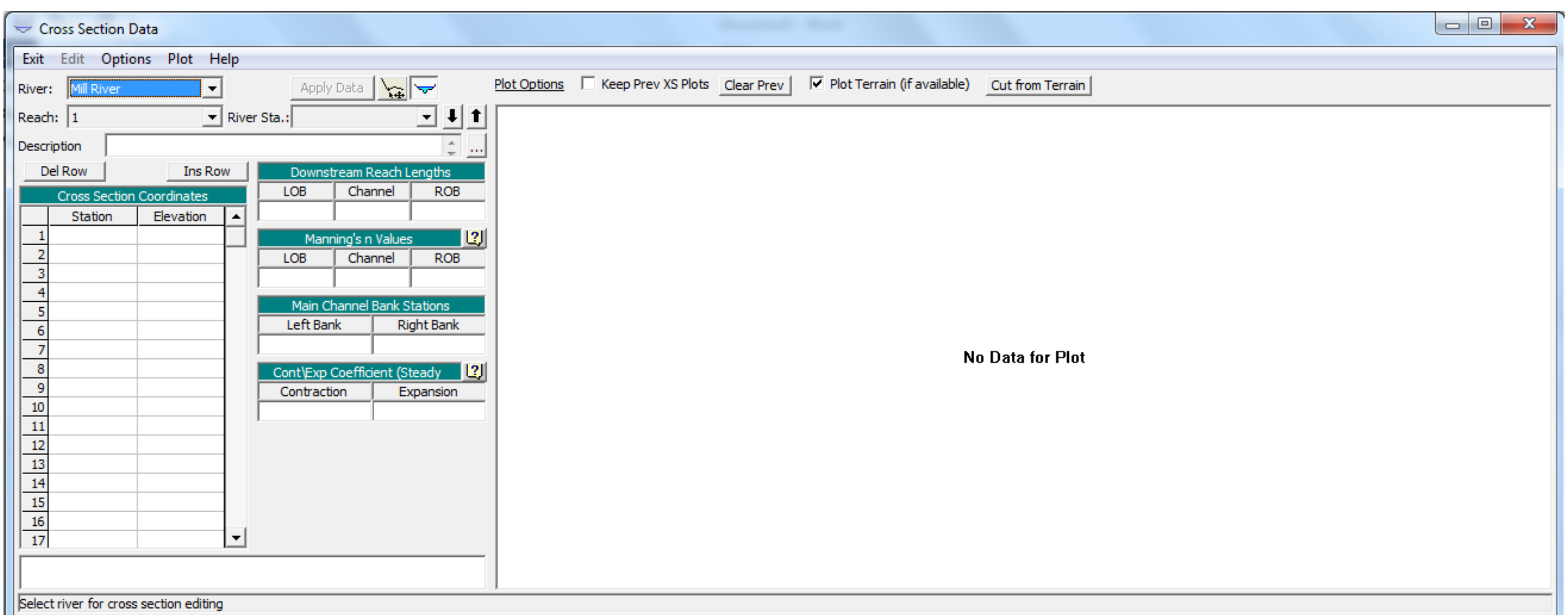


You will be prompted to name the river you are modelling and the reach within this river, as seen in the window above. Click ok. The reach shape will automatically update to show the river name and direction of flow as seen below.

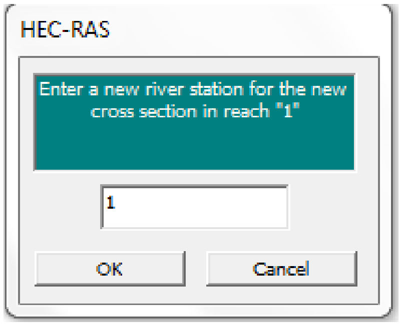


4. To create cross-sections along your reach, click on the **Edit and/or create cross sections** button  on the left side of the **Geometry Data** window.

The Cross Section Data window will appear as shown in the figure below.



shown in the window below.



Click ok.

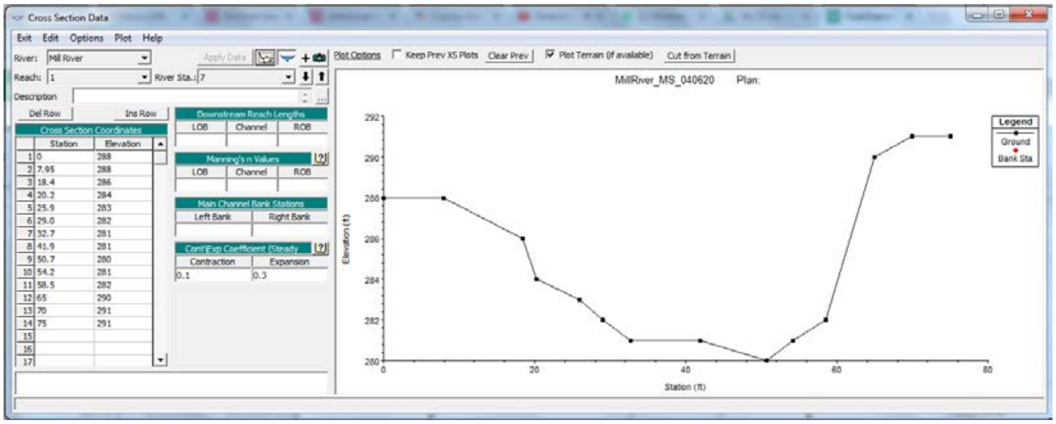
Tip: The default numbering mechanism for HEC-RAS is from downstream to upstream. i.e. smaller station numbers are further downstream, and river station 0 should be the furthest downstream.

Tip: For bigger river projects, river stations are typically numbered based on their location (X or Y coordinate, as deemed convenient)

5. For a new cross section, the following information should be entered to fully define it:

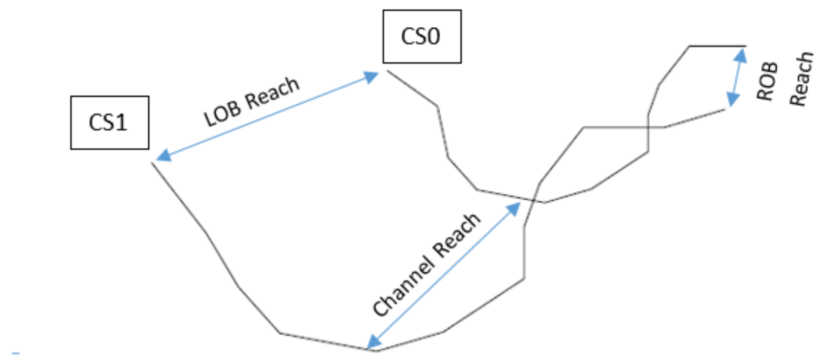
a. <u>Coordinate data of cross section points</u>: This is entered in the *Cross Section Coordinates* table. Each point is defined by two coordinate values, its station and elevation.
Station is the distance from a point to the left extremity of your cross-section.
Elevation is the elevation of the point above mean sea level.

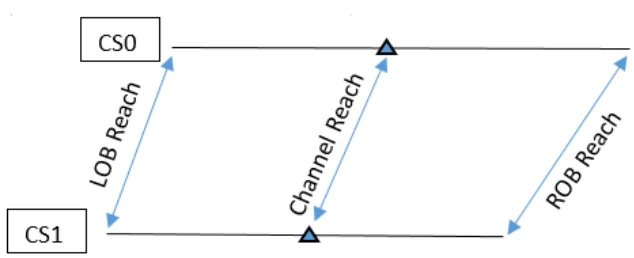
For the purposes of our example, the following (station, elevation) coordinates are entered by copying a list of previously-prepared coordinate list from an Excel sheet and pasting the list into the Cross Section Coordinates table as shown below.
Click the *Apply Data* button to show the resulting changes in the cross section shape.



Tip: When pasting multiple rows of data from Excel, make sure to select an adequate number of cells in the HEC-RAS table before you paste your data. If you only select one cell, only one value will be pasted from Excel into HEC-RAS. Unlike Excel, HEC-RAS does not automatically *populate the appropriate number of rows and columns based on the number of copied rows and columns.*

b. **Downstream Reach Length:** This is the distance between the current cross section and the following one downstream. It is divided into Right of Bank (ROB), Left of Bank (LOB), and Channel downstream reach lengths. The figures below show the downstream reach lengths of cross-section 1.





Top view of the river reach

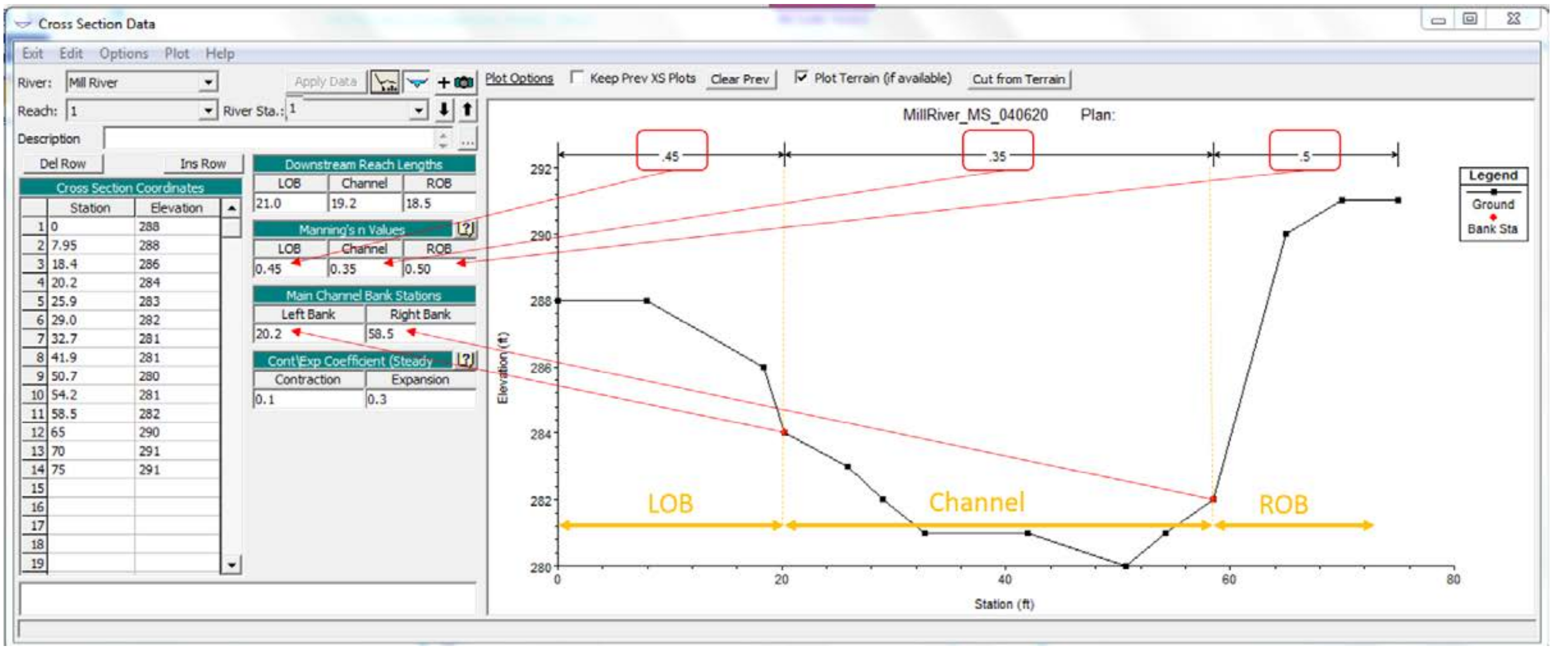
c. **Manning's roughness value,** which should be assigned for the Right Bank, Channel, and Left bank of each cross section.

d. **Main Channel Bank Station,** which specifies the border-points of the right and left banks.

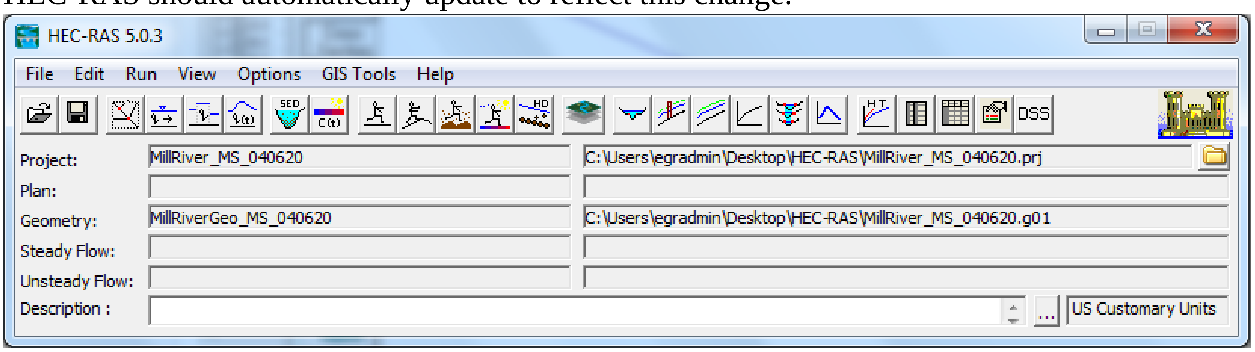
*Tip: Manning's number can be specified for each of the banks and the main channel as defined by **item d** above. Accordingly, make sure the definition of banks and main channel reflects the changes in Manning's number.*

e. **Expansion/Contraction Coefficients:** These are set to 0.1/0.3 by HEC-RAS. They can be changed to reflect flow through inline structures like bridges and weirs.

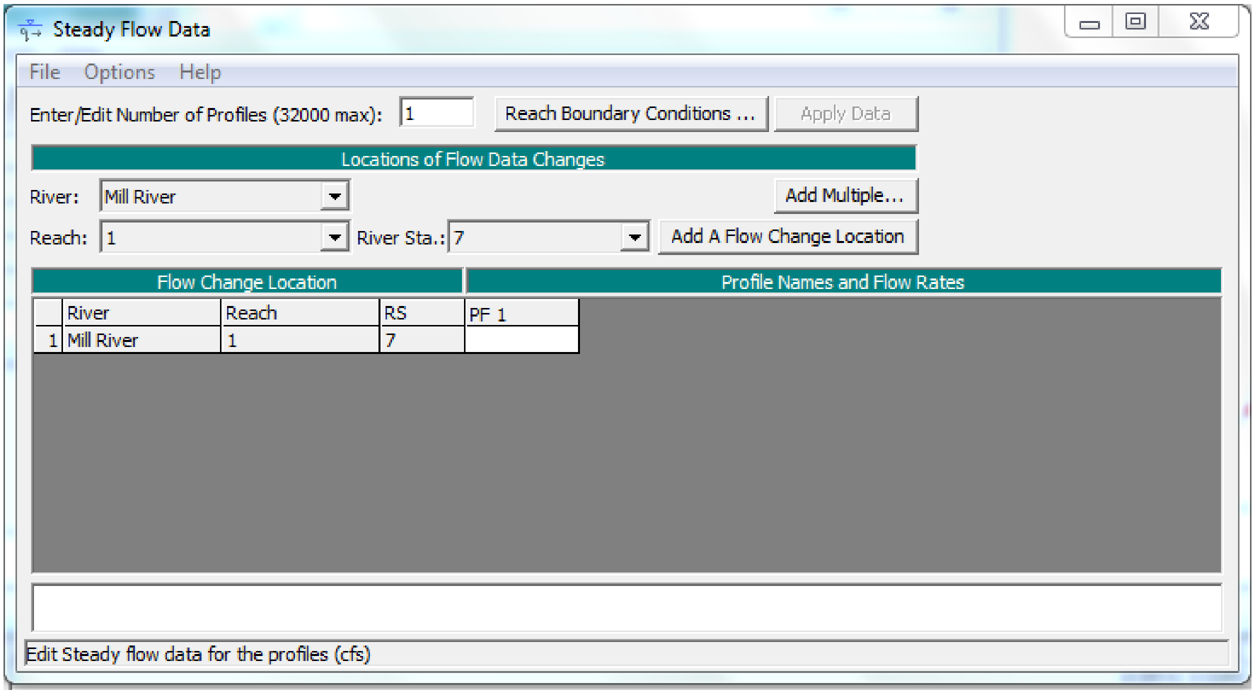
After filling the above values, your Geometric Data window should be similar to the one below:



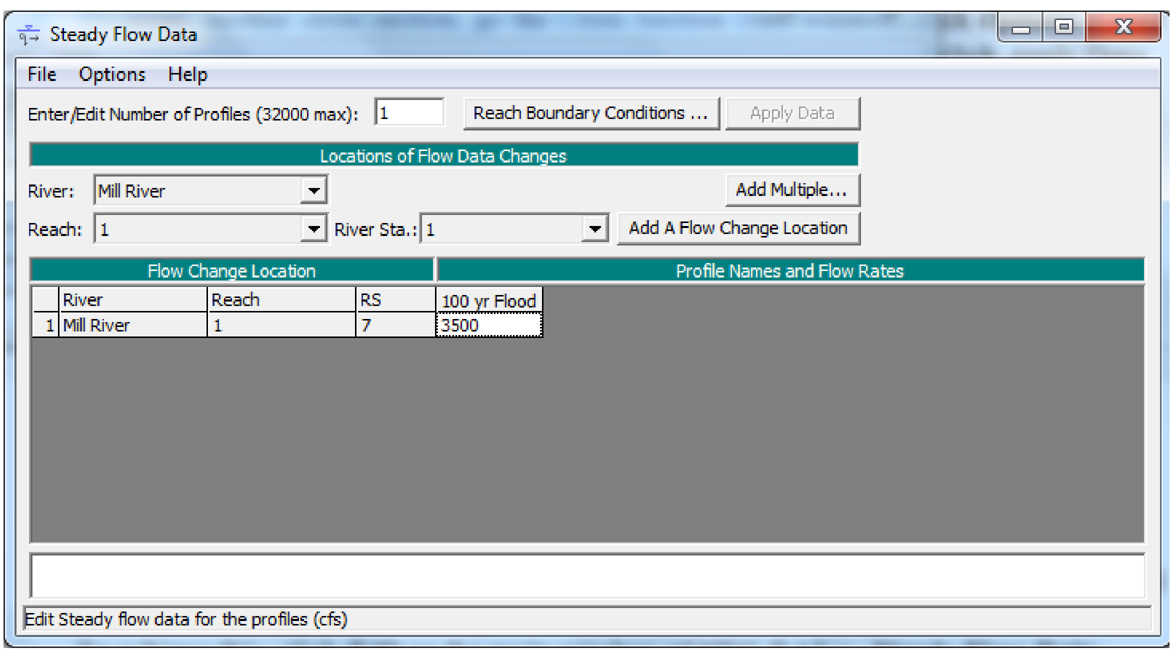
6. To save your geometry data, go the Geometric Data window, click **File** > **Save Geometry Data as**, name the file, and place it in the project folder. The *Geometry* path on the main window of HEC-RAS should automatically update to reflect this change.



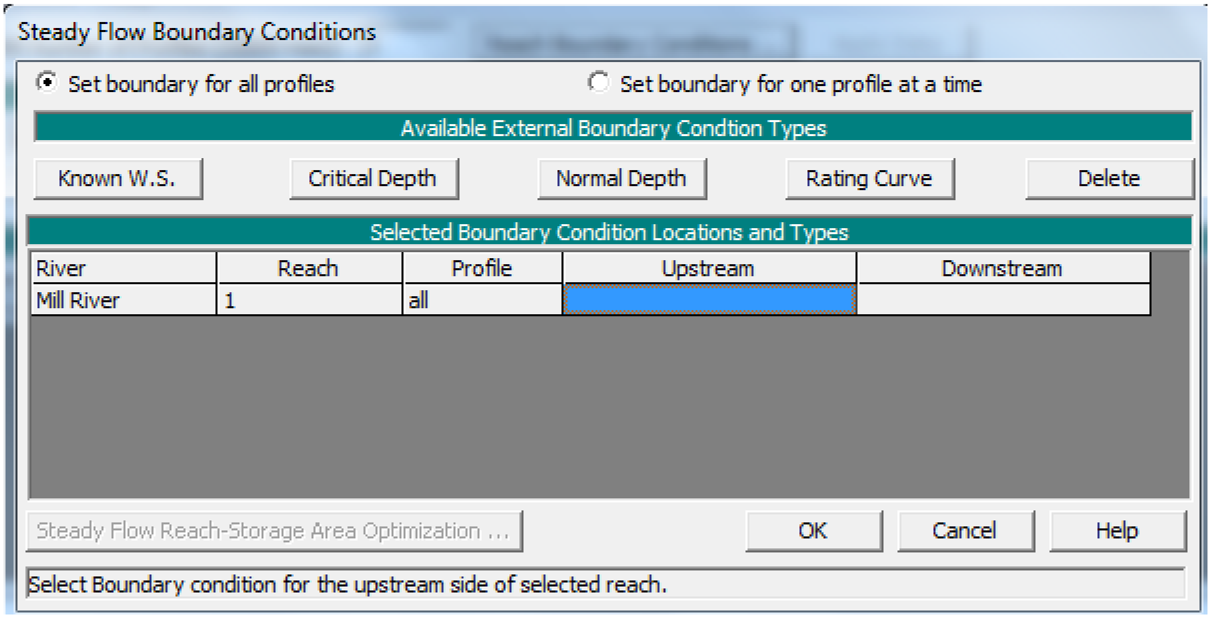
7. To create another cross section, go the Cross Section Data window, click ***Options > Add a new cross section***, and repeat sub-steps within step 5. Remember to click *Apply Data* after editing the geometric data and to save your geometry data frequently.
8. Now that you have fully defined the geometry of your river reach by creating and saving a Geometry file, you will define your steady flow conditions.
   To achieve this, click ***Edit*** on the main window of HEC-RAS > ***Steady Flow Data.*** The window below should appear.



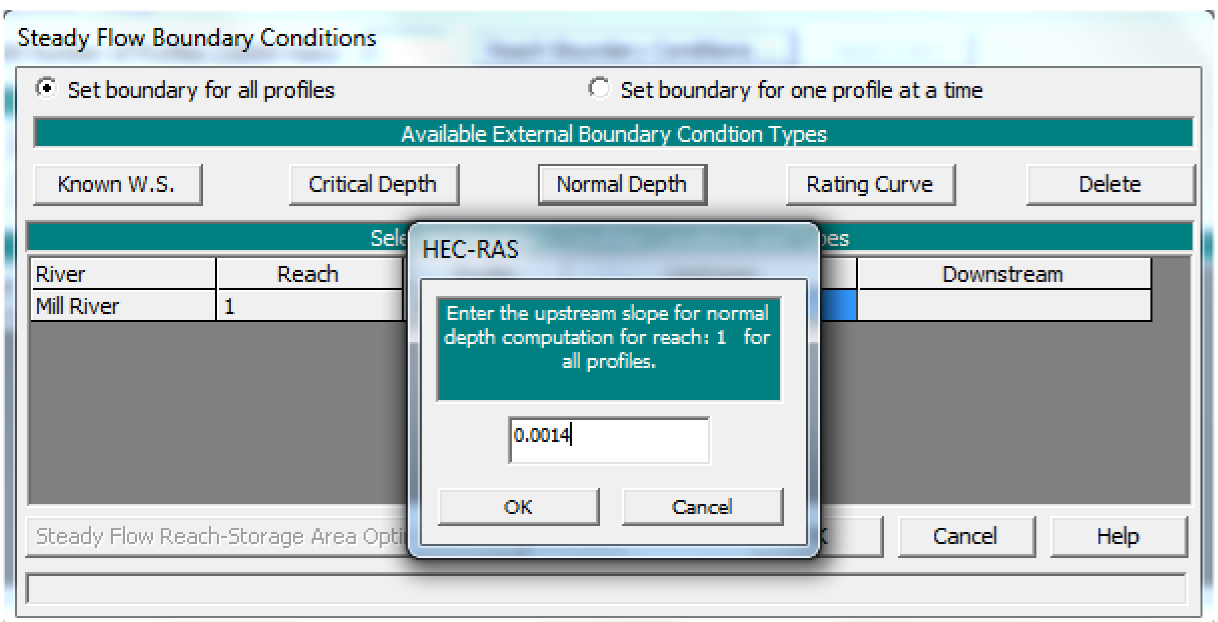
9. To enter the flow value of your river, type in the flow in the white box under *PF 1*. PF stands for Profile Flow, as shown in the window below.
   You can rename your Profile Flow name: On Steady Flow Data window, click ***File*** > ***Rename Flow Title*** > type in the name of your flow > click ***ok***.



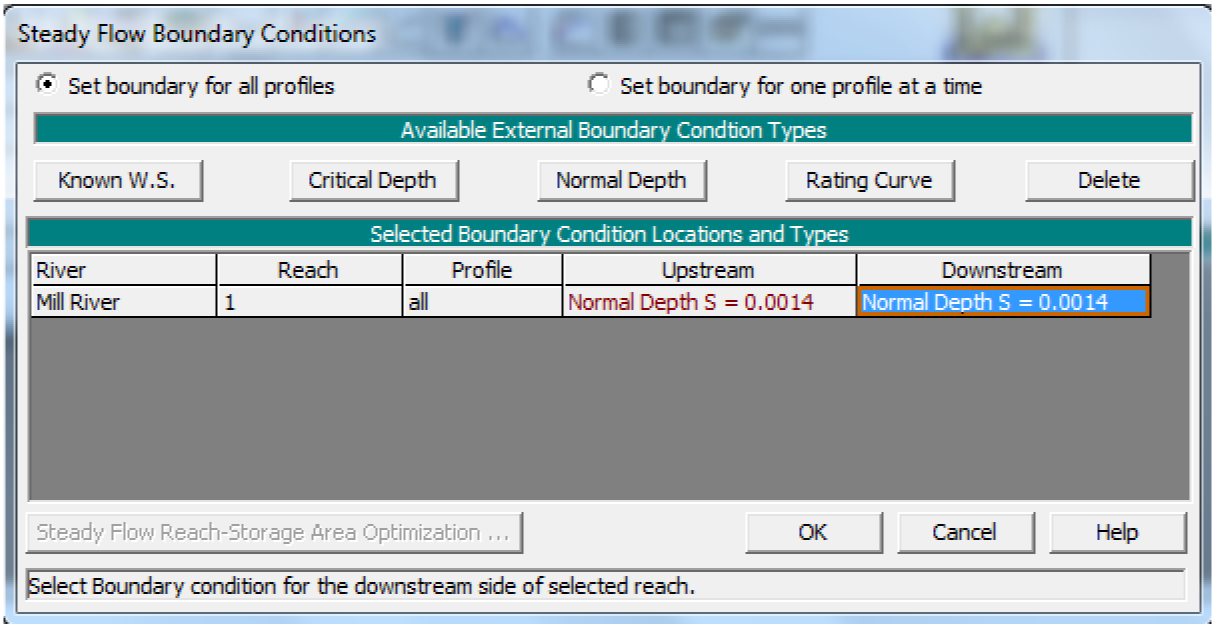
10. To define your boundary conditions, click *Reach Boundary Conditions*. The window below will appear, giving you four options for *Upstream* and *Downstream* boundary conditions: *Known Water Surface, Critical Depth, Normal Depth, and Rating Curve.*



Click on box under *Upstream*, then click *Normal Depth*. A window will appear prompting you to specify the upstream normal depth slope. This can be estimated by entering the channel slope. In our example, we enter 0.0014, meaning that the elevation of the channel changes by 1.4 ft every 1000 ft of reach length.

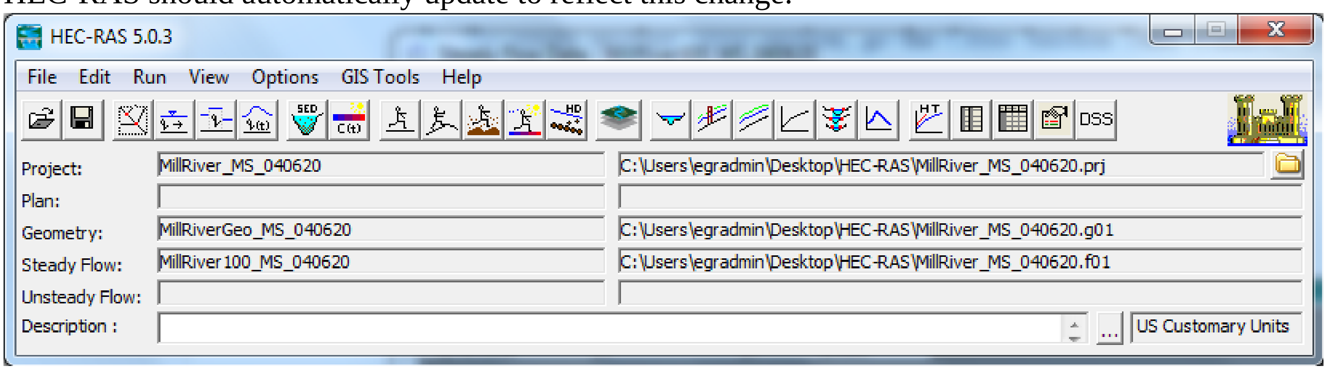


Click ok, and repeat for downstream boundary.

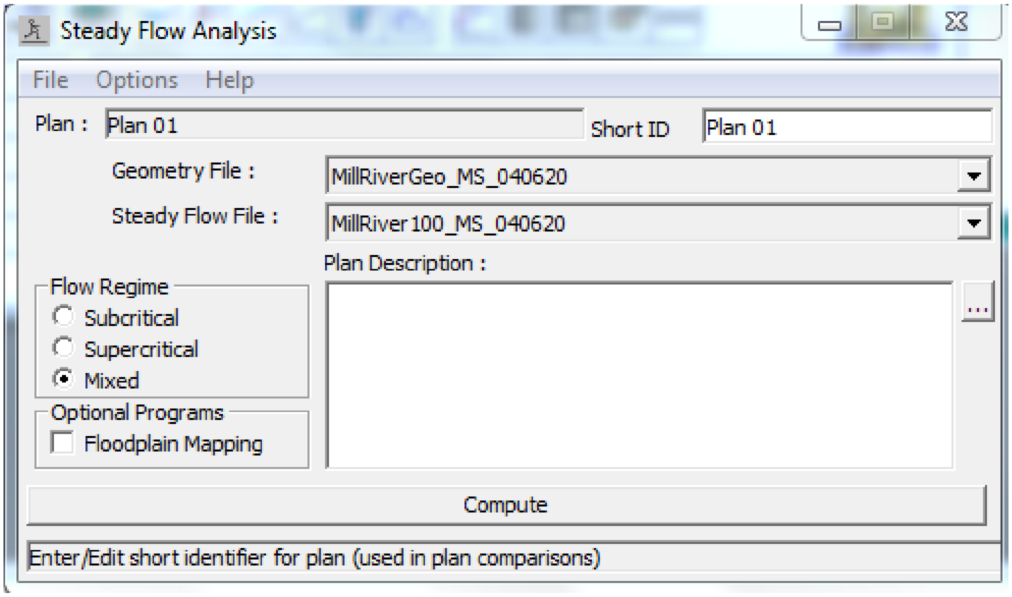


Click *ok*, then *Apply Data* when done.

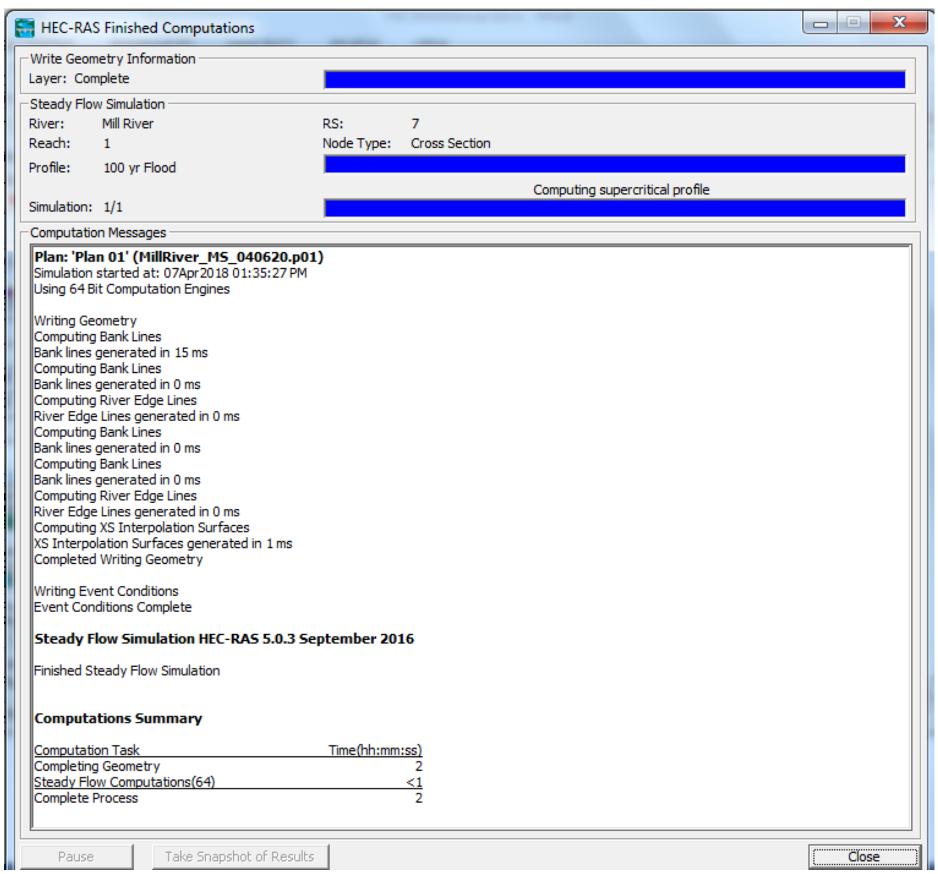
11. To save your flow data, go to the *Steady Flow Data* window, click on ***File > Save Flow Data As*** > name the file, and place it in the project folder. The *Steady Flow* path on the main window of HEC-RAS should automatically update to reflect this change.



12. To run your model, click ***Run*** on the main HEC-RAS window > ***Steady Flow Analysis.*** You will be prompted to choose a flow regime that is either *subcritical, mixed,* or *supercritical.* For our example, we will choose mixed. Click Compute.



The following window should appear. The blue bars will fill up to indicate the completion of the computation. Click *close*.



Data Manipulation Documentation
Created by: Maya Sleiman Created on: 04/07/2018

Data Set 1
Data Set 1 was collected on November 4th, 2017.
It covers the first six cross sections upstream (XS13 – XS7 in HEC-RAS model).

Below is the original format of the data, as retrieved from the Total Station SD Card by Bob Newton (Table 4-1).

Table 4-1: Raw Data from Data Set 1

Point Id	Northing	Easting	Orth. height	Time
A1	422228.5678	-724235.3781	93.9560	11/04/2017 09:59:44
A2	422232.1143	-724234.3234	93.0367	11/04/2017 10:01:40
A3	422235.0207	-724233.5142	92.5820	11/04/2017 10:02:25
A4	422236.6483	-724233.0576	92.0778	11/04/2017 10:03:56
A5	422239.2994	-724232.5977	91.8247	11/04/2017 10:04:56
A6	422241.7330	-724232.1736	91.8030	11/04/2017 10:05:36

The data was copied into Excel and the six cross sections were identified as follows. Highlighted rows are of coordinates that were taken using a Trimble GeoXH 2005 device (Table 4-2).

Table 4-2: Data from GPS from Data Set 1

Point Id	Easting	Northing	Orth. height
XS13_12(RIGHT)	-724235.3776	422228.5691	93.9557
XS13_11	-724235.3781	422228.5678	93.956
XS13_10	-724234.3234	422232.1143	93.0367
XS13_9	-724233.5142	422235.0207	92.582
XS13_8	-724233.0576	422236.6483	92.0778

When plotted on Google Maps (using longitude/latitude format), the coordinate points took the shape of the bend but appeared in a different place in Massachusetts. There was likely an error in either the information we got from the GPS device (on which the rest of data's coordinates were built) or in the entering of the GPS data into Total Station.

Given that HEC-RAS is not affected by the absolute position of the cross-sections (i.e. where they fall on a map) but rather by their relative position to other points in the model (i.e. distances and angles between a point and another), there was no reason to resurvey these points. Although their location in space was wrong, their relative positions was determined by Total Station, making them reliably accurate for the purposes of our model.

Data Set 2

Data set 2 was collected on March 11th, 2018. It includes XS4 through XS0 (XS7 is approximately halfway between the Brassworks Dam and XS0 is slightly downstream of the South Main Street Bridge.

Some cross sections in this set were physically surveyed (using Total Station) while others were extrapolated using different collected data:

- XS4 was fully taken using Total Station
- Location of XS2 and XS2 were surveyed using Total Station; Elevation was calculated using Total Station Elevation of bridge deck measured between bridge deck and river bed. (method fully documented in Appendix X)
- XS3 was projected from XS2, and XS0 was projected from XS1.

The raw data retrieved from the Total Station by Bob Newton is as follows (Table 4-3):

Table 4-3: Raw Data from Data Set 2

Point Id	Northing	Easting	Orth. height	Time
BRDGE	903407.1793	100818.3619	140.3260	02/24/2018 10:26:30
BRDGE2	903407.1845	100817.8891	140.3350	02/24/2018 10:29:48
BRDGE3	903407.1990	100817.8674	140.3352	02/24/2018 10:30:08
BRDGE4	903406.9805	100815.9645	140.3279	02/24/2018 10:34:16
BRDGE5	903406.5774	100812.6796	140.3149	02/24/2018 10:37:52
BRDGE6	903406.3001	100810.1951	140.2925	02/24/2018 10:39:40

The data was copied into Excel and the three cross sections were identified as follows. Highlighted rows belong to points whose points coordinates were found using a Trimble GeoXH 6000 device (Table 4-4).

Table 4-4: Figure 4-2: Data from GPS from Data Set 1

Point Id	Easting	Northing	Orth. height
XS4_14	100832.03	903339.29	139.6668
XS4_13	100829.31	903338.48	137.2871
XS4_12	100827.29	903338.22	136.5119
XS4_11	100825.18	903337.58	136.2171
XS4_10	100823.28	903337.2	136.1921
XS4_9	100821.1	903336.64	136.1035
XS4_8	100819.14	903336.2	136.0417
XS4_7	100818.05	903336.07	135.9737
XS4_6	100816.42	903335.95	136.1226
XS4_5	100814.43	903335.59	135.9135
XS4_4	100813.31	903335.34	135.9835
XS4_3	100812.21	903335.06	136.2373
XS4_2	100810.99	903334.66	136.4849
XS4_1	100809.58	903335.49	139.6787

Elevation Calculation of Bridge Cross Sections (XS2 and XS1)

Equation 1 was used to calculate the river bed elevation for each point in XS2 and XS1:

$$E_{RB} = E_{BD} - D_{BD \rightarrow RB} \qquad \text{Eqn. 1}$$

Where E_{BD} is the Total Station elevation of the bridge deck perpendicularly above a given XS

$D_{BD \rightarrow RB}$ is the measured distance between the bridge deck and the river bed at a given XS point

E_{RB} is the calculated elevation of a given XS point

The measured distances where imported into the Excel sheet above, and the equation was applied to calculate the elevation of each bridge XS point (Table 4-5).

Table 4-5: Riverbed Elevation Calculations

			E(BD)	D(BD-->RB)	E(RB)
XS2_10	100818.36	903407.18	140.326	3.70	136.62
XS2_9	100817.87	903407.2	140.3352	4.67	135.67
XS2_8	100815.96	903406.98	140.3279	5.15	135.18
XS2_7	100812.68	903406.58	140.3149	4.94	135.38
XS2_6	100810.2	903406.3	140.2925	4.85	135.44
XS2_5	100809.16	903406.17	140.2932	4.71	135.58
XS2_4	100806.68	903405.92	140.2704	4.30	135.97
XS2_3	100805.13	903405.68	140.2734	4.72	135.55
XS2_2	100804.42	903405.6	140.2703	4.69	135.58

Creation of XS3 from XS2 For Elevation Data:

A slope of 0.005 was approximated for the post-dam reach. A ~0.5m elevation drop over ~100m was noticed between XS4 and XS1 Slope = 5m/100m = 0.005. The distance between the 2 cross sections was measured at approximately 5m.

The elevation of XS3 was found using Equation 2:

$$E_{XS3}[m] = E_{XS2}[m] + 0.005(5m) \qquad \text{Eqn. 2}$$

The resulting elevations are listed below (Table 4-6):

Table 4-6: XS3 Elevations

Point ID	Elevation (m)
XS3_10	136.65
XS3_9	135.69
XS3_8	135.21
XS3_7	135.40
XS3_6	135.47
XS3_5	135.61
XS3_4	135.99
XS3_3	135.57
XS3_2	135.61
XS3_1	136.70

For Station Data:
All channel points were projected 5m upstream using AutoCAD, as shown in Figure 4-1. Additionally, two points were added on both extremities of the cross section ~6.5m away from the existing last points. Elevations of the added extremities points were approximated as the bridge deck elevation.

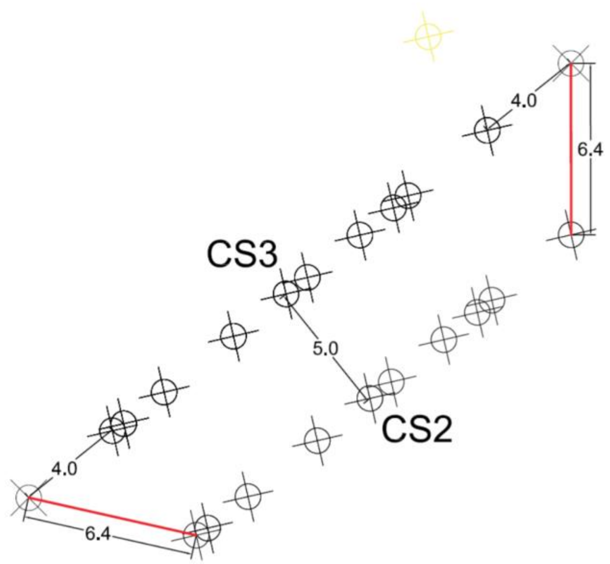


Figure 4-1: Projection in AutoCAD

Creation of XS0 from XS1

Given the prismatic and uniform nature of the channel downstream of South Main Street Bridge, it was decided to create XS0 30m downstream of XS1 (downstream side of the bridge) using a projection of XS1. Elevation values of XS0 were found using the previously approximated reach slope (0.005) and the distance between the two cross sections (30m) using Equation 3.

$$E_{XS0}[m] = E_{XS1}[m] - 0.005(30m) \qquad \text{Eqn. 3}$$

The resulting values are in Table 4-7.

Table 4-7: Elevations for XS1

Point ID	Elevation (m)
XS1_5	136.39
XS1_4	135.35
XS1_3	135.34
XS1_2	135.61
XS1_1	136.55

Data Correction

To correct the location and elevation values of the above two data sets, the following correction points were used:

- GPS coordinates (location, elevation) taken using Trimble GeoXH 6000 device at the guardrail of XS12, XS10, and XS8.
- GPS coordinates taken using the same Trimble at the downstream-side of the bridge deck. This is the same point where the Total Station was placed for Data Set 2 collection, and so was surveyed earlier along with Data Set 2.
- A known USGS point surveyed by Hills Engineers.

The collected data is in Table 4-8.

Table 4-8: Survey Control Points

Points	Source	N	E	Elevation (m)	Original Elevation (m)	Difference (m)
XS8_1_C	DC Team, Trimble GeoXH 6000	903982	100611.9	137.5	94.65	42.85
XS10_1_C	DC Team, Trimble GeoXH 6000	904041.65	100572.95	136.4	91.6	44.8
XS12_1_C	DC Team, Trimble GeoXH 6000	904079.4	100494.54	137.6	91.8	45.8
					Average Difference =	44.5

Points	Source	N	E	Elevation (m)	Original Elevation (m)	Difference (m)
USGS GPS pt	Hills Engineers	903405.42	100845.43	130.3	139.3	9.0

Elevation Corrections

For data set 1, differences in elevation between the original XSi_1 and the corrected XSi_1 were averaged. The resultant (44.5m) was added to each point in the above data set.

For data set 2, the difference in elevation between the original USGS point and the Hills Engineer USGS point (9m) was added to all points in the data set.

Note that the hydraulic model was not affected by this change, as the relative distances was between the points was unchanged.

Location Corrections

Data set 1 was entered into ArcGIS. Points XS12_1, XS10_1 and XS8_1 were matched to their corrected values found in the table above. The rest of the points in the data set were corrected accordingly.

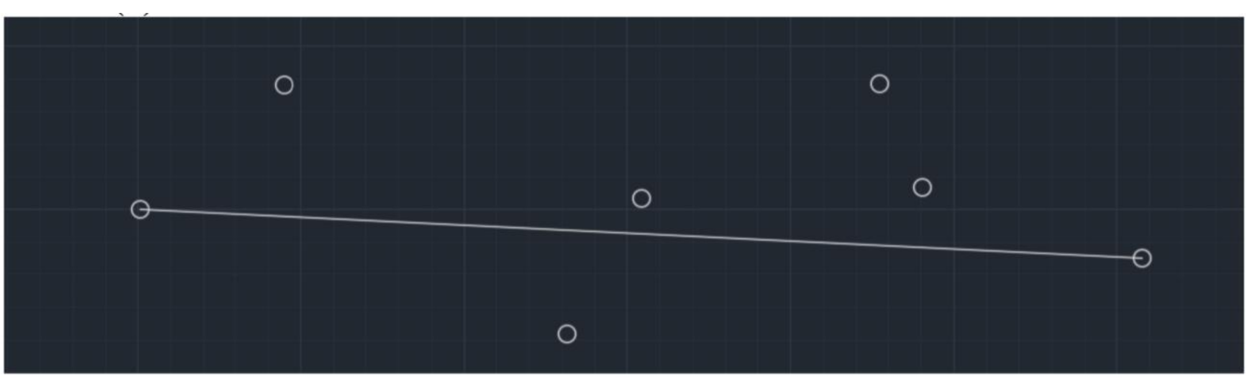
When Data set 2 was entered into AutoCAD, the data has to be flipped and mirrored . We hypothesized that we might have entered Easting for Northing and Northing for Easting when establishing the location of the Total Station. Similar to Data Set 1, Set 2 was entered into ArcGIS and corrected using the Hill Engineers USGS point.

Using AutoCAD to Find Station Data

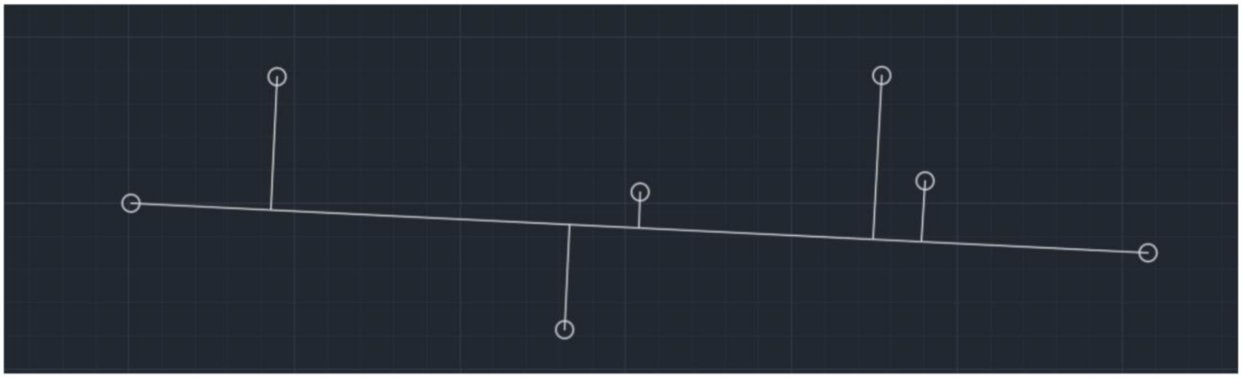
Each of the surveyed cross sections were imported into AutoCAD using the following method:

1. In Excel, use the concatenate tool to create for each coordinate point a cell that contains the northing and easting value of the point separated by a comma. To do this, select a cell, type "=CONCATENATE ("Northing Cell", ",","Easting Cell"). Drag down the above equation for all surveyed points in a cross section.
2. Copy the column of concatenated points.
3. In AutoCAD, go to **Draw > Multiple Points >** paste copied column into dialogue box.
4. Click **Zoom Extent** if you cannot see your points.

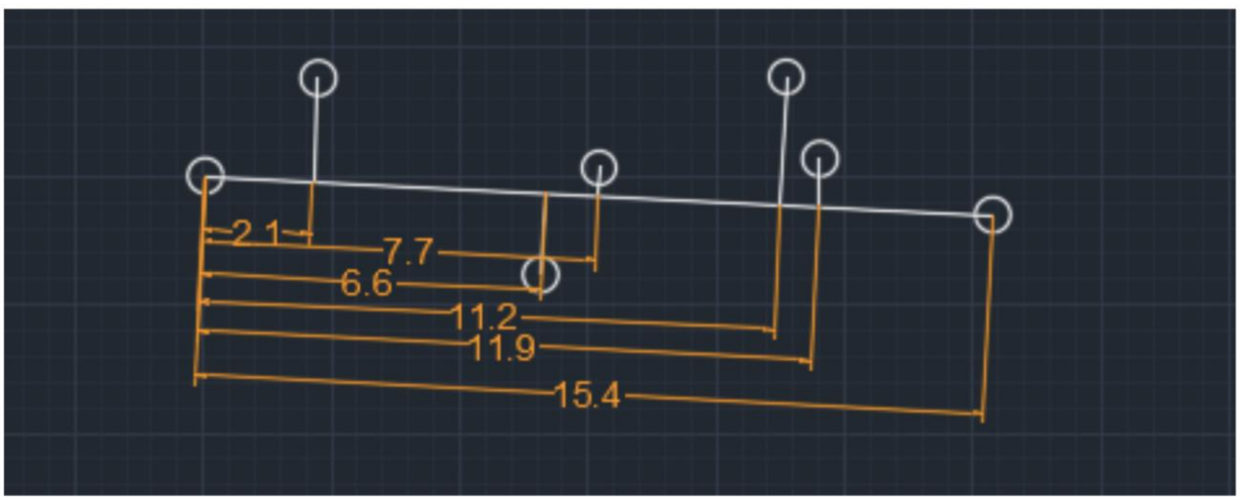
Connect the left and right extremity points of a cross section using a line. We will call this line (L).



5. For all XS points that do not fall on (L), connect the point to (L) using a line perpendicular to (L). The intersection between (L) and each of these connecting lines forms the "projected points".



6. Locate the left bank extremity of the cross section and measure distances between it and all other points on the cross section.



7. In this example, Station data would be as follows:

Table 4-9: Final Station Data

Point ID	Station
1	0
2	2.1
3	6.6
4	7.7
5	11.2
6	11.9
7	15.4

Appendix 5: Log Pearson Analysis

This appendix consists of the documentation for our Log Pearson Type III Analysis on the Mill River. The Log-Pearson Type III distribution tells you the likely values of discharges to expect in the river at various recurrence intervals based on the available historical record. This is helpful when designing structures in or near the river that may be affected by floods. It is also helpful when designing structures to protect against the largest expected event. According to the U.S. Water Advisory Committee on Water Data (1982), the Log-Pearson Type III Distribution is the recommended technique for flood frequency analysis.

To perform the analysis, we started with annual peak flow discharge data from the USGS stream gauge on the Mill River at Northampton, then prorated it to our site. We used this data to solve the following equation, where x is the discharge value, K is a frequency factor, and *σ* is the standard deviation of the logx values.

$$\log x = \overline{\log x} + K\sigma_{\log x}$$

The frequency factor K is a function of the skewness coefficient and return period, was found using the frequency factor table. For a detailed tutorial of how to calculate the Log Pearson Type III distribution, refer to Oregon State University's "Streamflow Evaluations for Watershed Restoration Planning and Design" at the following link: http://streamflow.engr.oregonstate.edu/analysis/floodfreq

Log Pearson Type III Analysis

Date	MM	DD	YYYY	WY	Q	$\log_{10}Q$	Rank	Y	$Y-Y_{mean}$	$(Y-Y_{mean})^2$	$(Y-Y_{mean})^3$
	Year				Annual Peak			LP3 Analysis			
4/17/41	4	17	1998	1998	169	2.228	46	2.228	-1.603	2.569356	-4.12E+00
6/16/42	6	16	1999	1999	2200	3.342	28	3.342	-0.488	0.238520	-1.16E-01
5/9/43	5	9	2000	2000	1300	3.114	36	3.114	-0.717	0.513894	-3.68E-01
11/16/43	11	16	2001	2002	942	2.974	41	2.974	-0.857	0.734032	-6.29E-01
5/21/45	5	21	2002	2002	679	2.832	44	2.832	-0.999	0.997877	-9.97E-01
4/28/46	4	28	2003	2003	1190	3.076	38	3.076	-0.755	0.570419	-4.31E-01
5/7/47	5	7	2004	2004	1470	3.167	32	3.167	-0.663	0.440219	-2.92E-01
5/19/48	5	19	2005	2005	2140	3.330	29	3.330	-0.500	0.250394	-1.25E-01
4/15/49	4	15	2006	2006	1480	3.170	31	3.170	-0.661	0.436321	-2.88E-01
4/23/50	4	23	2007	2007	3760	3.575	26	3.575	-0.256	0.065342	-1.67E-02
6/8/52	6	8	2008	2008	1380	3.140	33	3.140	-0.691	0.477382	-3.30E-01
3/31/53	3	31	2009	2009	923	2.965	42	2.965	-0.866	0.749274	-6.49E-01
9/13/54	9	13	2010	2010	1370	3.137	34	3.137	-0.694	0.481757	-3.34E-01
5/10/55	5	10	2011	2011	2630	3.420	27	3.420	-0.411	0.168799	-6.94E-02
5/1/56	5	1	2012	2012	753	2.877	43	2.877	-0.954	0.910140	-8.68E-01
4/22/57	4	22	2013	2013	1050	3.021	40	3.021	-0.810	0.655482	-5.31E-01
4/24/58	4	24	2014	2014	1220	3.086	37	3.086	-0.744	0.554203	-4.13E-01
6/19/59	6	19	2015	2015	1160	3.064	39	3.064	-0.766	0.587292	-4.50E-01
5/15/60	5	15	2016	2016	1680	3.225	30	3.225	-0.605	0.366628	-2.22E-01
5/29/61	5	29	2017	2017	1350	3.130	35	3.130	-0.700	0.490664	-3.44E-01
8/14/62	8	14	2018	2018	276	2.441	45	2.441	-1.390	1.931818	-2.69E+00
5/31/63	5	31	63	63	24000	4.380	16	4.380	0.549	0.301844	1.66E-01
4/28/65	4	28	65	65	21700	4.336	20	4.336	0.506	0.255684	1.29E-01
11/4/66	11	4	66	67	42500	4.628	6	4.628	0.798	0.636136	5.07E-01
4/16/68	4	16	68	68	17000	4.230	23	4.230	0.400	0.159713	6.38E-02
5/22/69	5	22	69	69	28000	4.447	14	4.447	0.616	0.379888	2.34E-01
5/7/70	5	7	70	70	36900	4.567	10	4.567	0.736	0.542018	3.99E-01
5/5/71	5	5	71	71	32200	4.508	12	4.508	0.677	0.458394	3.10E-01
5/8/72	5	8	72	72	23400	4.369	19	4.369	0.538	0.289883	1.56E-01
4/29/73	4	29	73	73	66000	4.820	1	4.820	0.989	0.977599	9.67E-01
6/8/75	6	8	75	75	18500	4.267	21	4.267	0.436	0.190414	8.31E-02
4/4/76	4	4	76	76	39800	4.600	8	4.600	0.769	0.591477	4.55E-01
4/25/77	4	25	77	77	24800	4.394	15	4.394	0.564	0.317695	1.79E-01
3/30/78	3	30	78	78	23900	4.378	17	4.378	0.548	0.299855	1.64E-01
4/29/79	4	29	79	79	53000	4.724	3	4.724	0.893	0.798285	7.13E-01
4/11/80	4	11	80	80	15200	4.182	24	4.182	0.351	0.123226	4.33E-02
9/25/81	9	25	81	81	41500	4.618	7	4.618	0.787	0.619747	4.88E-01
4/28/82	4	28	82	82	29600	4.471	13	4.471	0.640	0.410220	2.63E-01
4/18/83	4	18	83	83	48500	4.686	4	4.686	0.855	0.730912	6.25E-01
6/2/84	6	2	84	84	47500	4.677	5	4.677	0.846	0.715523	6.05E-01
4/19/85	4	19	85	85	17100	4.233	22	4.233	0.402	0.161756	6.51E-02
9/25/86	9	25	86	86	23500	4.371	18	4.371	0.540	0.291881	1.58E-01
4/2/87	4	2	87	87	55400	4.744	2	4.744	0.913	0.833025	7.60E-01
4/7/88	4	7	88	88	13700	4.137	25	4.137	0.306	0.093583	2.86E-02
5/15/89	5	15	89	89	36200	4.559	11	4.559	0.728	0.529840	3.86E-01
10/25/90	10	25	90	91	37500	4.574	9	4.574	0.743	0.552381	4.11E-01

Log Person Type III Analysis

n	21
Y_{mean}	3.063
S_Y	0.8423127
g	-1.300

p	RI (yrs)	K	Y_{LP3}	Q (cfs)
0.99	1.01	-3.211	0.358	2
0.5	2	0.21	3.240	1736
0.2	5	0.838	3.769	5868
0.1	10	1.064	3.959	9097
0.04	25	1.24	4.107	12798
0.02	50	1.324	4.178	15062
0.01	100	1.383	4.228	16888
0.005	200	1.424	4.262	18286
0.002	500	1.46232	4.294	19697
0.001	1000	1.48216	4.311	20470
0.0005	2000	1.49673	4.323	21056
0.0001	10000	1.51752	4.341	21923

To adapt this spreadsheet:

1. Replace data in blue with the peak event from each year (using USGS data)
2. If the data list (i.e., number of years) is longer or shorter, ensure that the range references in red cells are correct.
3. The rest of the file should adjust automatically; primary output in green.

skewness, g

RI	p	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7
1.0101	0.99	-0.990	-1.037	-1.087	-1.140	-1.197	-1.256	-1.318	-1.383	-1.449	-1.518	-1.588	-1.660	-1.733	-1.806
2	0.5	-0.307	-0.294	-0.282	-0.268	-0.254	-0.240	-0.225	-0.210	-0.195	-0.180	-0.164	-0.148	-0.132	-0.116
5	0.2	0.609	0.627	0.643	0.660	0.675	0.690	0.705	0.719	0.732	0.745	0.758	0.769	0.780	0.790
10	0.1	1.302	1.310	1.318	1.324	1.329	1.333	1.337	1.339	1.340	1.341	1.340	1.339	1.336	1.333
25	0.04	2.219	2.207	2.193	2.179	2.163	2.146	2.128	2.108	2.087	2.066	2.043	2.018	1.993	1.967
50	0.02	2.912	2.881	2.848	2.815	2.780	2.743	2.706	2.666	2.626	2.585	2.542	2.498	2.453	2.407
100	0.01	3.605	3.553	3.499	3.444	3.388	3.330	3.271	3.211	3.149	3.087	3.022	2.957	2.891	2.824
200	0.005	4.298	4.223	4.147	4.069	3.990	3.910	3.828	3.745	3.661	3.575	3.489	3.401	3.312	3.223
500	0.002	4.215	5.108	4.999	4.890	4.779	4.667	4.553	4.438	4.323	4.206	4.088	3.969	3.850	3.730
1000	0.001	5.908	5.775	5.642	5.507	5.371	5.234	5.095	4.955	4.815	4.673	4.531	4.388	4.244	4.100
2000	0.0005	6.601	6.443	6.383	6.122	5.960	5.797	5.633	6.467	5.301	5.134	4.967	4.799	4.631	4.462
10000	0.0001	8.210	7.989	7.766	7.543	7.318	7.093	6.867	6.640	6.412	6.185	5.957	5.729	5.501	5.274

skewness, g

RI	p	0.6	0.5	0.4	0.3	0.2	0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7
1.0101	0.99	-1.880	-1.955	-2.029	-2.104	-2.178	-2.252	-2.326	-2.400	-2.472	-2.544	-2.615	-2.686	-2.755	-2.824
2	0.5	-0.099	-0.083	-0.066	-0.050	-0.033	-0.017	0.000	0.017	0.033	0.050	0.066	0.083	0.099	0.116
5	0.2	0.800	0.808	0.816	0.824	0.830	0.836	0.842	0.846	0.850	0.853	0.855	0.856	0.857	0.857
10	0.1	1.328	1.323	1.317	1.309	1.301	1.292	1.282	1.270	1.258	1.245	1.231	1.216	1.200	1.183
25	0.04	1.939	1.910	1.880	1.849	1.818	1.785	1.751	1.716	1.680	1.643	1.606	1.567	1.528	1.488
50	0.02	2.359	2.311	2.261	2.211	2.159	2.107	2.054	2.000	1.945	1.890	1.834	1.777	1.720	1.663
100	0.01	2.755	2.686	2.615	2.544	2.472	2.400	2.326	2.252	2.178	2.104	2.029	1.955	1.880	1.806
200	0.005	3.132	3.041	2.949	2.856	2.763	2.670	2.576	2.482	2.388	2.294	2.201	2.108	2.016	1.926
500	0.002	3.609	3.487	3.366	3.244	3.122	3.000	2.878	2.757	2.637	2.517	2.399	2.000	2.169	2.057
1000	0.001	3.956	3.811	3.666	3.521	3.377	3.233	3.090	2.948	2.808	2.669	2.533	2.399	2.268	2.141
2000	0.0005	4.293	4.124	3.956	3.788	3.621	3.455	3.291	3.128	2.967	2.809	2.654	2.503	2.355	2.213
10000	0.0001	5.047	4.821	4.597	4.374	4.153	3.735	3.719	3.507	3.299	3.096	2.899	2.708	2.525	2.350

skewness, g

RI	p	-0.8	-0.9	-1.0	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-1.9	-2.0
1.0101	0.99	-2.891	-2.957	-3.022	-3.087	-3.149	-3.211	-3.271	-3.330	-3.880	-3.444	-3.499	-3.553	-3.605
2	0.5	0.132	0.148	0.164	0.180	0.195	0.210	0.225	0.240	0.254	0.268	0.282	0.294	0.307
5	0.2	0.856	0.854	0.852	0.848	0.844	0.838	0.832	0.825	0.817	0.808	0.799	0.788	0.777
10	0.1	1.166	1.147	1.128	1.107	1.086	1.064	1.041	1.018	0.994	0.970	0.945	0.920	0.895
25	0.04	1.448	1.407	1.366	1.324	1.282	1.240	1.198	1.157	1.116	1.075	1.035	0.996	0.959
50	0.02	1.606	1.549	1.492	1.435	1.379	1.324	1.270	1.217	1.166	1.116	1.069	1.023	0.980
100	0.01	1.733	1.660	1.588	1.518	1.449	1.383	1.318	1.256	1.197	1.140	1.087	1.037	0.990
200	0.005	1.837	1.749	1.664	1.581	1.501	1.424	1.351	1.282	1.216	1.155	1.097	1.044	0.995
500	0.002	1.948	1.842	1.741	1.643	1.550	1.462	1.380	1.303	1.231	1.165	1.105	1.049	0.998
1000	0.001	2.017	1.899	1.786	1.678	1.577	1.482	1.394	1.313	1.238	1.170	1.107	1.051	0.999
2000	0.0005	2.077	1.946	1.822	1.706	1.597	1.497	1.404	1.319	1.242	1.172	1.109	1.052	1.000
10000	0.0001	2.184	2.029	1.884	1.751	1.628	1.518	1.418	1.328	1.247	1.175	1.111	1.052	1.000

Appendix 6: Accuracy Calculations for HEC-RAS Model

This appendix details the calculations done to measure the accuracy of our model as compared to measured values

Stage-Discharge Relationship
Mill River, Haydenville, MA
South Main St. Bridge
CB: Brett Towler

Datum established on raised curb/deck at left side of center pier on upstream side of S. Main St. bridge.
Measurements of Delta taken with staff gage from datum to water surface elevation (WSE).
Depth established using distance from datum (bridge curb) to channel bottom
Data is unadjusted for lag (delay) between target site (bridge) and USGS 01171500 downstream.

Measured at 10 am on 2/24/18	$\Delta_{channel}$	15.5	(ft)
DA reported online for USGS 01171500	DA_{gage}	52.6	(mi^2)
DA from USGS StreamStats delineation	DA_{target}	29.3	(mi^2)
	Ratio	0.5570	(-)

Date (mm/dd/yyyy)	Time (24 hrs)	Date-Time (mm/dd/yy hh:mm)	Δ_{WSE} (ft)	Depth (ft)	Flow (cfs)	(A/P)	Flow (cfs)	Reading (-)	Notes (-)
2/24/2018	10:00	2/24/18 10:00	13.9	1.6	243	P	135	LR/MS/BT	Rising limb of hydrograph
2/25/2018	12:45	2/25/18 12:45	13.4	2.1	297	P	165	LR/MS/BT	Rising limb of hydrograph
2/26/2018	7:40	2/26/18 7:40	13.8	1.7	323	P	179	BT	Falling limb; hysteresis?
3/2/2018	14:40	3/2/18 14:40	13.2	2.3	440	P	245	BT	Rising limb of hydrograph
4/16/2018	18:10	4/16/18 18:10	12.0	3.5	979	P	545	BT	Rising limb of hydrograph

The HEC-RAS predicted river depth (D_predicted) at the upstream-facing side of the Bridge (XS2) is calculated by subtracting the river bed elevation at the middle of XS2 (E_B) from the WS Elevation outputed by HEC-RAS at XS2 (E_WS).
CB: Maya Sleiman

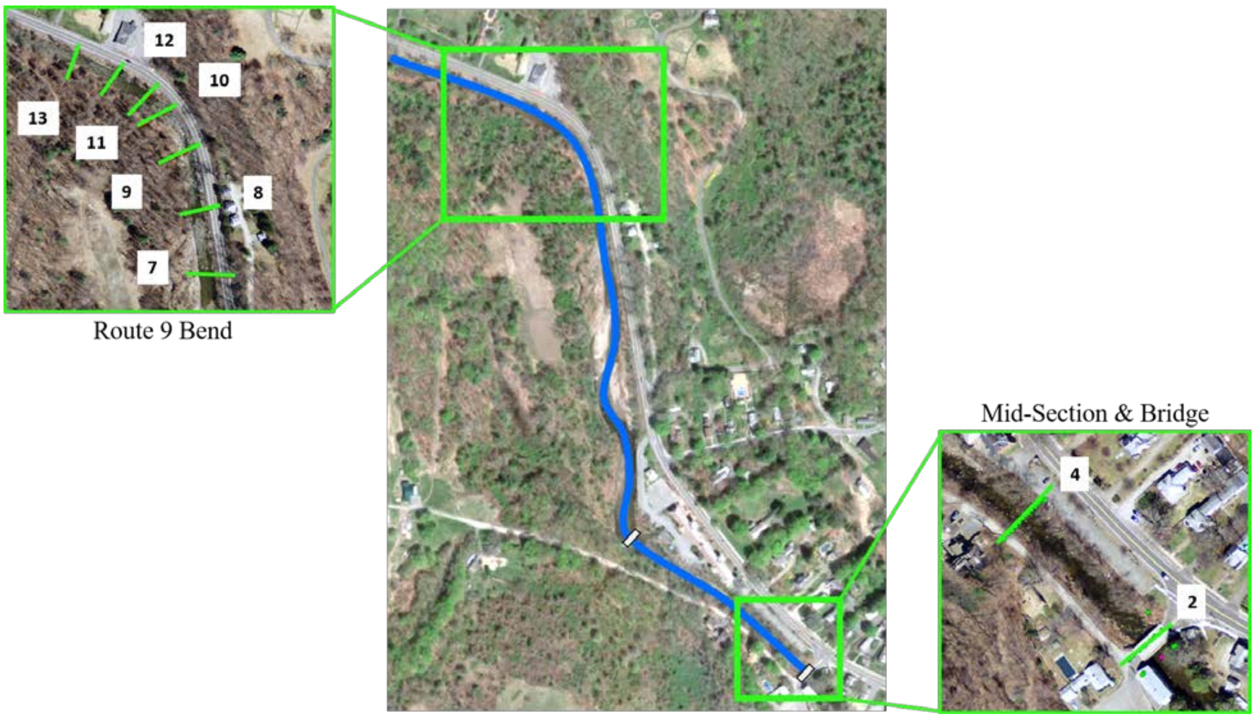
Key:

XS2 Bed Elevation at middle pier (ft)	E_B	415.36	ft
XS2 WS Elevation (ft) as outputed by HEC-RAS (ft)	E_WS		
XS2 calculated depth (ft) = E_WS - E_B	D_predicted		
Difference between measured and HEC-RAS predicted depth	Diff.		

Flow (cfs)	E_WS (ft)	D_predicted(ft)	Depth (ft)	Diff. (ft)
243	417.03	1.67	1.6	-0.07
297	417.19	1.83	2.1	0.27
323	417.25	1.89	1.7	-0.19
440	417.53	2.17	2.3	0.13
979	418.54	3.18	3.5	0.32

Appendix 7: Documentation of Site Visits

The following is a compilation of the eleven site visits that we conducted from October to March. Site Visits 6 and 10 were major bathymetric data collection visits. In Site Visit 6 we collected seven cross sections at the Route 9 bend; XS7 through XS13. Site Visit 10 consisted of the Mid-Section and Bridge cross sections, with a total of two cross sections; XS2 and XS4. In Site Visit 11 we set up control points for our two bathymetry data collections.



Site Visit Summary 1

Location: Mill River Route 9 bend; approached from Valley View Farms

Day: Monday, September 18, 2017

Time: 1:00PM - 3:00PM

Members Present: Gaby, Nick, Carl, Fereshta, Maya, Laura, Marcia

CB: Marcia Rojas

The site visit consisted of observing the sections between the brassworks dam and the straightaway right after the bend of route 9 (“The Pinch”).
On the drive over to the site we followed the roads that ran directly alongside/or nearest to the river. In some of the sections the stream was small and the height of the current water level to the top seemed low.

Brassworks - Just Downstream of Dam
We first arrived at the brassworks parking lot where we entered through a small incline path to the downstream side of the dam. There was a sandbar which we stood on.
The dam was substantially broken, a result of the last hurricane. The biggest break was at the far end, indicating a deeper and faster flow on the south side of the river at this point. On that same side, there is an abutment. The whole bridge itself was build here specifically because of the availability of bedrock for the foundation.
Downstream of the dam, remnants of the fallen bedrock pieces of the dam are visible.

Brassworks - Just Upstream of Dam
Just upstream, standing over a wall at the Brassworks parking lot we could see that the flow in the areas of large rocks has high flow (Figure 7-1).

Figure 7-1: Sightline Off Parking Lot Wall into Upstream Section of Dam (left); View from Parking Lot Wall (right)

Williamsburg Snack Bar - At the bend

Here we could see the clear bend of the road and river. There was very little shoulder, under 2 feet at some points. The cars drive by very quickly. The river itself is pretty far down and it is hard to see the water even from where we were standing on top of a slope. Farther down there is rock retainment by metal mesh.

Figure 7-2. From north side of river, across the road on slope, next to Williamsburg Snackbar on right side, looking down towards the Route 9 bend

Site Visit Summary 2

Location: Mill River Route 9 bend; approached from Valley View Farms

Day: Friday, October 6, 2017

Time: 3:00PM - 5:30PM

Members Present: Maya, Fereshta, Laura, Brett, Nick

Notes for collecting data:

- Try to pick places for the total station (Leica) such that you move it as little as possible.
- HEC RAS does not account for local turbulences, so we should make sure to note those when collecting data. How?
- Look for anomalies when taking a cross section. For example:
  - Manning's coefficient of friction changes significantly.
  - Hydraulic jumps (when flow moves from super to subcritical).
- Types of resistance in streamflow:
  - Skin drag (due to Manning's wall roughness) ⇒what HEC-RAS can model
  - Bed form resistance (drag resistance or momentum loss) ⇒due to bed vegetation, huge rocks, etc.
  - Wave resistance from distortion of free surface
  - Turbulence due to local acceleration that cause flow unsteadiness
- HEC-RAS assumes a flat surface.
- Think about your stream of focus (i.e. 100 year flood, winter flow, low flow during the summer, etc.). This will determine what you will be looking for during a site visit for data collection. For example: a stream contains a half-meter-high boulder. Do we care about this in the case of a 100-year flood event or during winter flows? Probably not

Total station data collection:

- At each cross section, 5 points will be taken (at a minimum):
  - Floodplain boundary points (2)
  - Water level boundary points (2)
  - Thalweg (1)
- For each of these three portions (floodplain 1, water bed, floodplain 2), a Manning's number can be assigned.
- Take as many pictures during site visits so you can refer to bed-properties (any boulders, mean size of rocks, etc.). This might later help in the calculation of Manning's roughness coefficient.
  - Use put a ruler in the picture when applicable.

Things we need before our next site visit:

- Machete
- 50 ft steel tape
- 6-12 inch ruler

Site Visit Summary 3

Location: Mill River Route 9 bend; approached from Valley View Farms

Day: Sunday, October 22, 2017

Time: 8:00AM - 12:00PM

Members Present: Maya, Marcia, Fereshta, Laura

Observations:

- We arrived at the river's edge and entered the river across from the point bar (Figure 7-3, point 1) without equipment to scope out a better access point closer to locations for taking measurements. Our goal is to minimize time carrying the equipment while in the river in order to avoid hazards related to personal safety or damage to equipment.
- Water level appeared low, similar to previous site visits earlier in the Fall.
- Rocks were larger in diameter upstream (Figure 7-4) as compared to downstream (Figure 7-5).

Completed Tasks:

- Marked reference points at the dam abutments with spray paint, and recorded GPS locations for use in future surveying
- Identified viable access points to river (Figure 7-3, points 1 & 2)
- Collected cross section data at dam using "Known Backsight" method

For next visit:

- Take remaining cross-sections, starting with upstream boundary
- Read collected data points using software (reach out to Bob Newton for access)

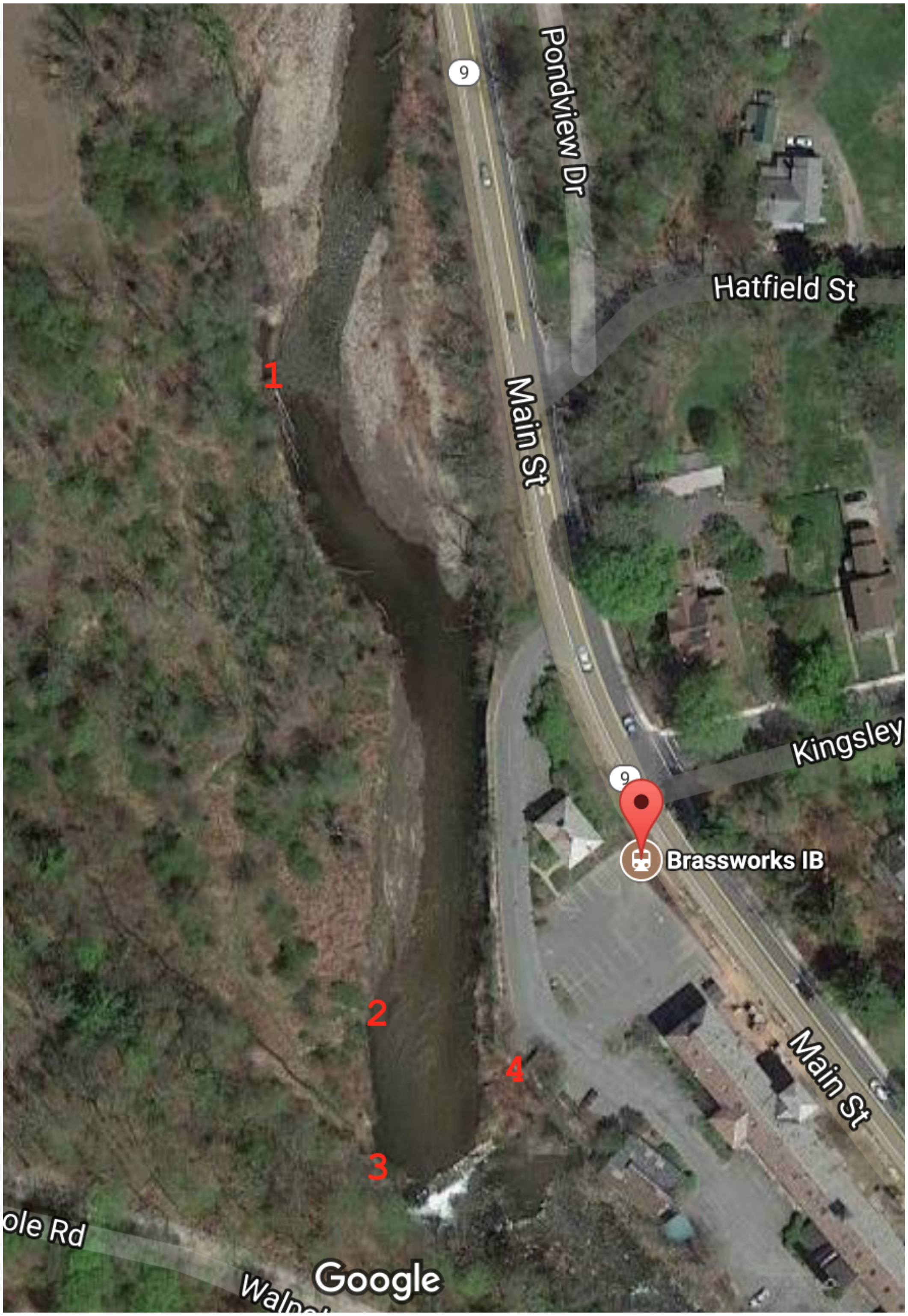


Figure 7-3: Locations of Importance at Site


Figure 7-4: Upstream


Figure 7-5: Downstream

Site Visit Summary 4

Location: Mill River Route 9 bend, Bridge, Brassworks Dam (approached from both sides)
Day: Monday, October 30, 2017
Time: 1:30PM - 3:00PM
Members Present: Laura, Sue Froehlich

Observations:

- Much higher flows than last visit - not safe for wading in (Figure 7-6)
- River level approximately 3 ft high at peak – noted wetted soil and depressed vegetation (Figure 7-7)

Tasks completed:

- Velocity test
    - Placed two bricks ~21 ft apart and measured time it took for a stick to float the distance
    - 21 ft / 3 sec = 7 ft/s

For next visit:

- Check measurements at USGS gauge
- Can take the bus to check on flow in the future (don't need to bring equipment)

Figure 7-6: Upstream of the dam

Figure 7-7: Depressed vegetation and wetted soil

Figure 7-8: Using observed soil and vegetation conditions to estimate river height at peak

Site Visit Summary 5

Location: Mill River Route 9 Bend, Approached from route 9
Day: Thursday, November 2, 2017
Time: 8:00 am- 3:00 pm
Members present: Marcia Rojas, Maya Sleiman, Fereshta Noori
CB: Fereshta Noori

Observations:

- We approached the river from Route 9, with the goal of making a full plan for measurement in the next site visit. The river flow was faster and water level higher than last visit.
- Some of the big rocks for erosion protection of the bend were moved to the middle of the road by water flow. (Figure 7-9)
- Wooden parts of the railing were angled towards the flow of the river.
- Vegetation on the floodplain were leaning on the ground, towards the river flow. (Figure 7-10)

Completed tasks:

- Walked and observed around the site (bend) to choose best access points.
- Decided on our measurement strategy for the next site visit.
- Chose fixed points for measurement.
- Chose measurement cross-sections based on the need, vegetation, and access possibility.

For next visit:

- Start collecting data at the cross-sections chosen in this visit.

Figure 7-9: Bank protection rocks in the river

Figure 7-10: Vegetation leaning toward water flow

Site Visit Summary 6

Location: Mill River Route 9 bend (approached from Route 9 side of river)
Day: Saturday, November 4, 2017
Time: 8:00AM - 3:00PM
Members Present: Marcia, Fereshta, Maya, Laura

Observations:

- Environmental conditions
  - ~35 ºF
  - Sunny
  - Low wind
  - Moderate river flow - still safe to walk in, but higher than initial site visits
- Trouble collecting some points with woody vegetation blocking sightlines
- Difficult traveling along road
- Points E10 and E11 are repeats; delete E10
- Point E16 may be the same as E17; if so, delete one
- Point E36 is questionable (hit 'record' before 'dist')
- Total station appeared to lag – possibly due to colder temperatures

Tasks completed:

- Collected cross section data for points 8 through 12 (Figure 7-11) plus one additional cross section between 7 and 8 that was determined useful at the site
- Moved total station 4 times, in the following order:
  - Point 12
  - Point 11
  - Point 10
  - Point 8
- Worked in pairs: one set with total station (Figure 7-12) and one with receiver (Figure 7-13)
  - Traded off responsibilities to allow each team member hands-on experience
  - Developed visual cues to communicate across the river
- Took photos of rock size at measurement points (Figure 7-14)

Follow-up tasks:

- Send data to Bob Newton to export onto computer
- Check USGS station measurements
- Input data into HEC-RAS
- Return survey equipment to Geo department

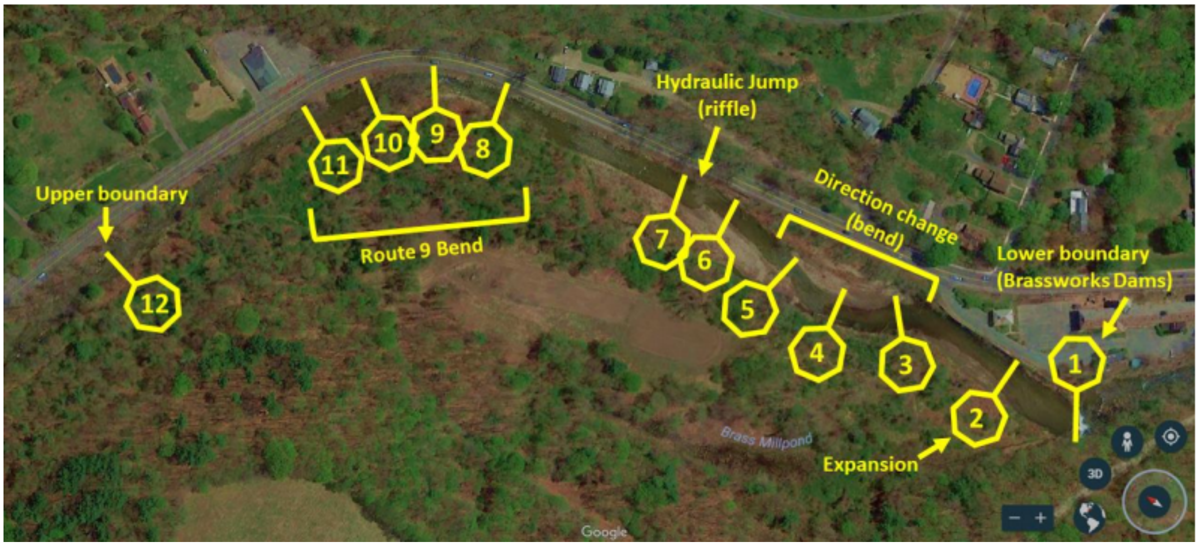


Figure 7-11. Labeled sections

Figure 7-12: Collecting data, facing total station with receiver (Fereshta) in the river


Figure 7-13: Collecting data, facing receiver with total station by guardrail


Figure 7-14: Sample of rock size at measurement points

Site Visit Summary 7

Location: Mill River Route 9 bend (approached from Route 9 side of river)
Day: Tuesday, December 19, 2017
Time: 2:00PM - 5:00PM
Members Present: Marcia, Fereshta, Maya, Laura
CB: Laura Rosenbauer

Observations:

- Environmental Conditions
  - ~40ºF, 4°C
  - Snow and ice
  - Cloudy
- Obstacles:
  - Because the ground was frozen, we had difficulty securely staking in the total station. We level the equipment several times throughout the process.
  - Ice was present at various points in the river
    - For the most part, ice was safe to walk on
    - We assumed the river bed elevation did not vary significantly from surrounding points where we successfully took measurements
  - Attempted cross section further downstream
    - Large sections of ice and the sun setting prevented completion
    - Access to river at the bridge is difficult -- need to brainstorm alternative methods of data collection for this section of the river for next site visit

Task Completed: Took one cross section immediately downstream of the dam (Figure 7-15)

Follow-up tasks:

- Return equipment to CEEDS
- Debrief site visit with Bob Newton/discuss collecting data in winter
- Select date for completing cross-sections
- Discuss and write out steps for next site visit

Figure 7-15: Flowing Water Shown in Blue; Dam Abutments Shown in Orange; Path of Data Collection Shown in Red

Figure 7-16: View of River Midway Between Bridge and Dam

Site Visit 8 Summary

Location: Mill River Route 9 Bend, Approached from Route 9
Day: Wednesday, January 31, 2017
Time: 7:00 am- 8:30 pm
Temperature: 14°F, -9°C
Members present: Marcia Rojas, Maya Sleiman, Laura Rosenbauer
CB: Maya Sleiman

This site visit was completed to:

- Assess stream conditions (frozen water thickness, flow intensity, water level, etc.)
- Locate cross sections for upcoming surveying and their access points

Observations:

- Water flow was comparable to flows during previous site visits, not too strong to access
- Water depth was also comparable to flows during previous site visits, i.e. accessible.
- Obstructions/Ice
    - Uneven ice coverage - thick in some places (i.e. can be walked on safely as seen in Figure 1), and thin in others (i.e. cracking hazard as seen in Figure 7-18).
    - Dam cracking is visible (Figure 7-19) compared to fall conditions (Figure 7-20)
    - Ice formations at the edges of the channel downstream of the dam. There is a gap between the surface ice formation and the water level (Figure 7-21).

Figure 7-17: Thick ice (area roughly marked) near dam, safe to walk on

Figure 7-18. Thin Ice formed on channel edge, prone to cracking, unsafe to walk on

Figure 7-19: Water flowing through Dam cracks

Figure 7-20: From initial site visit in Sep. 2017; shows no water flowing through right hand portion of the dam

Decision regarding cross-section location selection:

- The cross section at the dam will not be retaken, as accessibility has not improved since last site visit. Even with no ice formations, surveyors cannot move any closer to the dam due to strong current.
- The mid-section between the dam and the bridge will be taken at the location show in Figure 5. This location was chosen due to the absence of ice formations at its edges, thus facilitating access.
- Due to the complexity of river access at the bridge, an alternative surveying method was suggested. Attached is an explanation.

Figure 7-21: Chosen location for middle cross section (marked with dashed line) shows minimal surface ice formations on edges.

Site Visit 9 Assessment Summary

Location: Mill River, Main St bridge and Brassworks dam
Day: Thursday, February 8, 2018
Time: 2:00PM - 3:00PM
Temperature: 28°F, -2°C
Members present: Maya Sleiman, Laura Rosenbauer
CB: Maya Sleiman

This site visit was completed with the goal of assessing the site before our site visit 9 originally planned for Friday 02/09/18.

The following was noted:

- More ice has formed on the edges. As a result, the river is more constricted especially after the dam. (Figure 7-22)

Figure 7-22. More Ice has formed on the river edges, further constricting the flow.

- At the mid-section: ice has formed on edges at places where we had initially situated our cross section.

Figure 7-23. Access to middle cross section is more restricted following ice formation on edge

- The Bridge is approximately 18 ft high above the river bed.
- The plumbob was lowered to the river using the tape. The plumbob weight was not heavy enough to remain perpendicularly below us and was instead pushed by the river flow approximately 1m - 2m in the direction of the flow.

Site Visit Summary 10

Location: Mill River, Between Brassworks Dam and State Street Bridge
Date: Saturday, February 24, 2018
Time: 7:30AM - 11:30AM
Team Members Present: Marcia, Fereshta, Maya, Laura
Supporters Present: Sue Froehlich, Paul Wetzel, Brett Towler
CB: Fereshta Noori

Description:
This site visit was planned with the goal of collecting bathymetric data from three cross-sections; between Brassworks Dam and S State Street Bridge, at S State Street Bridge upstream, and S State Street Bridge downstream.

Observations:

- Environmental Conditions
    - 50/31ºF, 10/0°C
    - Some ice blocks at the river bank (Figure 1)
    - Partly Cloudy
- Obstacles:
    - High water flow
        - Velocity at the middle of cross-section was 3-4 ft/s (taken at the cross-section between dam and bridge)
        - A rope was stretched across the river cross-section and tied to trees on either sides of river to provide stability (Figure 7-24)
        - It was not easy/safe to get velocity measurements at deepest area of cross section
        - Due to the high flow, cross-sections at the bridge were taken using a telescope calibrated rod instead of tape measure and plumbob in "plumbob bathymetry method" (Figure 7-25)

Task Completed: Took one cross section in between S State Street Bridge and Brassworks Dam, and two cross-sections next to the bridge, both upstream and downstream. Collected velocity and water level measurements at cross-section between bridge and dam.

Follow-up tasks:

- Return equipment to CEEDS
- Get site visit data from Bob and prepare them for entering in HEC-RAS

Figure 7-24: River Safety Line

Figure 7-25: Survey Collection for XS4

Site Visit Summary 11

Location: Mill River Route 9 bend at Williamsburg Snack Bar (approached from Route 9 side of river), Brassworks Dam, & S. Main St. bridge
Day: Sunday, March 11, 2018
Time: 9:30AM - 1:00PM
Temperature: 33 - 40F
Members Present: Fereshta, Laura, Maya, Marcia
CB: Marcia Rojas

Goal: Relocation of control points for data correction and documentation.

Equipment: Trimble GeoXH 2005 Series Pocket PC set to Massachusetts State Plane Coordinate System

Tasks Completed:

- Collected and located two control points from each previous site visit at three major locations:
    - S. Main St. Bridge
    - Brassworks Dam
    - Route 9 Bend at the Williamsburg Snack Bar

  Table 1 features the points in the order that the major locations were stated. Figure 1 points out the major sections. The following pages provide further detailed imagery on each section, the points, and their surrounding.

Table 7-1. Control Points from three major project sections

	N	E	Elevation
BridgeTS - CP	903381.38	100852.75	131.4
USGS - CP	9034067.27	100845.05	129.7
DamTS - CP	903567	100666.9	132.5
XS 8 - CP	903982	100611.9	137.5
XS 10 - CP	904041.65	100572.95	136.4
XS 12 - CP	904079.4	100494.54	137.6

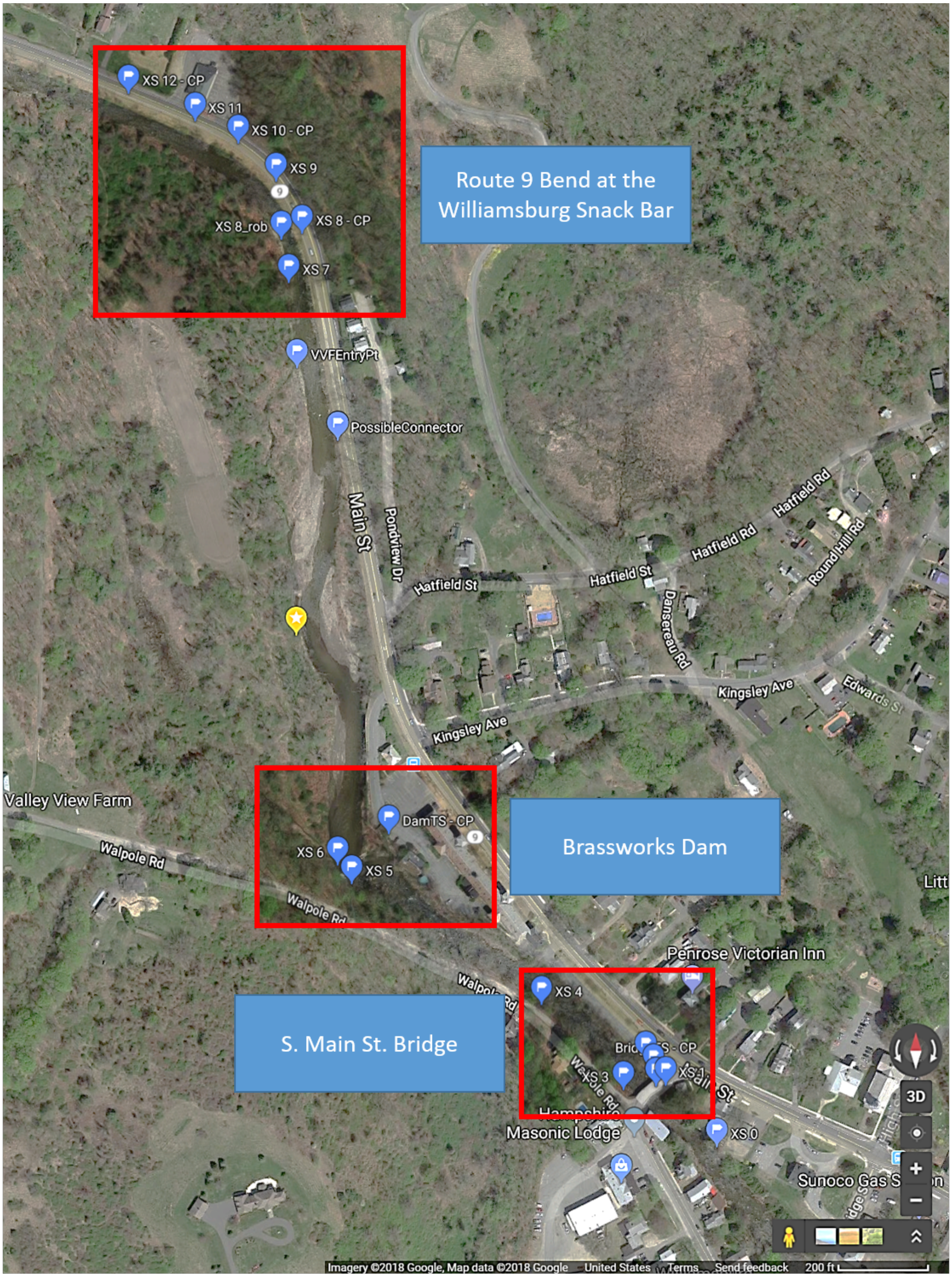


Figure 7-26. Major project sections

S. Main St. Bridge

BridgeTS - CP = Bridge total station control point

Figure 7-27: Site Visit 10, total station base location on S. Main St. bridge for post-dam data collection

Figure 7-28. Site Visit 11, marked control point for total station location

S. Main St. Bridge cont'd.

USGS - CP = USGS 1933 Benchmark control point

Figure 7-29: Site Visit 11, USGS benchmark 1933

Figure 7-30: Location of USGS benchmark, looking upstream from bridge, in the brush on the right hand side

Brassworks Dam

DamTS - CP= Brassworks Dam total station control point

Figure 7-31: Entry point location to the lower dam area, looking upstream

Figure 7-32: Aerial view of entry point location, near the North/West-facing end of the Brassworks building

Figure 7-33: Control point is the black point between the two marked arrows.

The *Route 9 Bend at the Williamsburg*
XS 8 - CP = Cross Section 8 control point
XS 10 - CP = Cross Section 10 control point
XS 12 - CP = Cross Section 12 control point

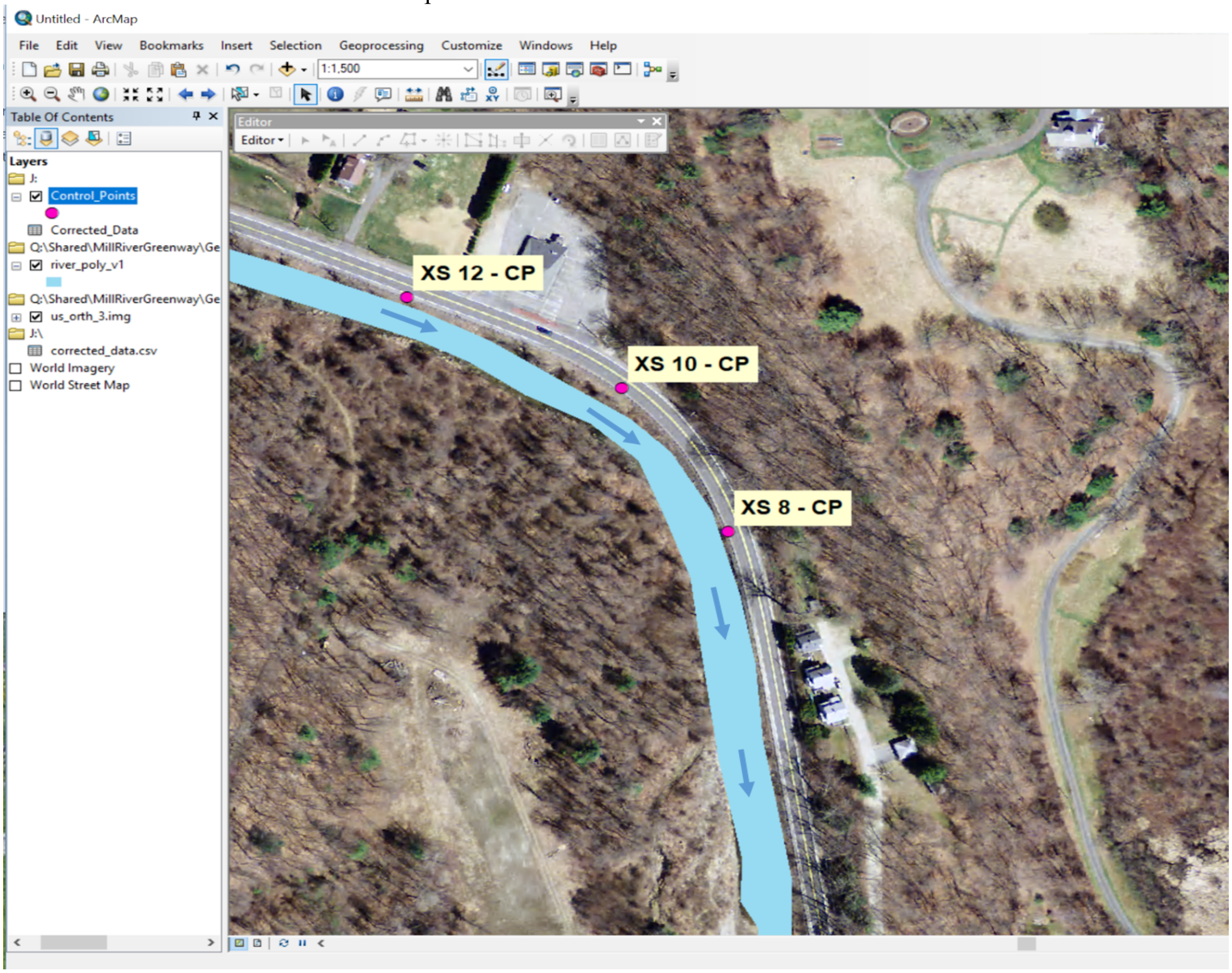


Figure 7-34: Cross section 8, 10, and 12 left of bank (LOB, looking downstream) control points

The *Route 9 Bend at the Williamsburg cont'd.*
XS 8 – CP

Figure 7-35: XS 8 - CP located on gabions. Sprayed only on right side of guardrail when looking at the river from the road

Figure 7-36: Electricity pole in front of XS 8 - CP location

The *Route 9 Bend at the Williamsburg cont'd.*
XS 8 – CP

Figure 7-37: View of river in front of XS 8 - CP location

The *Route 9 Bend at the Williamsburg cont'd.*
XS 10 - CP

Figure 7-38: XS 10 - CP located directly after the Snack Bar parking lot, heading South

Figure 7-39: View of river in front of XS 10 - CP location

Figure 7-40: Looking directly at XS 12 - CP, onto the road side

Figure 7-41: XS 12 - CP location, looking right onto the road towards Snack Bar

The *Route 9 Bend at the Williamsburg cont'd.*
XS 12 - CP

Figure 7-42: XS 12 - CP location, looking left onto the road towards Snack Bar

Follow-up tasks:

- Share control points with Hill Engineers surveying team
- Adjust and join data sets based on control points
- Build a GIS layer with corrected data points

Appendix 8: Dam and Cross Section 6 Development

This document includes our interpretation and process of dam implementation in our model. This document is developed by Brett Towler; we made some changes in this document to make it closer to the current conditions: Cross-section 6 developed in this document is wider than the actual cross-section. We used USGS map to estimate the width of this cross-section and the edge of river banks on left and right ends of the channel. Below is shown developed cross-section 6 before and after width adjustment.

Inline Dam Structure Development

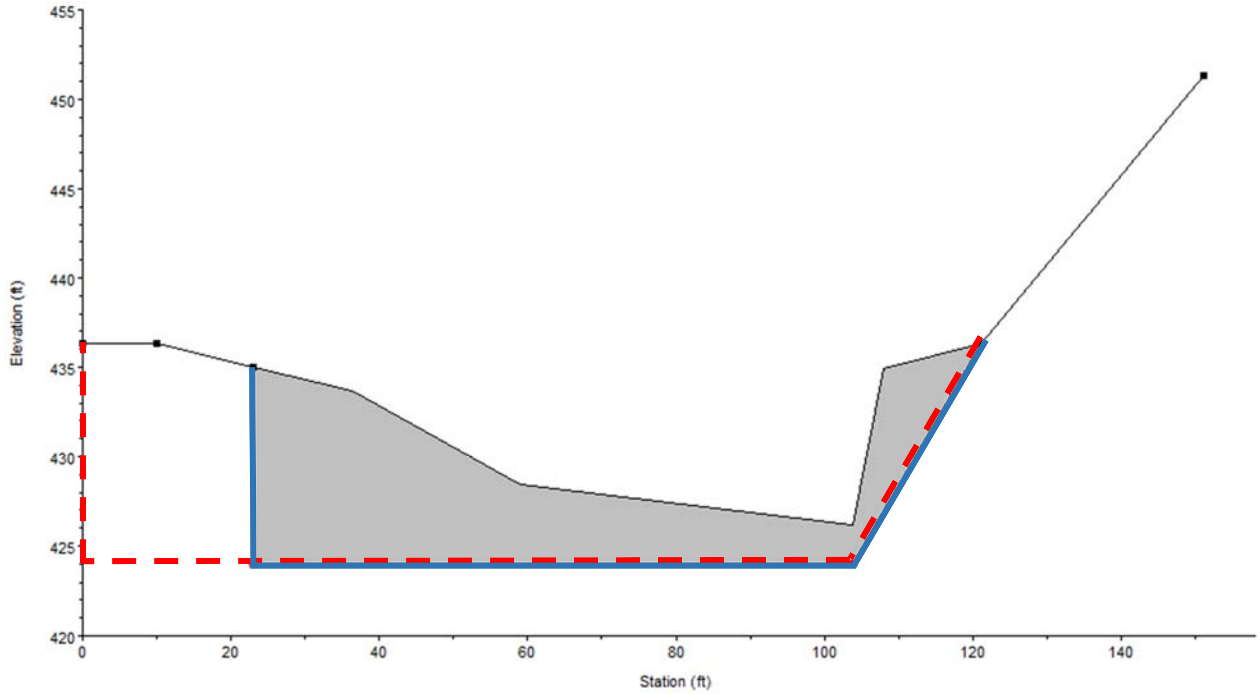
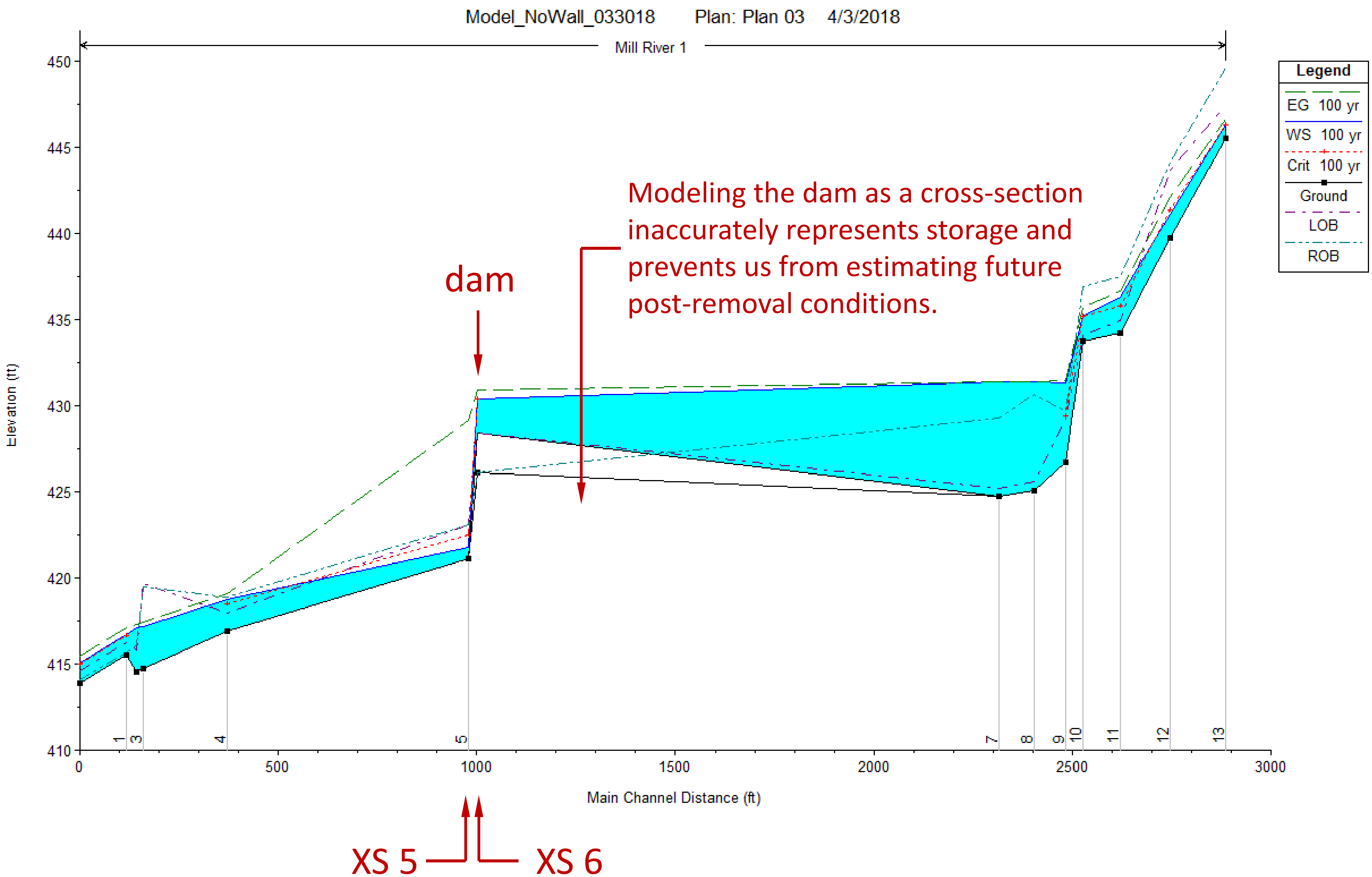
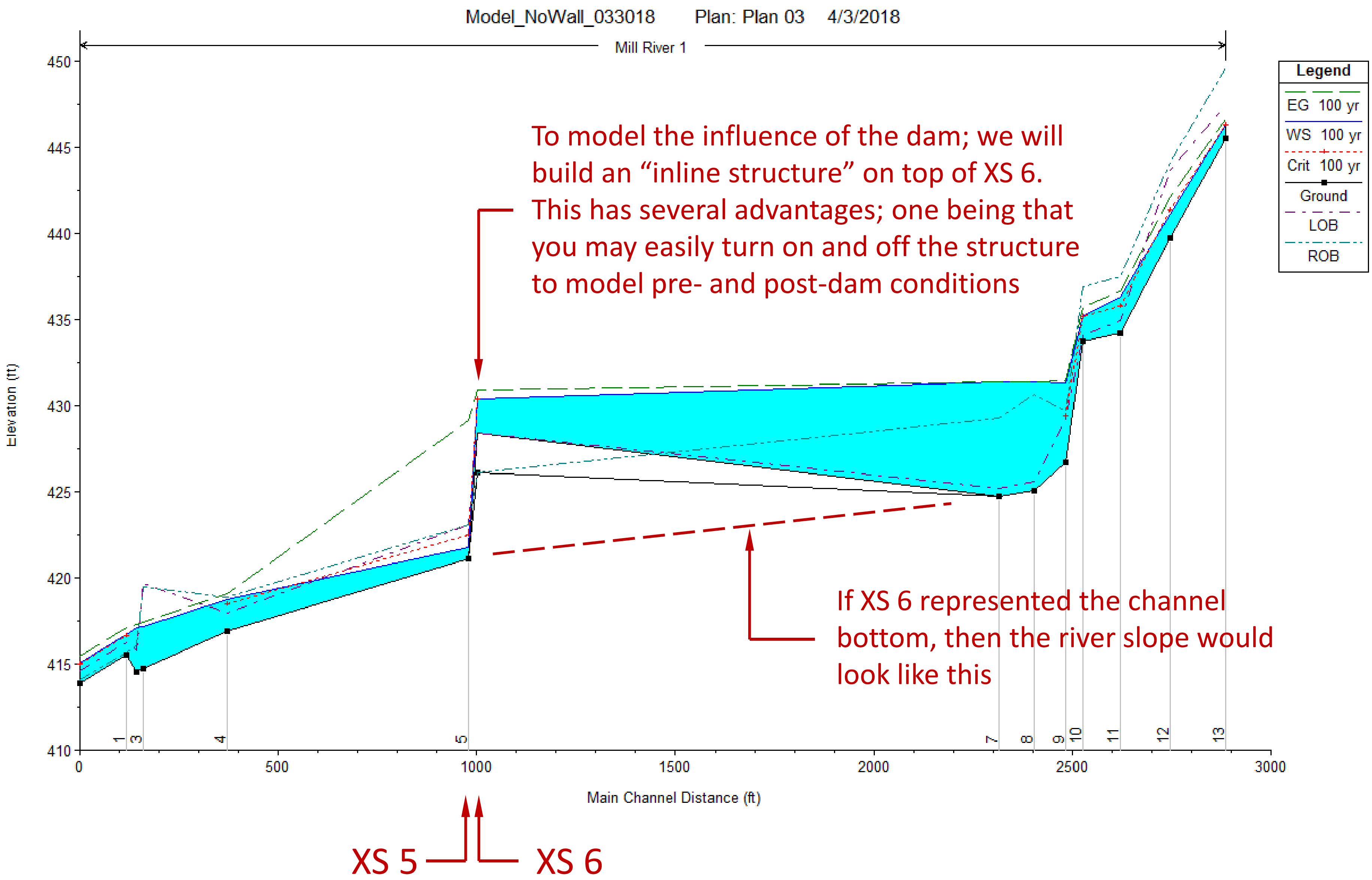


Figure 1. The red dashed line represents cross-section 6 without adjustment, and the solid blue line is after width adjustment.

In the current HEC-RAS model, cross section (XS) 6 represents the crest of the (partially breached) Brassworks dam; XS 5 is 22 feet downstream below the dam.



We want to alter XS 6 so that is represents the channel bottom, or more accurately a proposed future channel post dam removal.



Synthesizing a modified XS 6: We didn't survey the bottom, but we can synthesize the cross section based on visual evidence

The (partially breached) dam is built from placed stone and these photos suggest the channel bottom is below the lowest point in the breach.

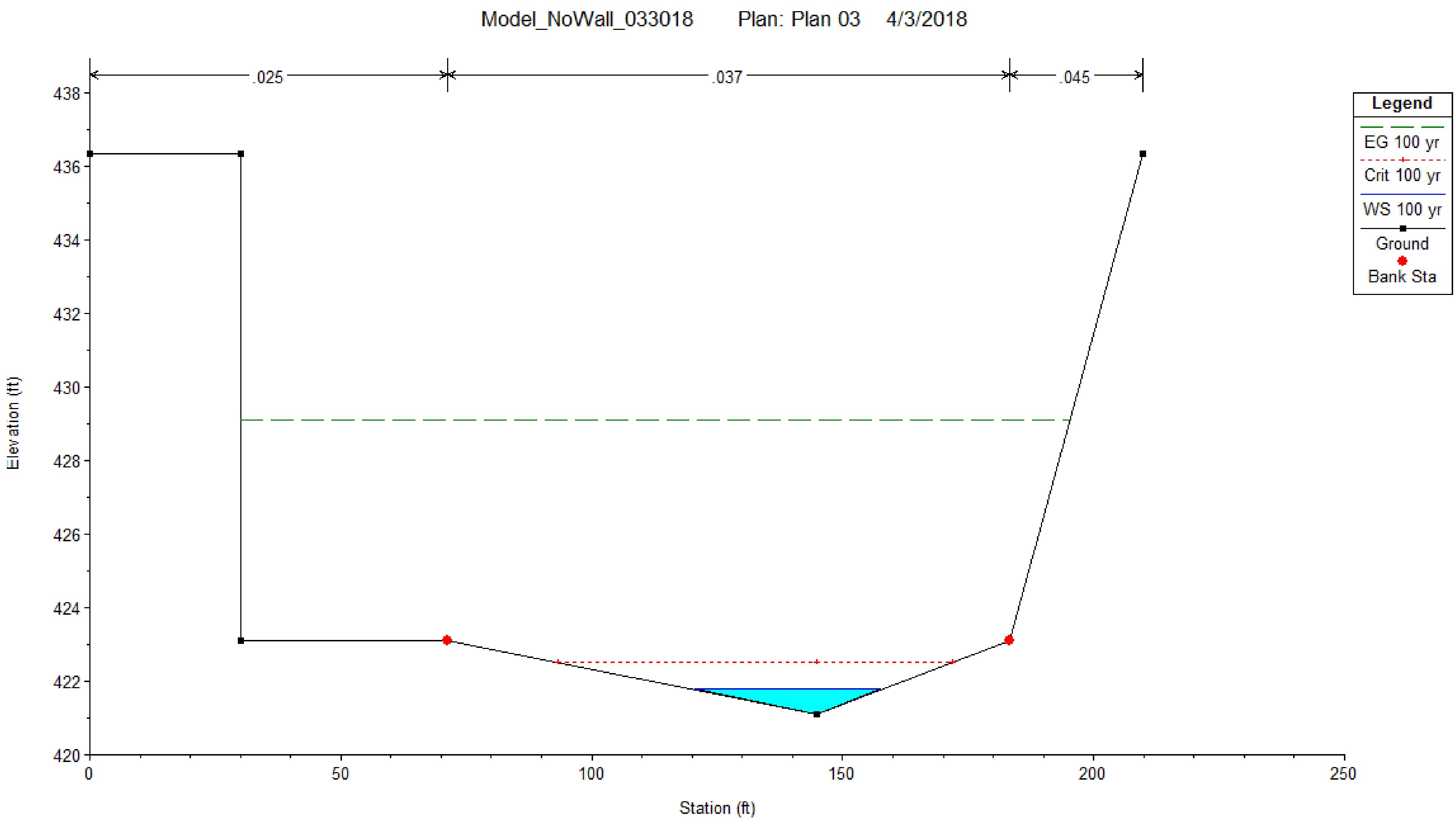
The dam was likely built on bedrock (i.e. ledge).

Synthesizing a modified XS 6: We didn't survey the bottom, but we can synthesize the cross section based on visual evidence

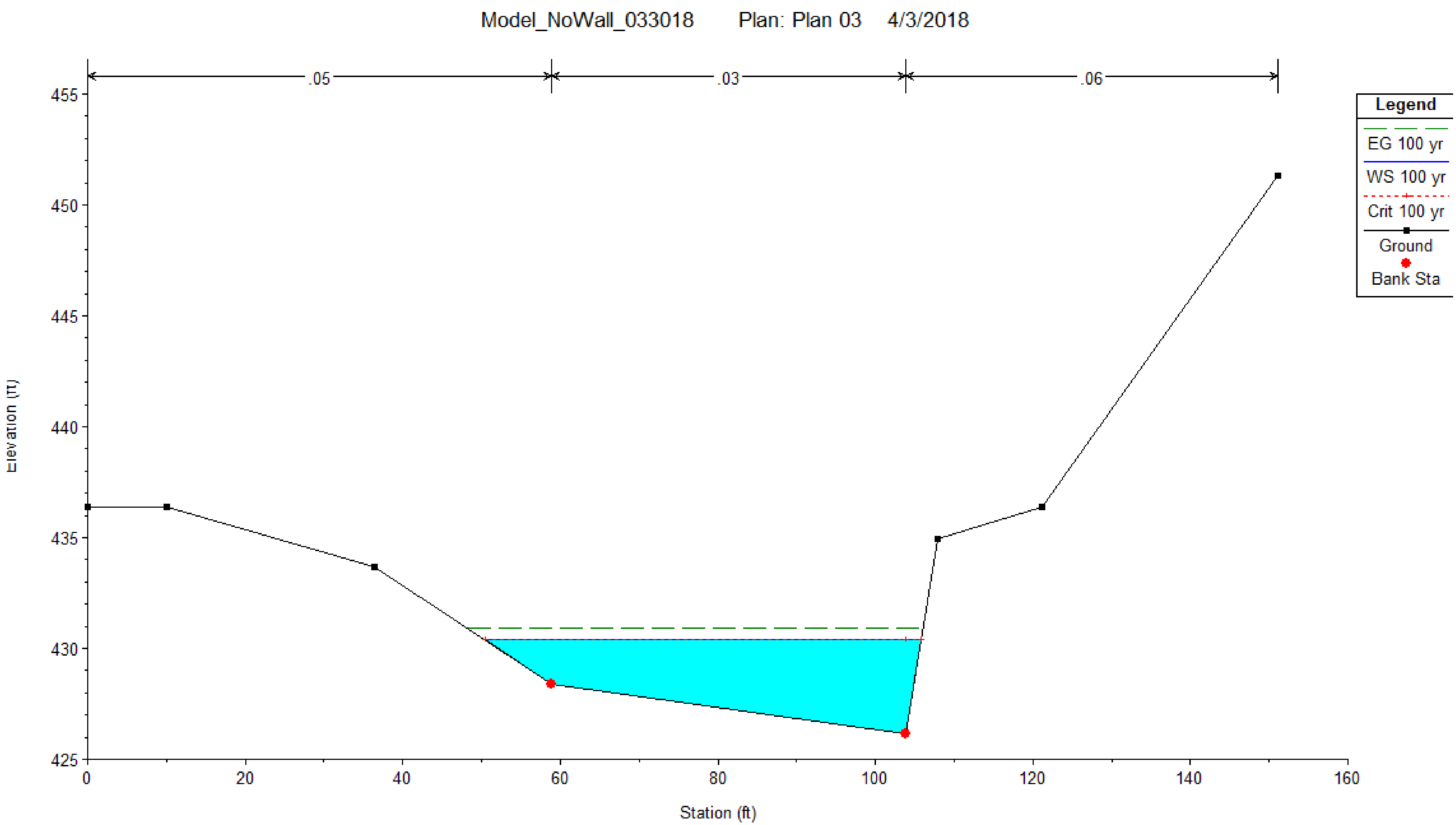
And there is evidence that the upstream side is choked with sediment/transported material

This is common with run-of-river dams; upstream they are chocked with sediment. While this reduces storage with the dam in place, keep in mind this material with rapidly flush out and the stable channel slope will re-establish once the dam is removed.

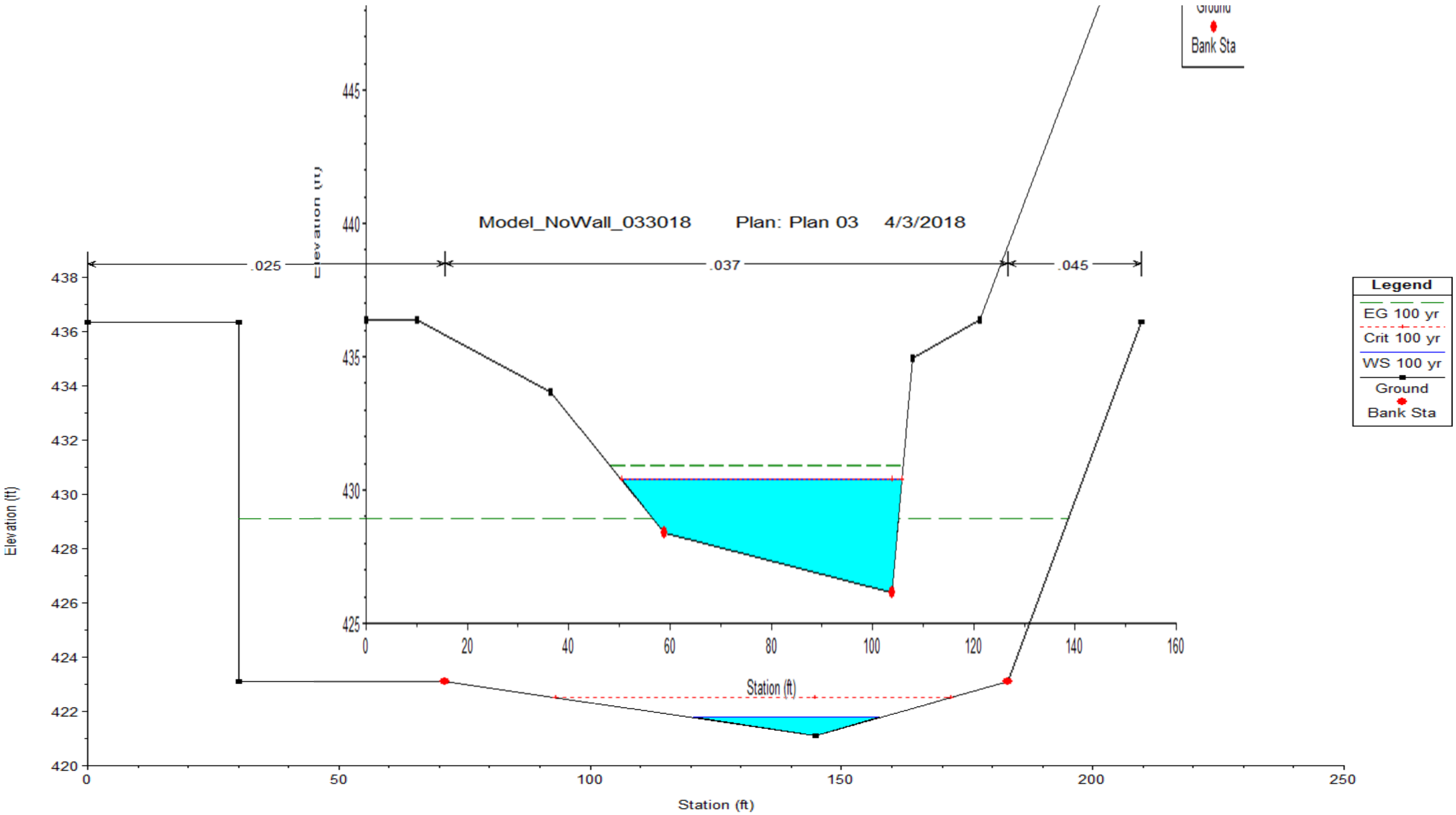
Here is the existing XS 5 that captures the channel bottom below the dam.



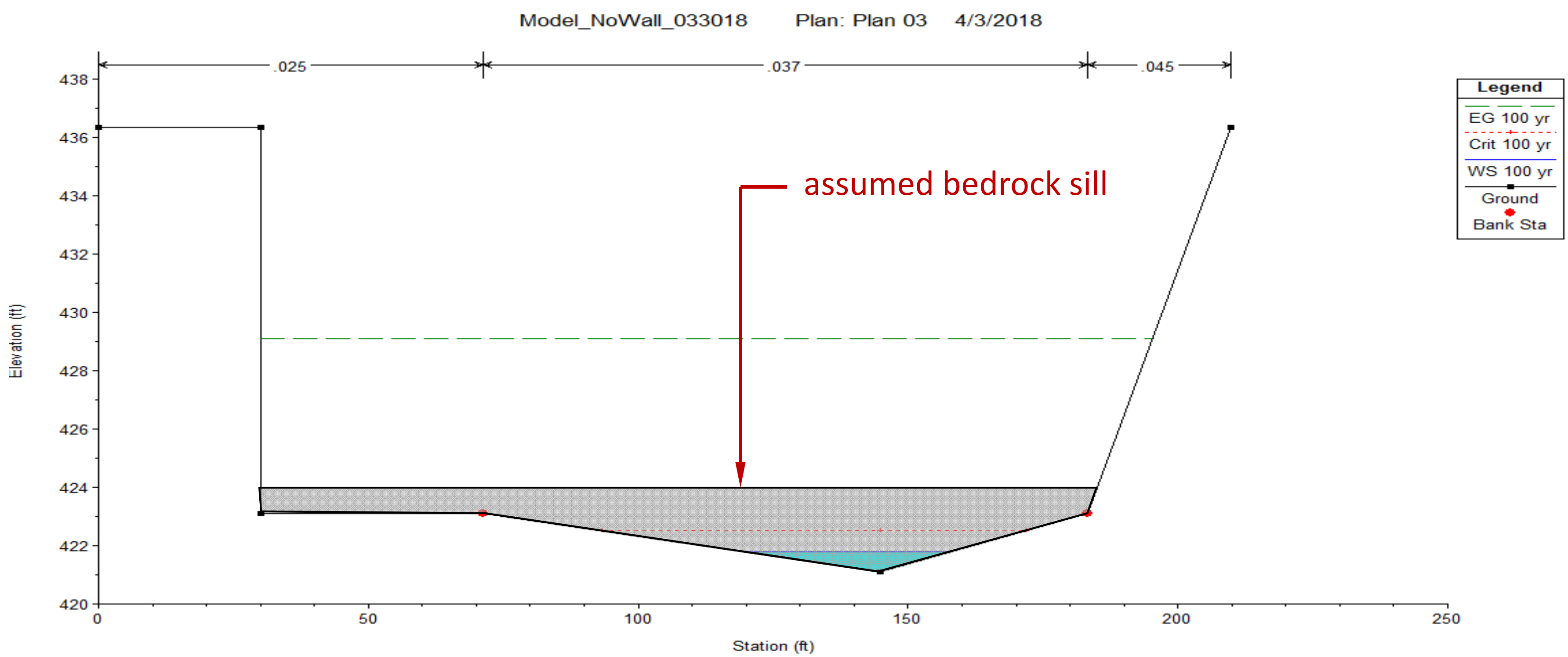
And here's XS 6, the dam crest. How do we modify this to represent the channel?



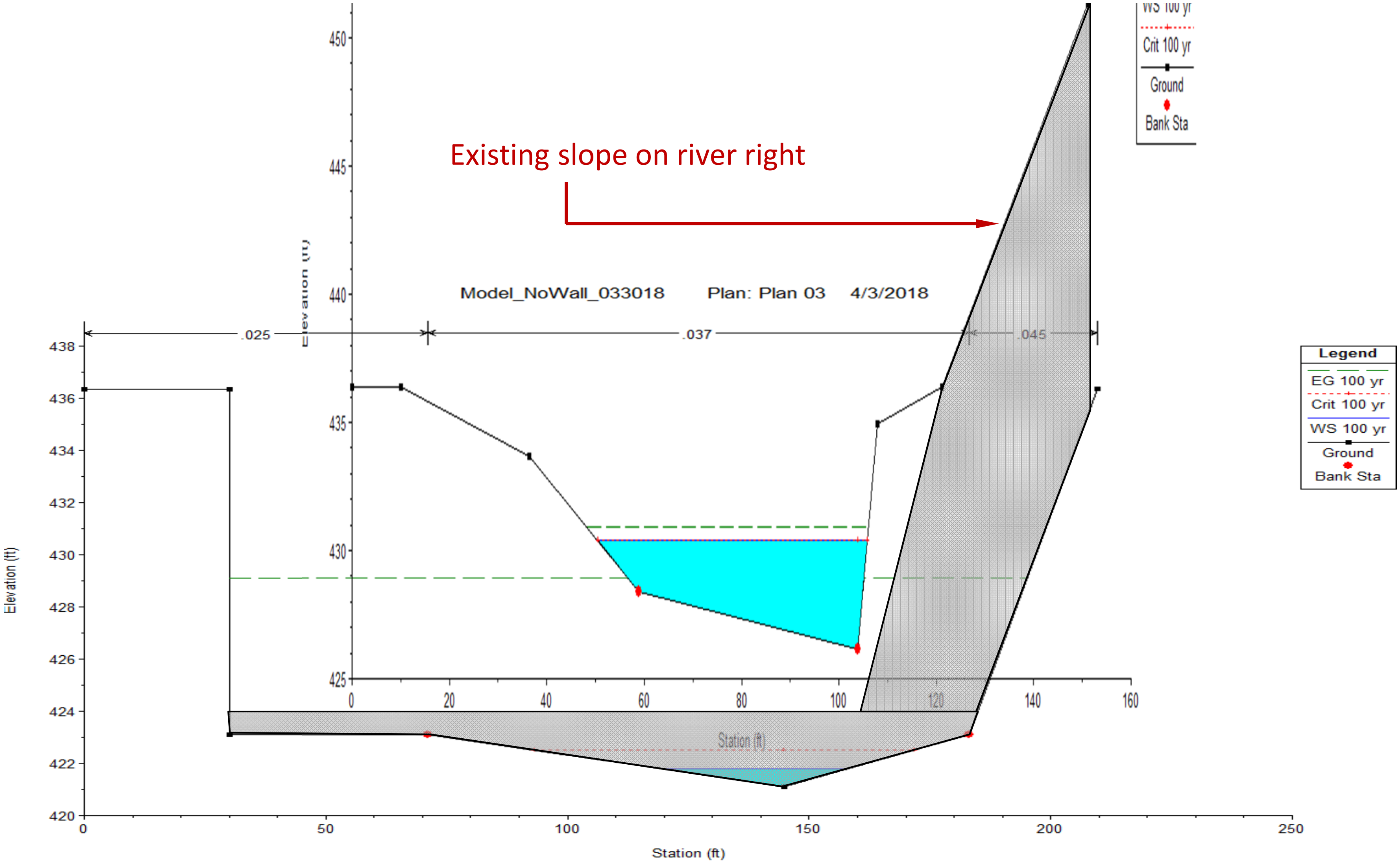
If we superimpose the 2 XS on top of each other using a common scale, we can envision the drawing below as what you would see looking downstream from the impoundment (if you had x-ray vision).



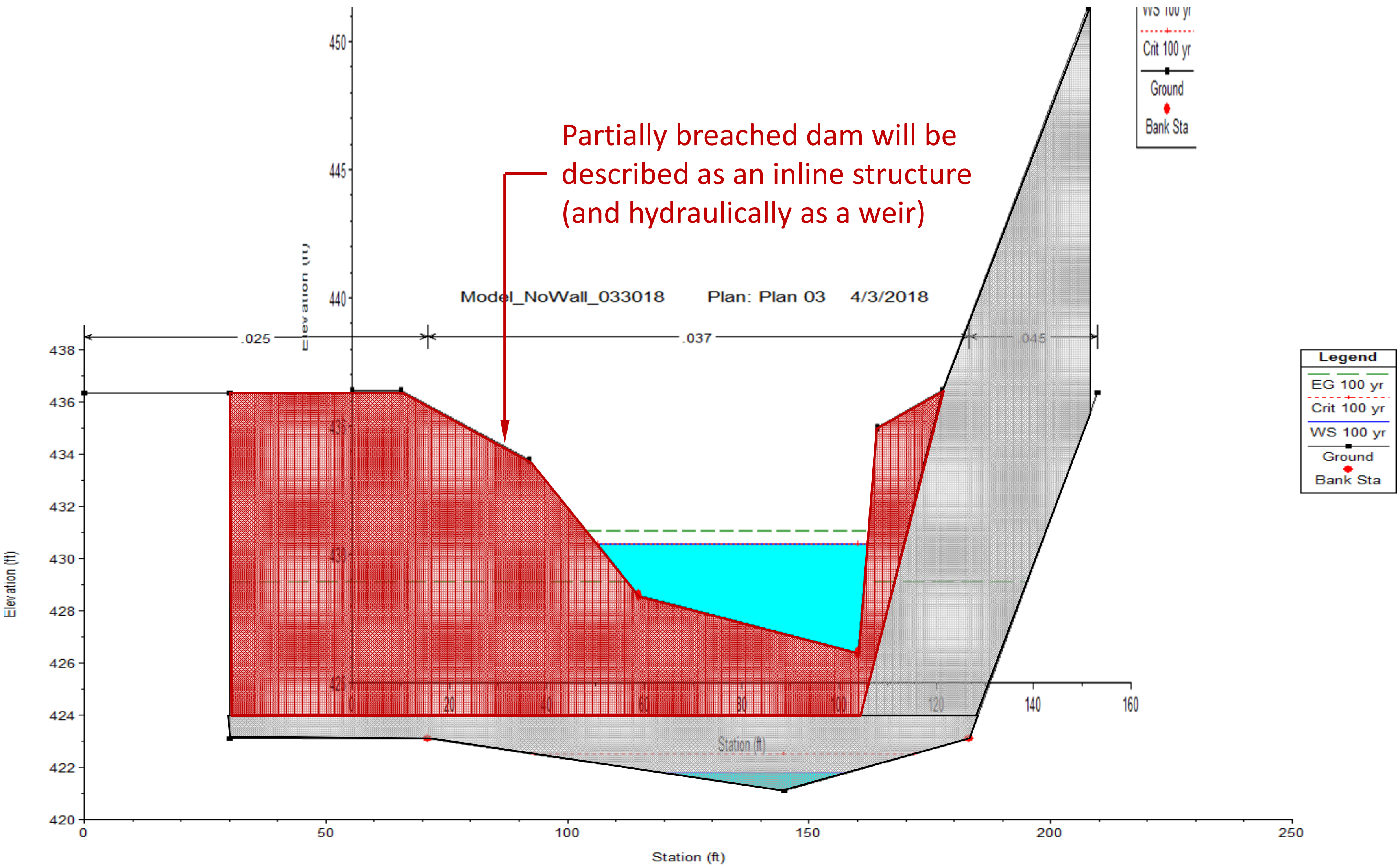
Look at XS 5 (below the dam), and begin to modify it to represent XS 6 (without the dam). First, lets assume that the base of the dam was originally chipped to a level sill to provide a foundation for the placed stone… and that this sill is at about elevation 424 ft.



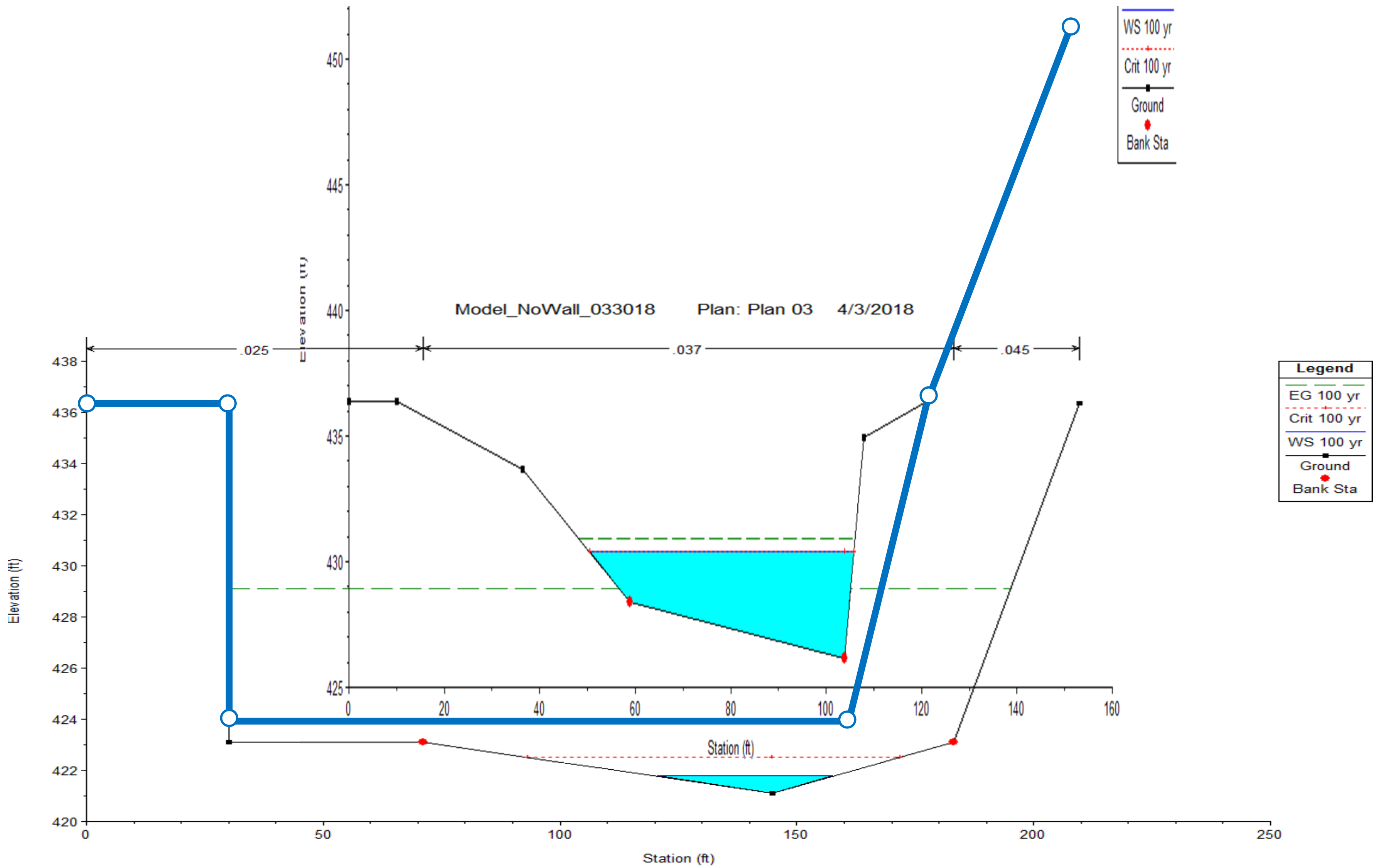
We also want to preserve the river right bank topography that you noted in your survey at XS 6. That bank is not part of the dam and will remain after removal. However, we do need to extrapolate the slope down to the channel bottom.



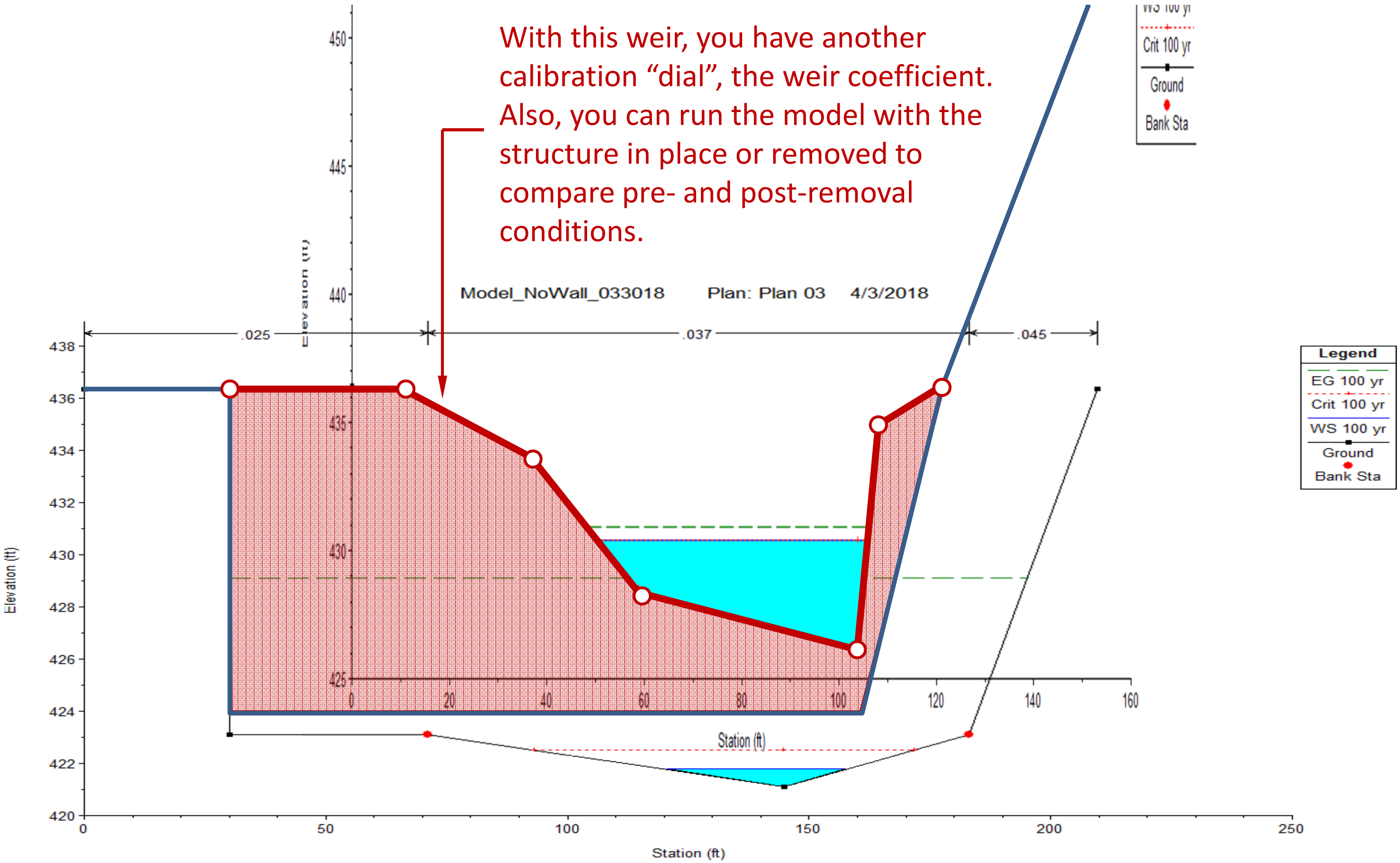
Finally, we can assume that the dam is what remains! We'll use what is gray to describe the new XS 6 and what is red to describe the inline structure.



Now, by hand, modify XS 6 so that its geometry is represented by the blue line. I've used 6 points, you can certainly use more if necessary.



From the geometry editor, create the inline structure (button on left) and model it as a broad crested weir with a coefficient of 3.0 using (at least) the 7 points below.



Appendix 9: Change of Hydraulic Conditions Due to Dam Removal

This table shows a summary of water surface elevations and velocities in each cross-section for 2, 10, 25, 50, and 100-year flood events both with and without the dam. It also includes velocity and elevation changes after removal of the Brassworks Dam.

Cross-Section	Flood Event (yr)	Water Surface Elevation (ft)		% Elevation Change After Dam Removal	Channel Velocity (ft/s)		% Velocity Change After Dam Removal
		Dam	NoDam		Dam	NoDam	
13	2	447.37	447.37	0.0000	6.36	6.36	0.00
13	10	447.96	447.96	0.0000	7.39	7.39	0.00
13	25	448.17	448.17	0.0000	7.68	7.68	0.00
13	50	448.38	448.38	0.0000	7.53	7.53	0.00
13	100	448.64	448.64	0.0000	7.12	7.12	0.00
12	2	442.85	442.85	0.0000	11.59	11.59	0.00
12	10	444.29	444.29	0.0000	11.93	11.93	0.00
12	25	444.92	444.92	0.0000	11.79	11.79	0.00
12	50	445.3	445.3	0.0000	11.81	11.81	0.00
12	100	445.52	445.52	0.0000	12.1	12.1	0.00
11	2	436.98	436.98	0.0000	14.69	14.69	0.00
11	10	437.68	437.68	0.0000	18.22	18.22	0.00
11	25	437.88	437.88	0.0000	19.65	19.65	0.00
11	50	438.02	438.02	0.0000	20.38	20.38	0.00
11	100	438.16	438.16	0.0000	20.79	20.79	0.00
10	2	437.18	437.18	0.0000	9.43	9.43	0.00
10	10	438.43	438.43	0.0000	11.24	11.24	0.00
10	25	438.86	438.86	0.0000	11.84	11.84	0.00
10	50	439.13	439.13	0.0000	12.19	12.19	0.00
10	100	439.38	439.38	0.0000	12.43	12.43	0.00
9	2	430.24	430.24	0.0000	21.67	21.67	0.00
9	10	431.18	431.18	0.0000	24.22	24.22	0.00
9	25	431.51	431.51	0.0000	24.98	24.98	0.00
9	50	431.72	431.72	0.0000	25.43	25.43	0.00
9	100	431.9	431.9	0.0000	25.81	25.81	0.00
8	2	431.85	431.79	0.0139	6.06	6.13	1.16
8	10	433.57	433.36	0.0484	7.76	8.06	3.87
8	25	434.16	433.87	0.0668	8.21	8.62	4.99
8	50	434.51	434.18	0.0759	8.47	8.95	5.67
8	100	434.81	434.45	0.0828	8.69	9.23	6.21
7	2	431.75	431.69	0.0139	5.41	5.48	1.29
7	10	433.48	433.25	0.0531	6.98	7.25	3.87
7	25	434.06	433.76	0.0691	7.44	7.81	4.97
7	50	434.42	434.07	0.0806	7.71	8.15	5.71
7	100	434.71	434.33	0.0874	7.94	8.42	6.05
6	2	431.58	426.04	1.2837	2.16	8.14	276.85
6	10	433.26	426.96	1.4541	3.09	9.8	217.15
6	25	433.82	427.3	1.5029	3.41	10.33	202.93
6	50	434.15	427.5	1.5317	3.62	10.65	194.20
6	100	434.44	427.68	1.5560	3.79	10.92	188.13

Cross-Section	Flood Event (yr)	Water Surface Elevation (ft)		% Elevation Change After Dam Removal	Channel Velocity (ft/s)		% Velocity Change After Dam Removal
		Dam	NoDam		Dam	NoDam	
5	2	424.48	422.94	0.3628	4.21	14.6	246.79
5	10	425.65	423.34	0.5427	4.57	16.83	268.27
5	25	426.11	423.45	0.6243	4.67	17.65	277.94
5	50	426.41	423.52	0.6778	4.72	18.1	283.47
5	100	426.67	423.59	0.7219	4.76	18.49	288.45
4	2	420.9	420.9	0.0000	7.76	7.76	0.00
4	10	422.12	422.12	0.0000	9.81	9.81	0.00
4	25	422.53	422.53	0.0000	10.52	10.52	0.00
4	50	422.78	422.78	0.0000	10.95	10.95	0.00
4	100	423	423	0.0000	11.3	11.3	0.00
3	2	419.14	419.14	0.0000	8.04	8.04	0.00
3	10	420.41	420.41	0.0000	9.77	9.77	0.00
3	25	420.86	420.86	0.0000	10.32	10.32	0.00
3	50	421.14	421.14	0.0000	10.65	10.65	0.00
3	100	421.4	421.4	0.0000	10.89	10.89	0.00
2	2	419.1	419.1	0.0000	7.58	7.58	0.00
2	10	420.36	420.36	0.0000	9.27	9.27	0.00
2	25	420.8	420.8	0.0000	9.83	9.83	0.00
2	50	421.06	421.06	0.0000	10.18	10.18	0.00
2	100	421.31	421.31	0.0000	10.45	10.45	0.00
1	2	418.41	418.41	0.0000	9.25	9.25	0.00
1	10	419.6	419.6	0.0000	11.07	11.07	0.00
1	25	420.01	420.01	0.0000	11.71	11.71	0.00
1	50	420.29	420.29	0.0000	12.04	12.04	0.00
1	100	420.51	420.51	0.0000	12.35	12.35	0.00
0	2	416.69	416.69	0.0000	9.69	9.69	0.00
0	10	417.68	417.68	0.0000	12.16	12.16	0.00
0	25	418.05	418.05	0.0000	12.9	12.9	0.00
0	50	418.27	418.27	0.0000	13.38	13.38	0.00
0	100	418.47	418.47	0.0000	13.75	13.75	0.00

Appendix 10: Initial Screening of Designs

This appendix details the reasoning behind our initial elimination of log jams, gabions, traditional crib walls, timber retaining wall, and brush mattresses. These decisions took place prior to our formal concept selection process.

Log Jams
Log jams were ruled out early because they were likely to increase water levels and lead to flooding. Additionally, they have a high potential for risk within the first 5 years, which our clients have expressed concern over. Although they could potentially be paired with other alternatives to overcome these drawbacks, the moderately high cost of log jams makes them an unattractive option. Compounding all of these factors, we decided to eliminate log jams.

Gabions
Gabions are an expensive hardscaping alternative, with very little load-bearing capacity. We researched vegetated gabions, as the vegetation would overcome the traditional structure's lack of visual aesthetics, reduce the increase in temperature, and allow vegetation to grow. However, the addition of plants would compromise the structural integrity entirely. Gabions are geometrically incapable of being paired with a retaining wall or any other load-bearing structure, so for this reason we eliminated them. Additionally, we feel confident about our decision to remove gabions as an option considering the fact that they already exist along a section of the river, and clearly they are not sufficient since we are currently looking for other options.

Traditional Crib Walls
Traditional Crib Walls are most often used on land, typically along roadways. Because our site is on a river, and therefore provides the necessary water, soil, and sun exposure, it is much more advantageous to use live crib walls in the place of traditional crib walls. We did not find research indicating structural weakening due to vegetation, as was the case with gabions. In every case, we would therefore prefer live crib walls, so we eliminated their traditional counterpart.

Timber Retaining Wall
In discussing retaining walls with our liaisons, they indicated that they had already decided on concrete for the wall's material. Live crib walls already provide us with an alternative wall composed of wood, so we do not need to consider timber retaining walls as well.

Brush Mattress
Brush mattresses are similar to brush layers, but brush layers have the additional benefit of being encapsulated in geotextiles, providing more form and structure. We consequently decided to eliminate this alternative from consideration.

Appendix 11: Velocities and Water Surface Levels of Existing Conditions at the Bend for 2, 50, and 100 year flood

This appendix lists the outputs from our existing conditions model in HEC-RAS.

HEC-RAS Plan: Plan 01 River: Mill River Reach: 1

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	13	2 yr	1351.00	447.37	6.36
1	13	10 yr	2365.00	447.96	7.39
1	13	25 yr	2775.00	448.17	7.68
1	13	50 yr	3042.00	448.38	7.53
1	13	100 yr	3279.00	448.64	7.12
1	12	2 yr	1351.00	442.85	11.59
1	12	10 yr	2365.00	444.29	11.93
1	12	25 yr	2775.00	444.92	11.79
1	12	50 yr	3042.00	445.30	11.81
1	12	100 yr	3279.00	445.52	12.10
1	11	2 yr	1351.00	436.98	14.69
1	11	10 yr	2365.00	437.68	18.22
1	11	25 yr	2775.00	437.88	19.65
1	11	50 yr	3042.00	438.02	20.38
1	11	100 yr	3279.00	438.16	20.79
1	10	2 yr	1351.00	437.18	9.43
1	10	10 yr	2365.00	438.43	11.24
1	10	25 yr	2775.00	438.86	11.84
1	10	50 yr	3042.00	439.13	12.19
1	10	100 yr	3279.00	439.38	12.43
1	9	2 yr	1351.00	430.24	21.67
1	9	10 yr	2365.00	431.18	24.22
1	9	25 yr	2775.00	431.51	24.98
1	9	50 yr	3042.00	431.72	25.43
1	9	100 yr	3279.00	431.90	25.81
1	8	2 yr	1351.00	431.85	6.06
1	8	10 yr	2365.00	433.57	7.76
1	8	25 yr	2775.00	434.16	8.21
1	8	50 yr	3042.00	434.51	8.47
1	8	100 yr	3279.00	434.81	8.69

HEC-RAS Plan: Plan 01 River: Mill River Reach: 1 (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	7	2 yr	1351.00	431.75	5.41
1	7	10 yr	2365.00	433.48	6.98
1	7	25 yr	2775.00	434.06	7.44
1	7	50 yr	3042.00	434.42	7.71
1	7	100 yr	3279.00	434.71	7.94
1	6	2 yr	1351.00	431.58	2.16
1	6	10 yr	2365.00	433.26	3.09
1	6	25 yr	2775.00	433.82	3.41
1	6	50 yr	3042.00	434.15	3.62
1	6	100 yr	3279.00	434.44	3.79
1	5.5		Inl Struct		
1	5	2 yr	1351.00	424.48	4.21
1	5	10 yr	2365.00	425.65	4.57
1	5	25 yr	2775.00	426.11	4.67
1	5	50 yr	3042.00	426.41	4.72
1	5	100 yr	3279.00	426.67	4.76
1	4	2 yr	1351.00	420.90	7.76
1	4	10 yr	2365.00	422.12	9.81
1	4	25 yr	2775.00	422.53	10.52
1	4	50 yr	3042.00	422.78	10.95
1	4	100 yr	3279.00	423.00	11.30
1	3	2 yr	1351.00	419.14	8.04
1	3	10 yr	2365.00	420.41	9.77
1	3	25 yr	2775.00	420.86	10.32
1	3	50 yr	3042.00	421.14	10.65
1	3	100 yr	3279.00	421.40	10.89
1	2	2 yr	1351.00	419.10	7.58
1	2	10 yr	2365.00	420.36	9.27
1	2	25 yr	2775.00	420.80	9.83
1	2	50 yr	3042.00	421.06	10.18

HEC-RAS Plan: Plan 01   River: Mill River   Reach: 1 (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	2	100 yr	3279.00	421.31	10.45
1	1	2 yr	1351.00	418.41	9.25
1	1	10 yr	2365.00	419.60	11.07
1	1	25 yr	2775.00	420.01	11.71
1	1	50 yr	3042.00	420.29	12.04
1	1	100 yr	3279.00	420.51	12.35
1	0	2 yr	1351.00	416.69	9.69
1	0	10 yr	2365.00	417.68	12.16
1	0	25 yr	2775.00	418.05	12.90
1	0	50 yr	3042.00	418.27	13.38
1	0	100 yr	3279.00	418.47	13.75

Appendix 12: Alternatives Research

This appendix summarizes the external literature review of alternatives, with visualizations accompanying each description. We conducted research on live crib walls, retaining walls, stream barbs, live staking, live siltation, brush layers, riprap, fabric encapsulated lifts, live fascines, and wattle fences.

Live Crib Wall: "Live crib walls are constructed with interlocking, untreated logs and live stems. The logs are anchored into the slope, forming the wall, and vegetation is initially used to tie the logs together. Long-term stability to the slope is further developed with the vegetation's root growth. With time, the logs naturally degrade and the vegetation becomes the structure itself." (Ohio Dept. of Natural Resources, 2010)

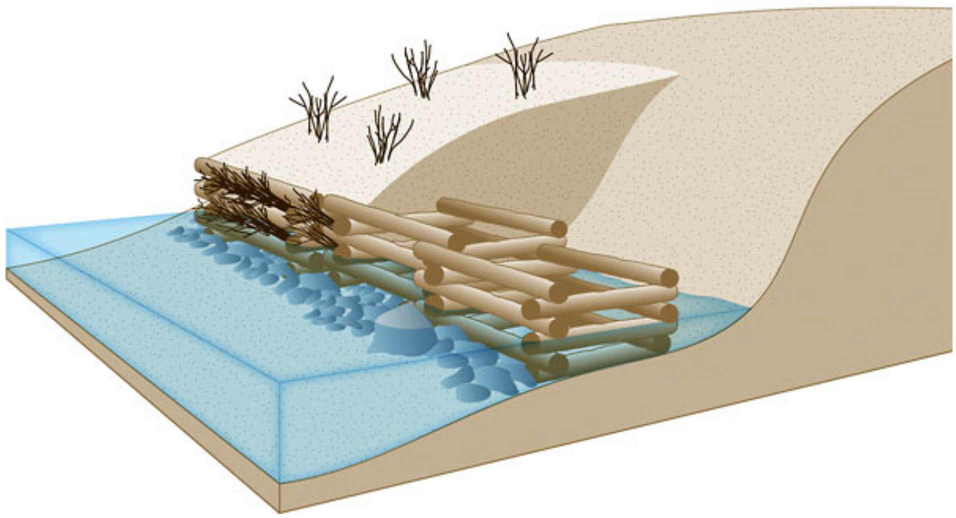


Figure 12-1. Visualization of Live Crib Wall (http://www.timmessick.com/illustrations/h2a29ab0e#h2a29ab0e)

Retaining Wall:
Types of Retaining Walls (U.S. Army Corps of Engineers, 1989):

- Gravity
  - Rely on the weight of the wall system to resist overturning
  - Materials
    - Concrete or stone masonry
    - Can use steel to minimize size of wall sections
  - Disadvantages
    - Not economical for high walls (but maybe in our case since the greenway will be adding weight for stabilization and the river will provide lateral forces)
- Cantilever
  - Fully reinforced to resist applied moments and shears
  - Special type of gravity wall in which part of the stabilizing weight is supplied by the weight of the backfill resting on the base slab
  - Economical up to a height of 8m
  - Materials
    - Reinforced Concrete
    - Steel reinforcement bars
    - Most economical type of conventional wall for common heights
- Anchored
  - Resist lateral forces primarily by the use of tieback anchors

- Advantages
    - Known for reliability, longevity, and economy
    - Can be installed at any inclination through all types of overburden and rock
  - Disadvantages
    - In fine-grained soils, effective groundwater discharge systems may be difficult to construct and to maintain
    - Nearby construction may change soils stresses, decreasing tieback capacity possibly leading to failure.
- Mechanically stabilized backfill
  - Involves the inclusion of the reinforcement in the soil to form a coherent mass
  - Can be used in combination with geotextiles
  - Materials
    - Primarily soil
    - Performance improved by small quantities of other materials in the form of strips, grids, sheets, rods, or fibers. Resist tensile forces that soil alone is unable to withstand.
  - Advantages
    - Economical compared to conventional retaining walls
    - Construction is usually easy and rapid - does not require skilled labor or specialized equipment
    - Capable of withstanding dynamic loads imposed by wave action, wheel loads, and impact of small boats
    - Stable under chemical and biological conditions normally occurring in soils
    - More aesthetically pleasing
  - Disadvantages
    - Corrosion of metallic reinforcement occurs and must be assessed on a project basis by determining the potential aggressiveness of the soil
    - Requires wider excavation than conventional retaining walls
    - Excavation behind the wall is restricted
- Gravity and cantilever walls are most common, usually constructed of cast-in-place concrete

Of the many types of retaining wall, we would use concrete Cantilevered wall, as they are the most aesthetically pleasing for its price, and one of the most commonly used walls.

Based on research we were hoping to use a Mechanically Stabilized Earth Wall, but our liaison, Jim Hyslip, provided the following reasoning for why this would not be an appropriate solution in our case:

> "A MSE wall would be a good alternative if there was a good way to armor the face to provide 'hardened' infrastructure to allow the road/greenway and the river to happily coexist for a very long time. Once you've designed a robust face for the MSE wall, then you're probably getting close to a mass gravity structure that doesn't need reinforcement.

Also, for an MSE wall, the lowest tensile grid is always the longest, and quick rule-of-thumb is the bottom grid is around 75% to 100% of the height of a wall. So a 12 ft high wall would need a bottom flat space behind the wall of at least 12 feet, to allow placement of the bottom grid. At our site, I think that would put the excavation for the new wall underneath the existing roadway."
(Email from Jim Hyslip 3/13/18)

Figure 12-2. River Retaining Wall (https://howardsykes.mycouncillor.org.uk/2016/08/18/duchess-street-pencil-brook-deteriorating-retaining-wall/)

Stream Barbs: "Stream barbs are low dikes or sill-like structures that extend from the bank towards the stream in an upstream direction. As flow passes over the sill of the stream barb, it accelerates, similar to flow over the weir of a drop structure, and discharges normal to the face of the weir. Thus, a portion of the stream flow is redirected in a direction perpendicular to the angled downstream edge of the weir. " (USDA, 2013)

Figure 12-3. Stream Barbs
(https://drainage.pca.state.mn.us/index.php?title=Stream_Barbs/J-hook_Vanes)

Live Staking: "Live staking involves the insertion and tampering of live, rootable vegetative cuttings into the ground. If correctly prepared, handled and placed, the live stake will root and grow. A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture." (USDA , 2013)

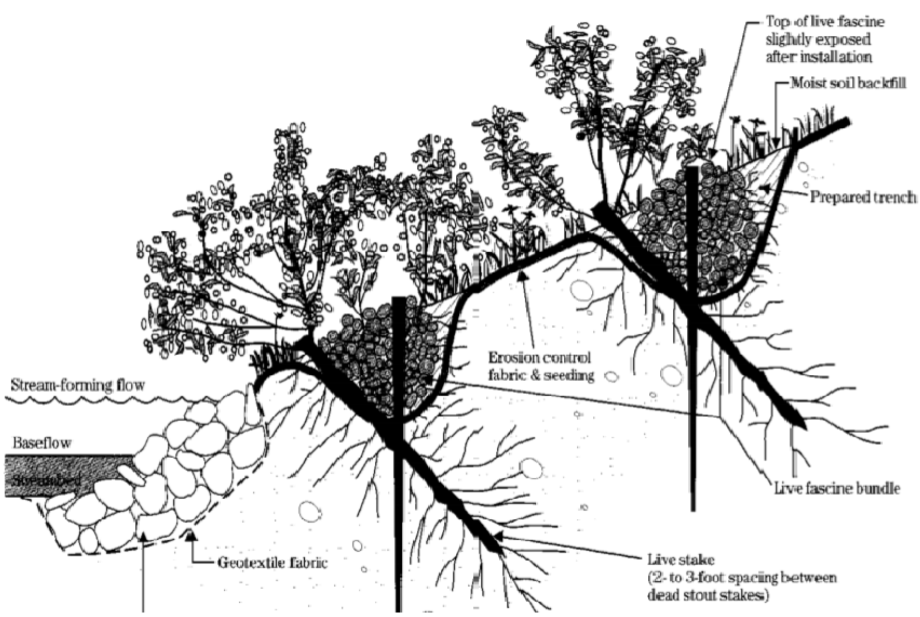


Figure 12-4. Live Staking Sketch (USDA, 2013)

Figure 12-5. Live Staking
(https://www.cardnonativeplantnursery.com/about-the-nursery/nursery-notes/posts/nursery-notes/2015/03/02/live-stakes-in-the-dead-of-winter)

Live Siltation: Live Siltation is a streambank vegetation method placed at normal high water level involving digging a trench for placement of live cuttings. This stabilizes the near-bottom slope of the bank, slowing down of the flow, and habitat.

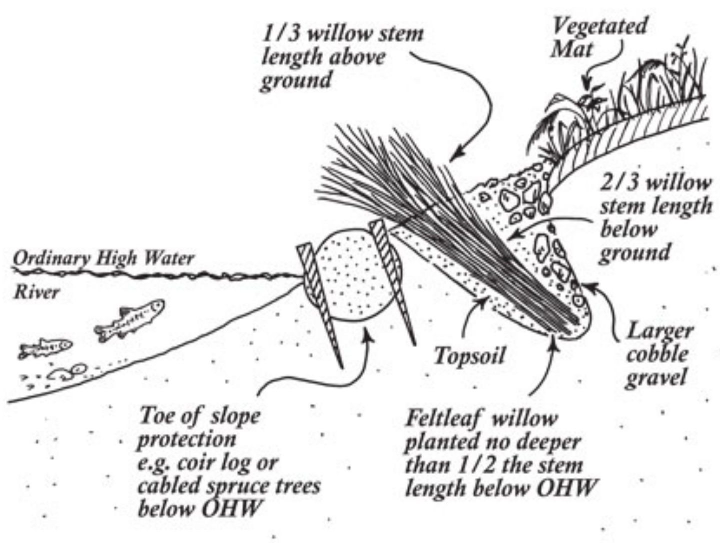


Figure 12-6. Live Siltation Sketch
(http://www.adfg.alaska.gov/index.cfm?adfg=streambankprotection.siltation)

Figure 12-7. Live Siltation
(http://www.adfg.alaska.gov/index.cfm?adfg=streambankprotection.siltation**)**

<u>Brush Layers</u>: These are horizontally placed cuttings placed between layers of soil. The soil may or may not be encapsulated. Brush layers protect the bank from erosion and allow for.

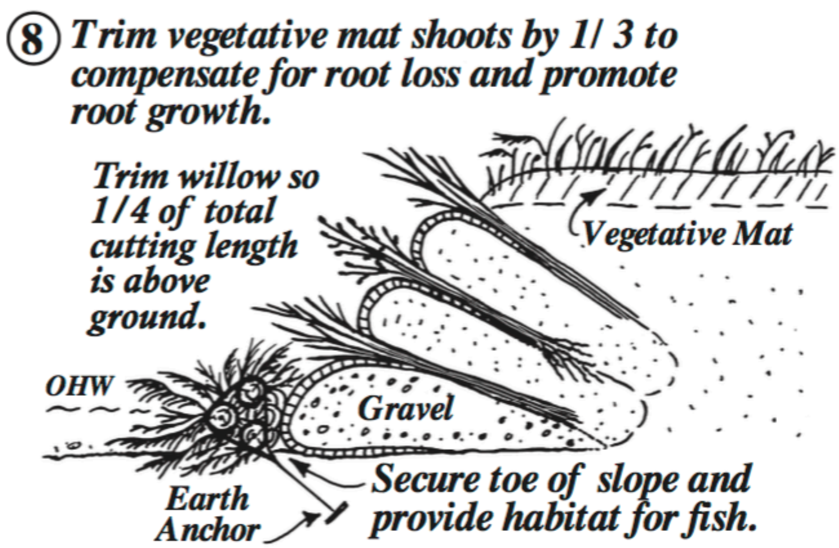


Figure 12-8. Brush Layers Sketch
(http://www.adfg.alaska.gov/index.cfm?adfg=streambankprotection.layering)

Figure 12-9. Brush Layers
(https://www.dec.ny.gov/docs/water_pdf/sec4.pdf)

Riprap: Riprap is the layering of (typically angular) rocks along a threatened area to counteract the constant wearing away of land brought about by repetitive hydrologic activity. It is the traditional response to controlling and minimizing erosion along shorelines and riverbanks.

Figure 12-10. Riprap
(http://www.westconsultants.com/services/technology-and-software-development/riprap-design-system/)

Fabric Encapsulated Lifts: Soil layers are "encapsulated" inside of biodegradable fabric to form the lift. Each new course, or layer, of lift is placed on the preceding course but stepped back to create the desired slope. They are planted or seeded to long-rooted native plants that help to stabilize the soil layers.

Figure 12-11. Fabric Encapsulated Lifts
(https://www.rachelcontracting.com/projects/handy-creek-bank-stabilization)

Live Fascines: Live fascines are long bundles of live woody vegetation buried in a streambank parallel to the flow. The plant bundles sprout and develop roots that stabilizes the soil.

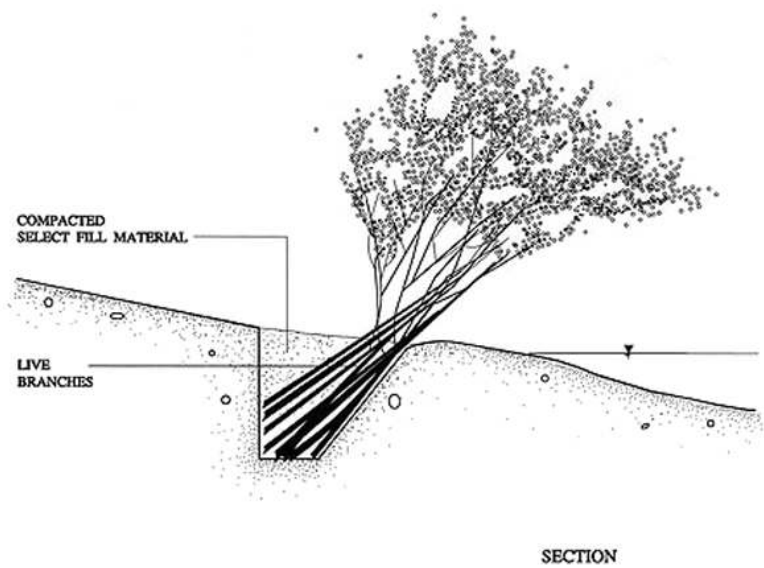


Figure 12-12. Live Fascines Sketch
(http://www.sotir.com/publications/brushing_erosion.html)

Figure 12-12. Live Fascines
(http://www.bender-rekultivierungen.de/en/services/bioengineering/)

Wattle Fences: These wood fences form miniature retaining walls that hold back soil in place to prevent erosion, and also protect against erosion caused by the stream.

Figure 12-14. Wattle Fences
(http://www.kennebecasisriver.ca/wattle.html)

References:

Fischenich, J. Craig, and Robbin B. Sotir. "Vegetated Reinforced Soil Slope Streambank Erosion Control." *Ecosystem Management and Restoration Research Program*, May 2003, U.S. Army Engineer Research and Development Center.

"Kansas Engineering Technical Note No. KS-1." *United Stated Department of Agriculture*, Natural Resources Conservation Service, 23 Jan. 2013.

"Ohio Stream Management Guide." *Guide No. 17*, Ohio Department of Natural Resources, 2010.

"Retaining and Flood Walls." *Engineer Manual 1110-2-2502*, U.S. Army Corps of Engineers, 1989.

Appendix 13: Design Verification for Hydraulic Model and Bank Protection Designs

The following is documentation of the HEC-RAS model and bank protection fulfillment of the design requirements. The verification material is introduced as listed below. Note the verifications that are appendices are not featured in this document ensemble, since they are already within this report.

Hydraulic Model Verification:

HR-V-01 – Figure 13 from Final Report

HR-V-02 – Figure 13 from Final Report

HR-V-03 – Appendix 6: Accuracy Calculations for HEC-RAS Model

HR-V-04 – Figure 14 from Final Report

HR-V-05 – Hill Engineers Email Confirmation

Recommended Bank Protection Design Verification:

BP-V-01 – NCRS Technical Supplement 14I: Streambank Soil Bioengineering – *Table TS14I–4*

& NRCS Part 654 Restoration Design National Engineering Handbook: Chapter 8 Threshold Channel Design – *Figure 8–25*

& HEC-RAS Alternatives Model Velocity Outputs (With and Without Dam)

BP-V-02 – Same as above

BP-V-03 – HEC-RAS Cross Sections

BP-V-04 – Figure 15 from Final Report

Hydraulic Model Verification

HR-V-01 & HR-V-02

Figure 13 from Final Report

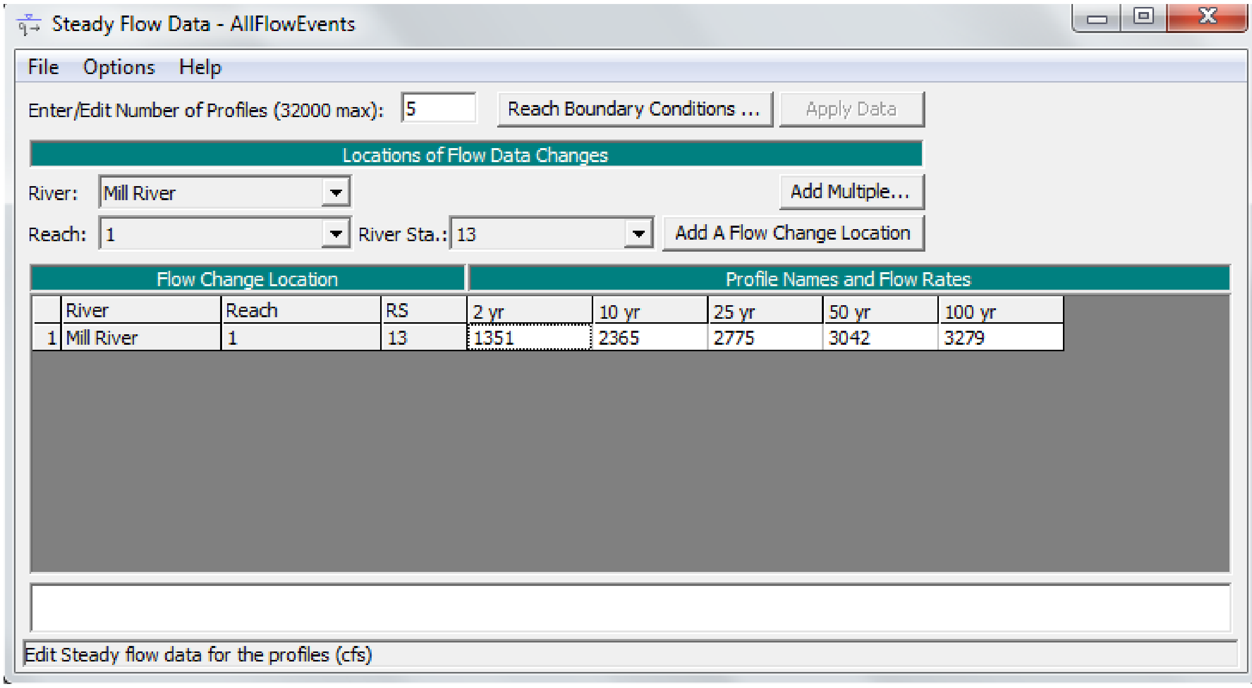


Figure 13. Screenshot from HEC-RAS Showing Flows of the 2, 10, 25, 50, 100 year floods

HR-V-04 – Figure 14 from Final Report

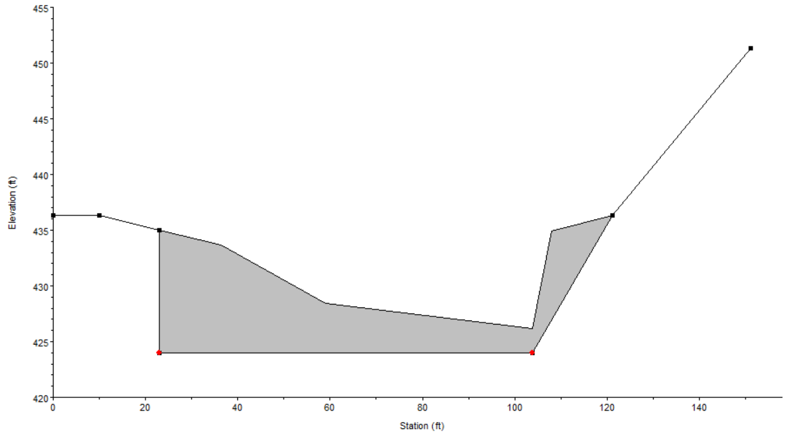


Figure 14. HEC-RAS Screenshot Showing the Brassworks Dam Modeled as an Inline Structure

Marcia Rojas <mrojas@smith.edu>

Survey Shadowing

Timothy Armstrong <tarmstrong@hillengineers.com> Mon, Mar 26, 2018 at 11:54 AM
To: Marcia Rojas <mrojas@smith.edu>

Marcia,

I've taken a look at the control information you provided, that was a nice presentation. I have a few comments regarding the data from a surveyors perspective. I do not know what sort of accuracy you need between all the data points for your analysis, so this may not matter for you. The Trimble GeoXH you used to collect the coordinates on your control points is what we refer to as a sub-meter unit. Due to the way it is calculating its position, it always had error in it that is in the 1' to 2' range. It's not so much that it is wrong , it's that the data has uncertainty in it that prevents the point from being more precise. You can see that in the coordinate comparison on the USGS disk that we have both located (see below). It all really depends on what the requirements are for the final application of the data.

306 (Hill point)	2963922.605	330857.0334	427.37	MDSK USGS+
Smith (meters)	903406.27	100845.05	129.7	
Smith (USFT)	2963925.4	330855.8	425.52	
Difference	-2.795	1.2334	1.85	

That is the amount of difference I expect to see between a sub-meter GPS point and out survey point. Each of the control points will likely have this amount of error, but not in a consistent direction. This is strictly looking at the control points and does not take into account the total station data. Any points located with the total station from the same setup should be consistent together. I also do not know how this may, or may not, affect your hydrology work. Your advisor who processed that data may have done some adjustment as well. I'd be happy to look at all your data if you would like.

I would be happy to answer any additional questions you may have or you data as well.

Sincerely,

Tim

Tim Armstrong, PLS

Chief Land Surveyor

50 Depot Street

Dalton, MA 01226

413-684-0925 X148

fax 413-684-0267

www.hillengineersma.com

HR-V-05

Smith College

Marcia Rojas <mrojas@smith.edu>

Bathymetry Data Control Points

1 message

Marcia Rojas <mrojas@smith.edu> Wed, Mar 14, 2018 at 4:06 PM

To: Tim Armstrong <tarmstrong@hillengineers.com>

Dear Tim,

Attached you will find the Site Visit 11 Summary PDF containing the information on the control points for our bathymetry data.
Please let me know if you have any questions!

Best,
Marcia

--
Marcia Rojas
Smith College '18
mrojas@smith.edu

Site Visit 11 Summary.pdf
11392K

Bank Protection Design Verification

BP-V-01 & BP-V-02

NCRS Technical Supplement 14I: Streambank Soil Bioengineering – *Table TS14I–4*

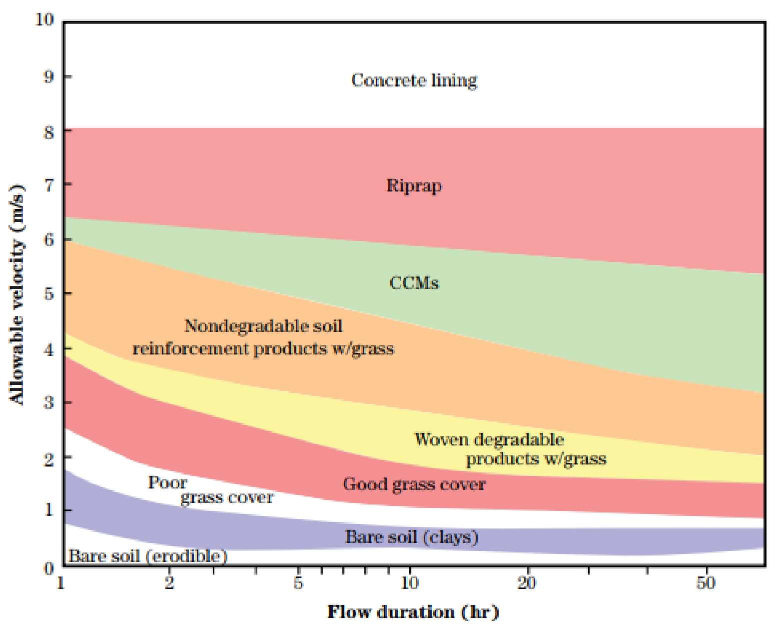
Table TS14I–4 Compiled permissible shear stress levels for streambank soil bioengineering practices

Practice	Permissible shear stress (lb/ft²)*	Permissible velocity (ft/s)*
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Live poles in woven coir TRM (Depends on installation and anchoring of coir)	Initial: 2 to 2.5 Established: 3 to 5+	Initial: 3 to 5 Established: 3 to 10
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8+	Initial: 5 to 10+ Established: 12+
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8+	Initial: 3 to 4 Established: 10+
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3+	Initial: 5 to 8 Established: 8 to 10+
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6+	Initial: 2 to 4 Established: 10+
Live cribwall (Depends on nature of the fill (rock or earth), compaction and anchoring)	Initial: 2 to 4+ Established: 5 to 6+	Initial: 3 to 6 Established: 10 to 12
Vegetated reinforced soil slopes (VRSS) (Depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+
Grass turf—bermudagrass, excellent stand (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8
Live brush wattle fence (Depends on soil conditions and depth of stakes)	Initial: 0.2 to 2 Established: 1.0 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3+	Initial: 5 to 8 Established: 6 to 10+

* (USDA NRCS 1996b; Hoag and Fripp 2002; Fischenich 2001; Gerstgrasser 1999; Nunnally and Sotir 1997; Gray and Sotir 1996; Schiechtl and Stern 1994; USACE 1997; Florineth 1982; Schoklitsch 1937)

NRCS Part 654 Restoration Design National Engineering Handbook: Chapter 8 Threshold Channel Design – *Figure 8–25*

Figure 8–25 Effect of flow duration on allowable velocities for various channel linings



*For slopes <5%

BP-V-01

HEC-RAS Plan: Plan 08   River: Mill River   Reach: 1

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	13	2 yr	1351.00	447.37	6.37
1	13	10 yr	2365.00	447.97	7.37
1	13	25 yr	2775.00	448.16	7.72
1	13	50 yr	3042.00	448.34	7.73
1	13	100 yr	3279.00	448.57	7.45
1	12	2 yr	1351.00	442.85	11.58
1	12	10 yr	2365.00	444.28	11.96
1	12	25 yr	2775.00	444.92	11.81
1	12	50 yr	3042.00	445.29	11.82
1	12	100 yr	3279.00	445.52	12.12
1	11	2 yr	1351.00	436.96	14.34
1	11	10 yr	2365.00	437.67	17.31
1	11	25 yr	2775.00	437.88	18.59
1	11	50 yr	3042.00	438.02	19.24
1	11	100 yr	3279.00	438.16	19.60
1	10	2 yr	1351.00	437.15	9.29
1	10	10 yr	2365.00	438.37	11.12
1	10	25 yr	2775.00	438.79	11.75
1	10	50 yr	3042.00	439.06	12.13
1	10	100 yr	3279.00	439.31	12.38
1	9	2 yr	1351.00	430.06	20.48
1	9	10 yr	2365.00	430.89	22.22
1	9	25 yr	2775.00	431.19	22.76
1	9	50 yr	3042.00	431.38	23.09
1	9	100 yr	3279.00	431.55	23.38
1	8	2 yr	1351.00	431.85	5.98
1	8	10 yr	2365.00	433.52	7.88
1	8	25 yr	2775.00	434.07	8.53
1	8	50 yr	3042.00	434.39	8.94
1	8	100 yr	3279.00	434.67	9.28
1	7	2 yr	1351.00	431.75	5.23
1	7	10 yr	2365.00	433.48	6.81
1	7	25 yr	2775.00	434.04	7.35
1	7	50 yr	3042.00	434.38	7.68
1	7	100 yr	3279.00	434.67	7.97
1	6	2 yr	1351.00	431.58	2.16
1	6	10 yr	2365.00	433.26	3.09
1	6	25 yr	2775.00	433.82	3.41
1	6	50 yr	3042.00	434.15	3.62
1	6	100 yr	3279.00	434.44	3.79
1	5.5		Inl Struct		
1	5	2 yr	1351.00	424.48	4.20

BP-V-01

HEC-RAS Plan: Plan 08 River: Mill River Reach: 1 (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	5	10 yr	2365.00	425.66	4.56
1	5	25 yr	2775.00	426.12	4.66
1	5	50 yr	3042.00	426.41	4.71
1	5	100 yr	3279.00	426.67	4.76
1	4	2 yr	1351.00	420.89	7.80
1	4	10 yr	2365.00	422.09	9.87
1	4	25 yr	2775.00	422.51	10.56
1	4	50 yr	3042.00	422.78	10.96
1	4	100 yr	3279.00	423.00	11.30
1	3	2 yr	1351.00	419.18	7.93
1	3	10 yr	2365.00	420.51	9.53
1	3	25 yr	2775.00	421.01	9.99
1	3	50 yr	3042.00	421.33	10.24
1	3	100 yr	3279.00	421.62	10.43
1	2	2 yr	1351.00	419.10	7.89
1	2	10 yr	2365.00	420.41	9.67
1	2	25 yr	2775.00	420.91	10.19
1	2	50 yr	3042.00	421.20	10.54
1	2	100 yr	3279.00	421.47	10.81
1	1	2 yr	1351.00	418.42	9.30
1	1	10 yr	2365.00	419.62	11.17
1	1	25 yr	2775.00	420.03	11.82
1	1	50 yr	3042.00	420.31	12.15
1	1	100 yr	3279.00	420.54	12.47
1	0	2 yr	1351.00	416.67	9.74
1	0	10 yr	2365.00	417.64	12.30
1	0	25 yr	2775.00	418.00	13.06
1	0	50 yr	3042.00	418.21	13.56
1	0	100 yr	3279.00	418.41	13.91

BP-V-02

HEC-RAS Plan: Plan 07   River: Mill River   Reach: 1

Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	13	2 yr	1351.00	447.37	6.37
1	13	10 yr	2365.00	447.97	7.37
1	13	25 yr	2775.00	448.16	7.72
1	13	50 yr	3042.00	448.34	7.73
1	13	100 yr	3279.00	448.57	7.45
1	12	2 yr	1351.00	442.85	11.58
1	12	10 yr	2365.00	444.28	11.96
1	12	25 yr	2775.00	444.92	11.81
1	12	50 yr	3042.00	445.29	11.82
1	12	100 yr	3279.00	445.52	12.12
1	11	2 yr	1351.00	436.96	14.34
1	11	10 yr	2365.00	437.67	17.31
1	11	25 yr	2775.00	437.88	18.59
1	11	50 yr	3042.00	438.02	19.24
1	11	100 yr	3279.00	438.16	19.60
1	10	2 yr	1351.00	437.15	9.29
1	10	10 yr	2365.00	438.37	11.12
1	10	25 yr	2775.00	438.79	11.75
1	10	50 yr	3042.00	439.06	12.13
1	10	100 yr	3279.00	439.31	12.38
1	9	2 yr	1351.00	430.06	20.48
1	9	10 yr	2365.00	430.89	22.22
1	9	25 yr	2775.00	431.19	22.76
1	9	50 yr	3042.00	431.38	23.09
1	9	100 yr	3279.00	431.55	23.38
1	8	2 yr	1351.00	431.80	6.03
1	8	10 yr	2365.00	433.33	8.12
1	8	25 yr	2775.00	433.83	8.83
1	8	50 yr	3042.00	434.13	9.27
1	8	100 yr	3279.00	434.39	9.64
1	7	2 yr	1351.00	431.70	5.29
1	7	10 yr	2365.00	433.27	7.03
1	7	25 yr	2775.00	433.79	7.62
1	7	50 yr	3042.00	434.11	7.99
1	7	100 yr	3279.00	434.37	8.29
1	6	2 yr	1351.00	426.04	8.14
1	6	10 yr	2365.00	426.96	9.80
1	6	25 yr	2775.00	427.30	10.33
1	6	50 yr	3042.00	427.50	10.65
1	6	100 yr	3279.00	427.68	10.92
1	5	2 yr	1351.00	422.94	14.60
1	5	10 yr	2365.00	423.34	16.83
1	5	25 yr	2775.00	423.45	17.65

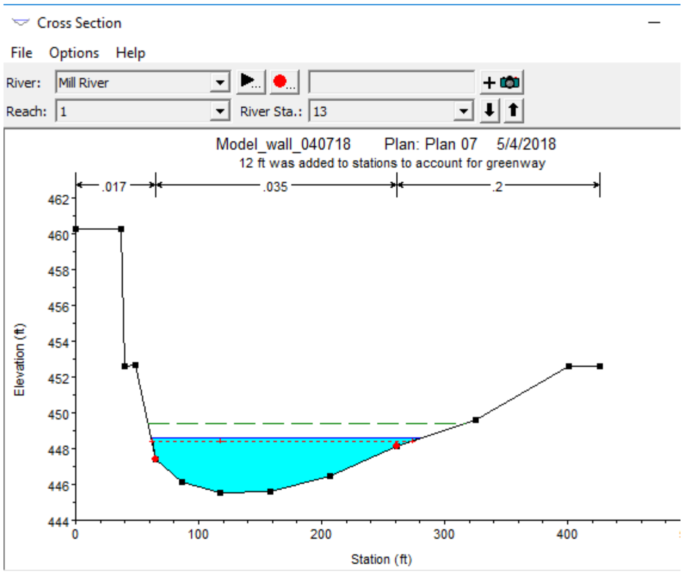
BP-V-02

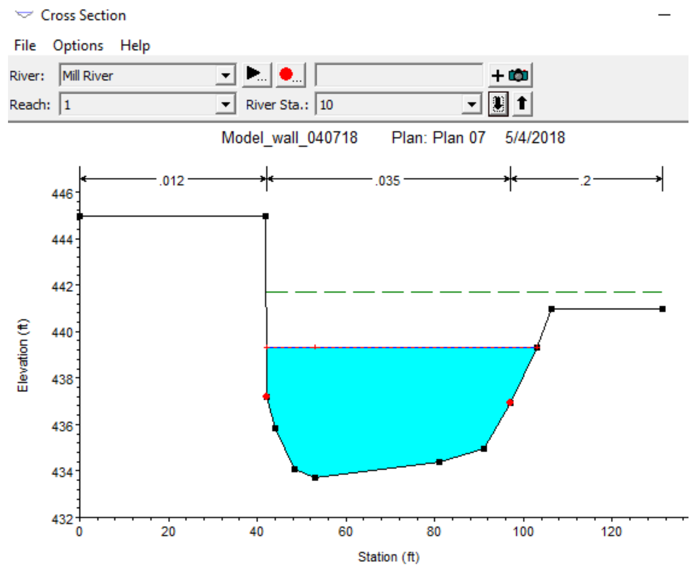
HEC-RAS Plan: Plan 07 River: Mill River Reach: 1 (Continued)

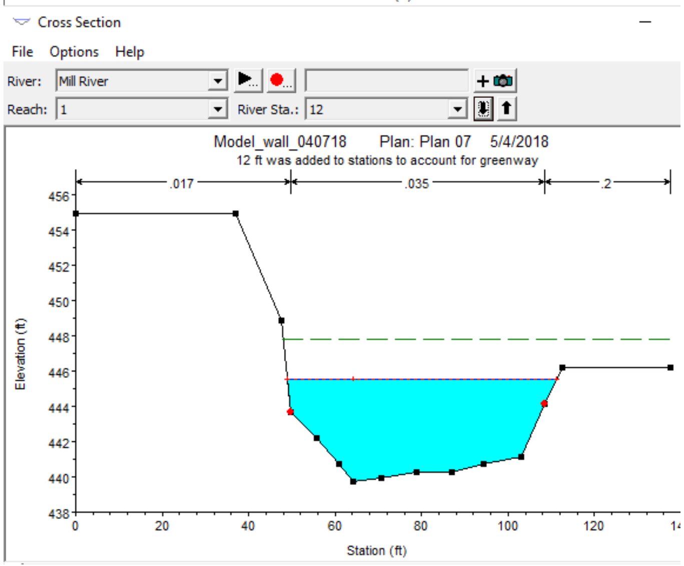
Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl
			(cfs)	(ft)	(ft/s)
1	5	50 yr	3042.00	423.52	18.10
1	5	100 yr	3279.00	423.59	18.49
1	4	2 yr	1351.00	420.89	7.80
1	4	10 yr	2365.00	422.09	9.87
1	4	25 yr	2775.00	422.51	10.56
1	4	50 yr	3042.00	422.78	10.96
1	4	100 yr	3279.00	423.00	11.30
1	3	2 yr	1351.00	419.18	7.93
1	3	10 yr	2365.00	420.51	9.53
1	3	25 yr	2775.00	421.01	9.99
1	3	50 yr	3042.00	421.33	10.24
1	3	100 yr	3279.00	421.62	10.43
1	2	2 yr	1351.00	419.10	7.89
1	2	10 yr	2365.00	420.41	9.67
1	2	25 yr	2775.00	420.91	10.19
1	2	50 yr	3042.00	421.20	10.54
1	2	100 yr	3279.00	421.47	10.81
1	1	2 yr	1351.00	418.42	9.30
1	1	10 yr	2365.00	419.62	11.17
1	1	25 yr	2775.00	420.03	11.82
1	1	50 yr	3042.00	420.31	12.15
1	1	100 yr	3279.00	420.54	12.47
1	0	2 yr	1351.00	416.67	9.74
1	0	10 yr	2365.00	417.64	12.30
1	0	25 yr	2775.00	418.00	13.06
1	0	50 yr	3042.00	418.21	13.56
1	0	100 yr	3279.00	418.41	13.91

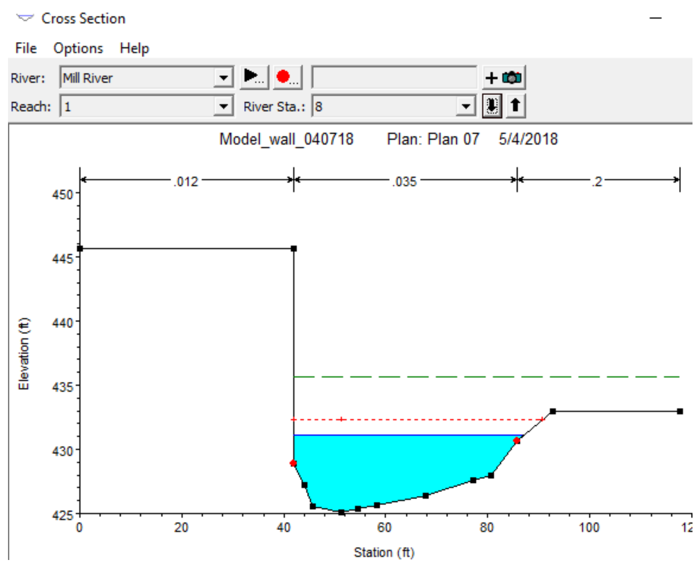
BP-V-03

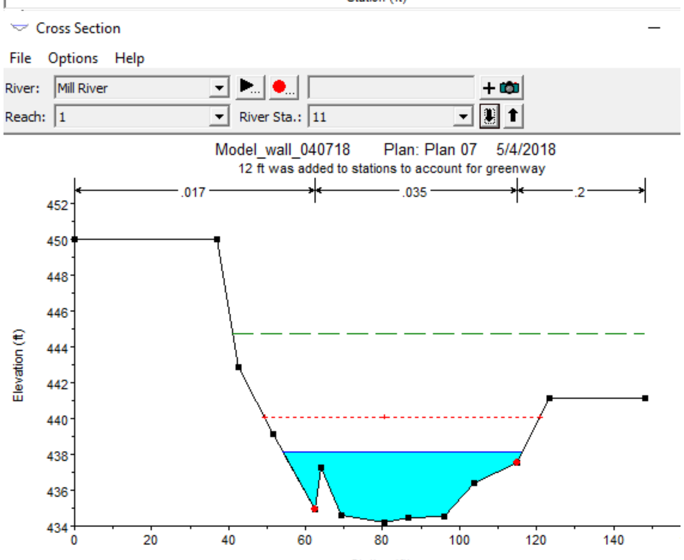
100-Year Flood Bank Protection Design with Dam

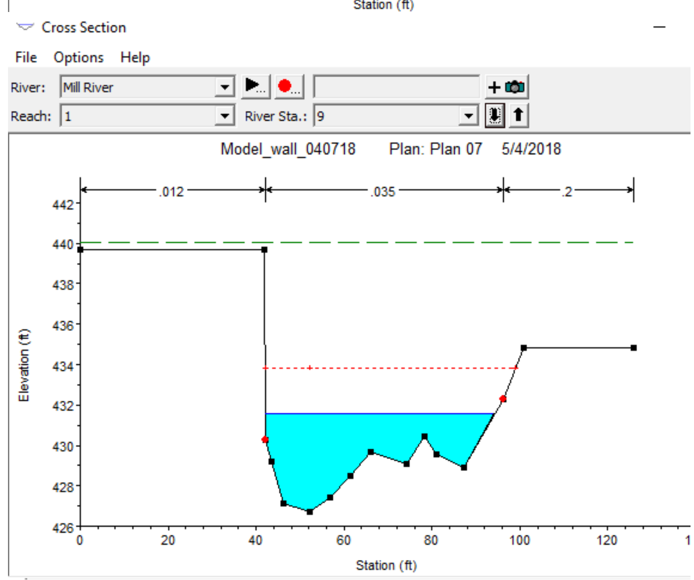




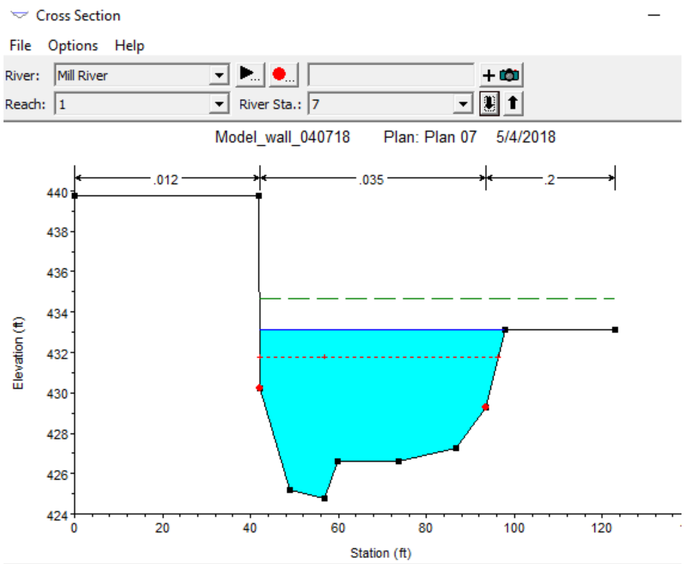


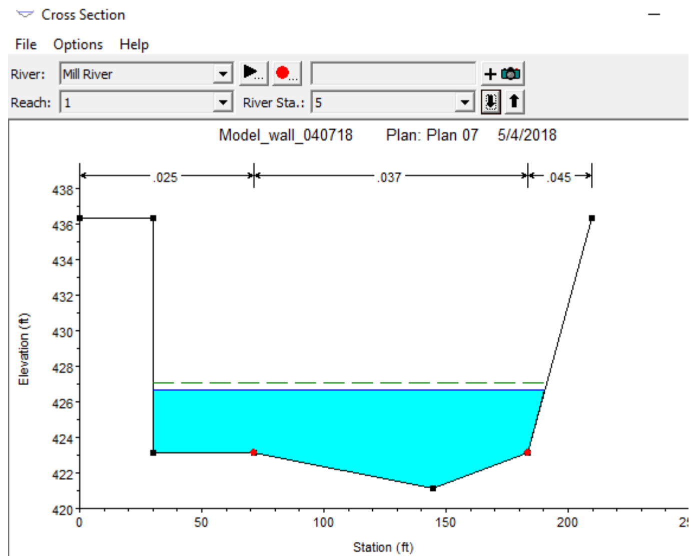


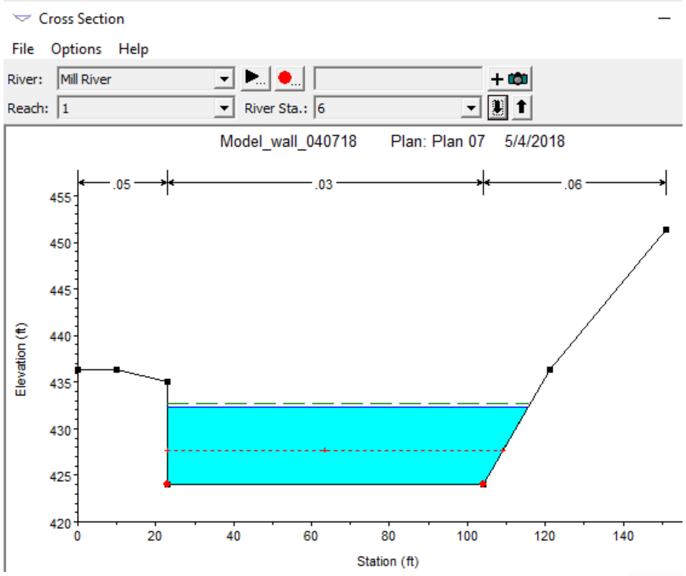


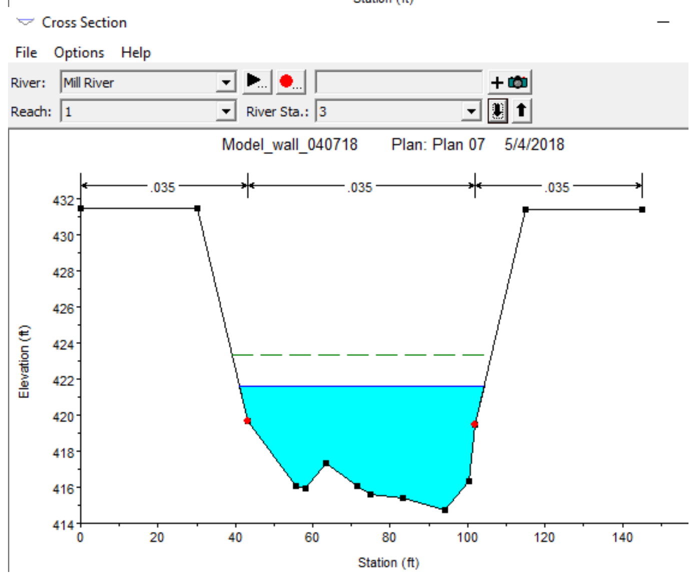


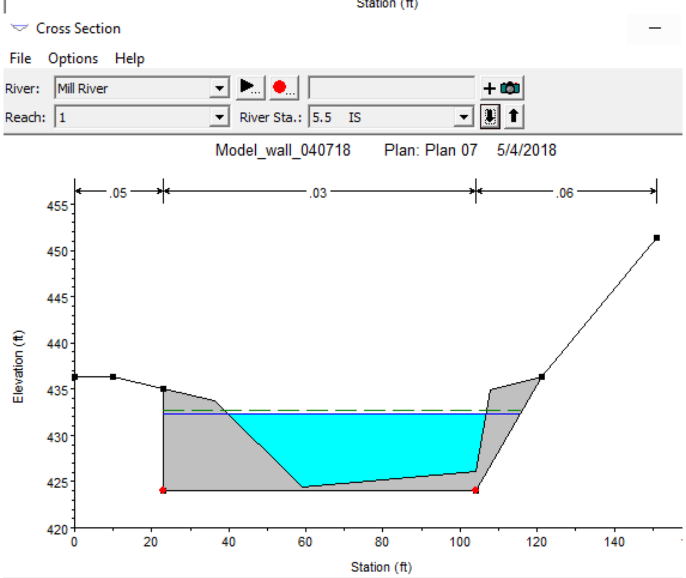
BP-V-03

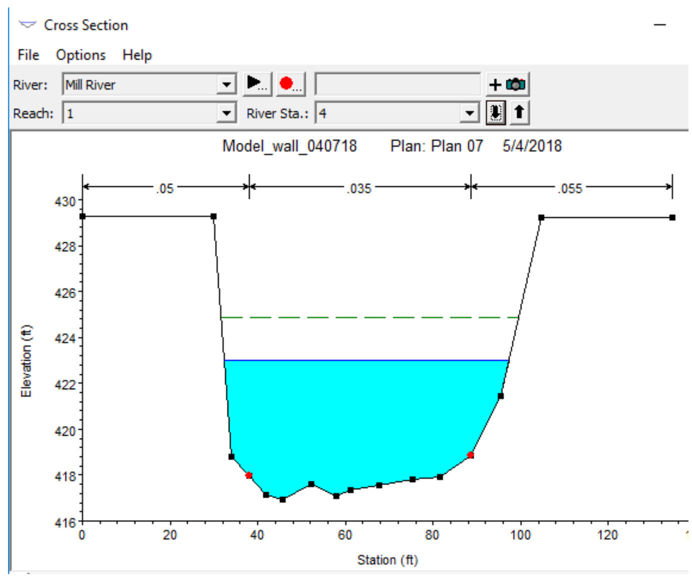

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 7
Model_wall_040718 Plan: Plan 07 5/4/2018
.012
.035
.2
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 5
Model_wall_040718 Plan: Plan 07 5/4/2018
.025
.037
.045
Elevation (ft)
Station (ft)

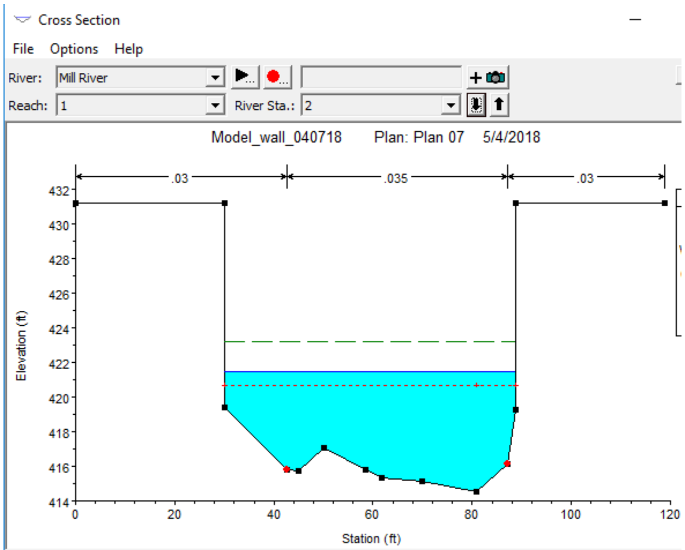

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 6
Model_wall_040718 Plan: Plan 07 5/4/2018
.05
.03
.06
Elevation (ft)
Station (ft)

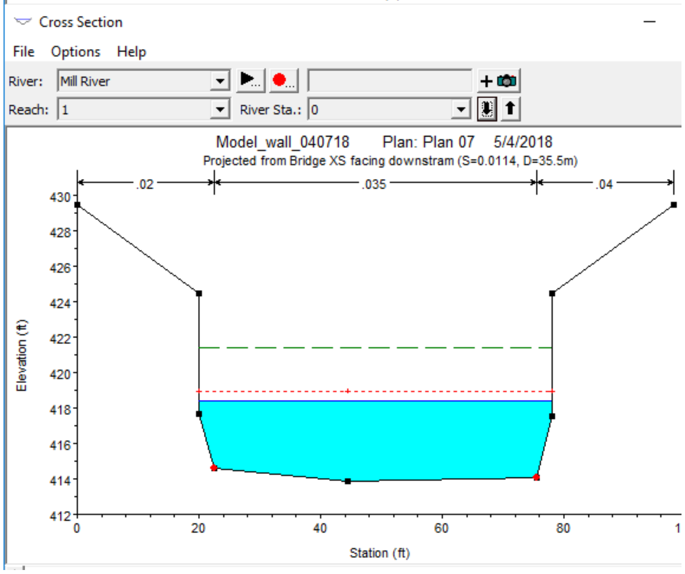

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 3
Model_wall_040718 Plan: Plan 07 5/4/2018
.035
.035
.035
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 5.5 IS
Model_wall_040718 Plan: Plan 07 5/4/2018
.05
.03
.06
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 4
Model_wall_040718 Plan: Plan 07 5/4/2018
.05
.035
.055
Elevation (ft)
Station (ft)

BP-V-03


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 2
Model_wall_040718 Plan: Plan 07 5/4/2018
.03
.035
.03
Elevation (ft)
Station (ft)


Cross Section
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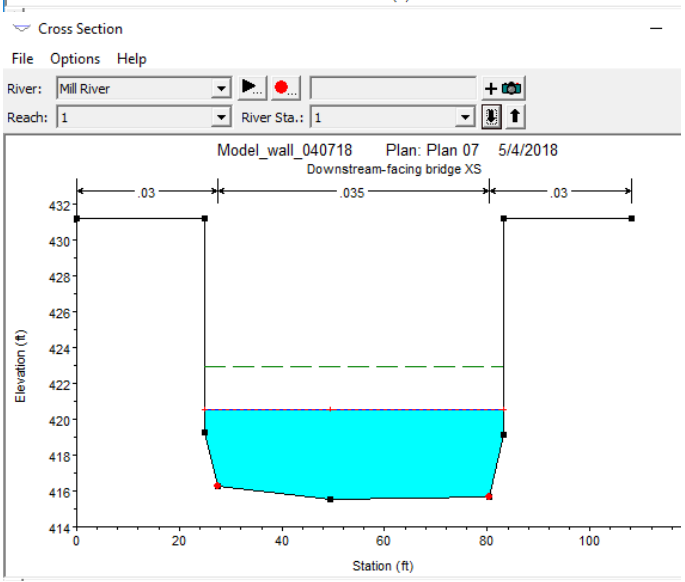
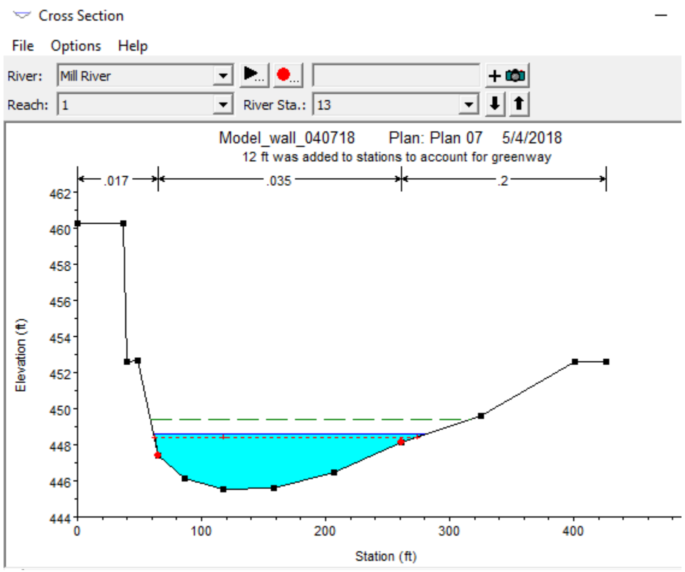
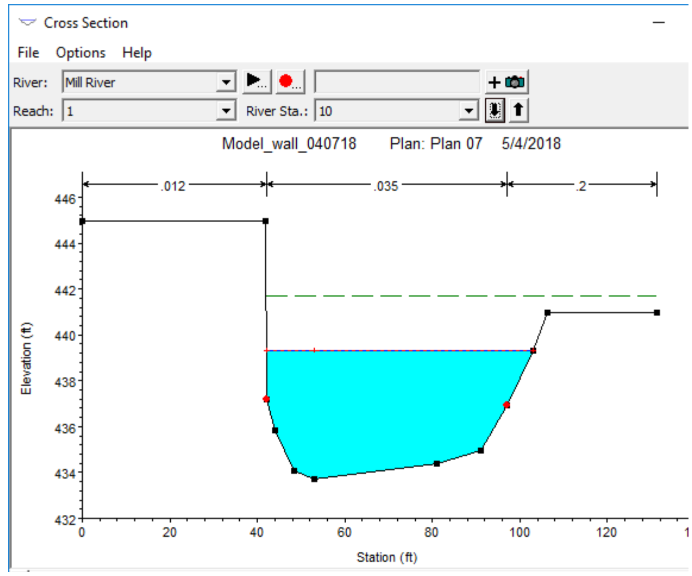
Reach: 1
River Sta.: 0
Model_wall_040718 Plan: Plan 07 5/4/2018
Projected from Bridge XS facing downstram (S=0.0114, D=35.5m)
.02
.035
.04
Elevation (ft)
Station (ft)

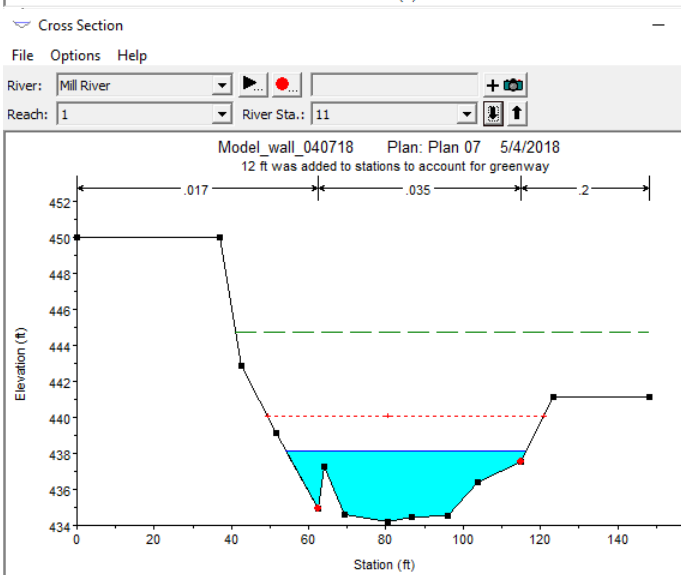

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 1
Model_wall_040718 Plan: Plan 07 5/4/2018
Downstream-facing bridge XS
.03
.035
.03
Elevation (ft)
Station (ft)

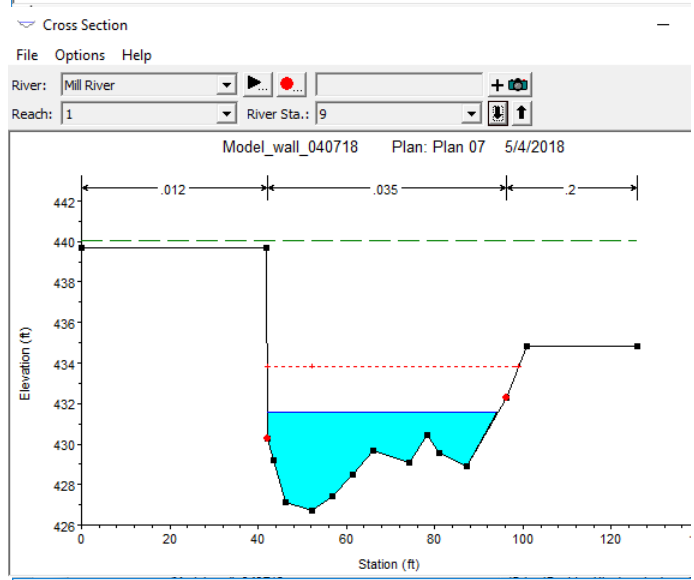
BP-V-03

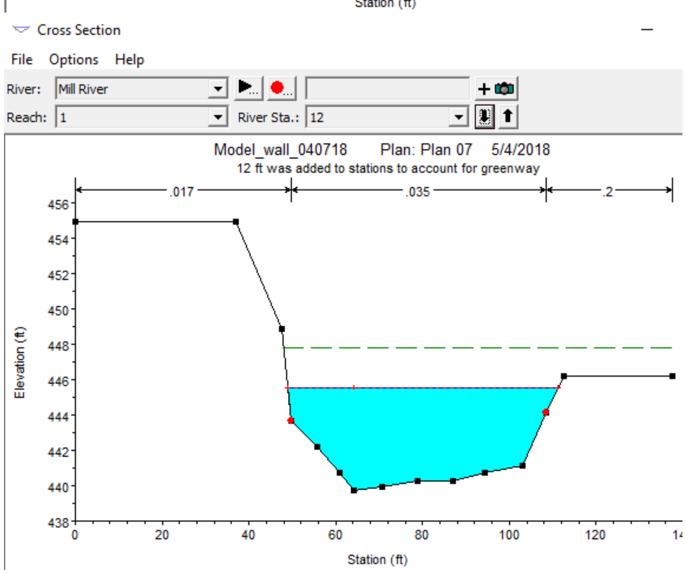
100-Year Flood Bank Protection Design without Dam

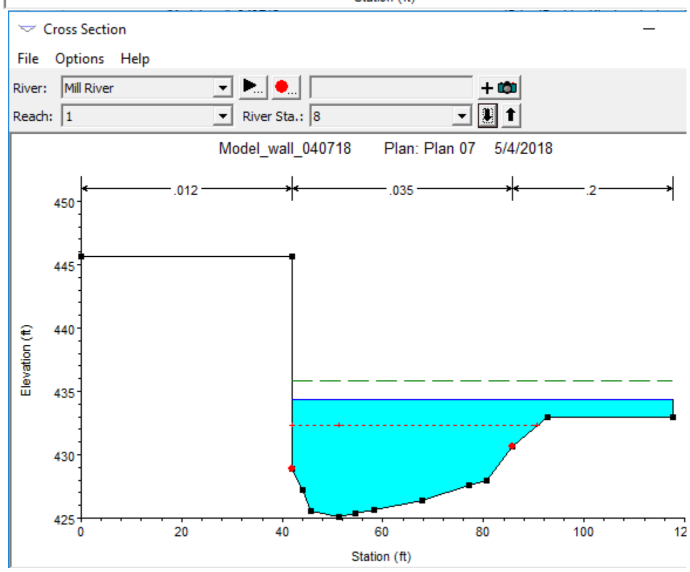




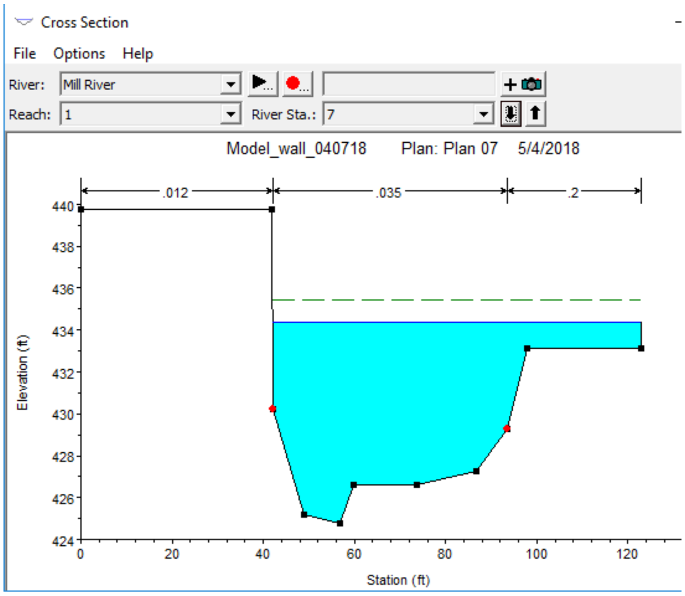


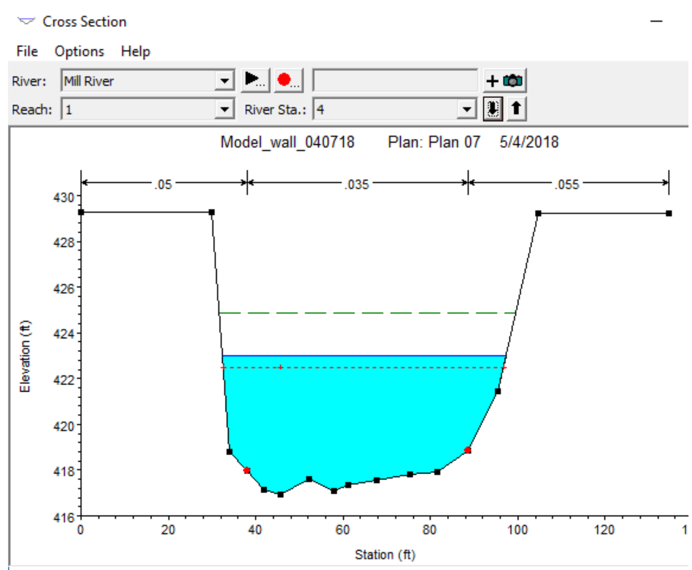


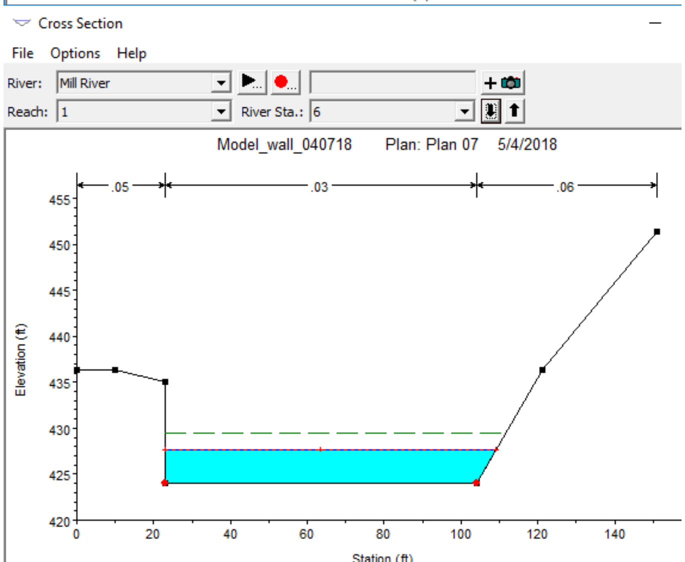


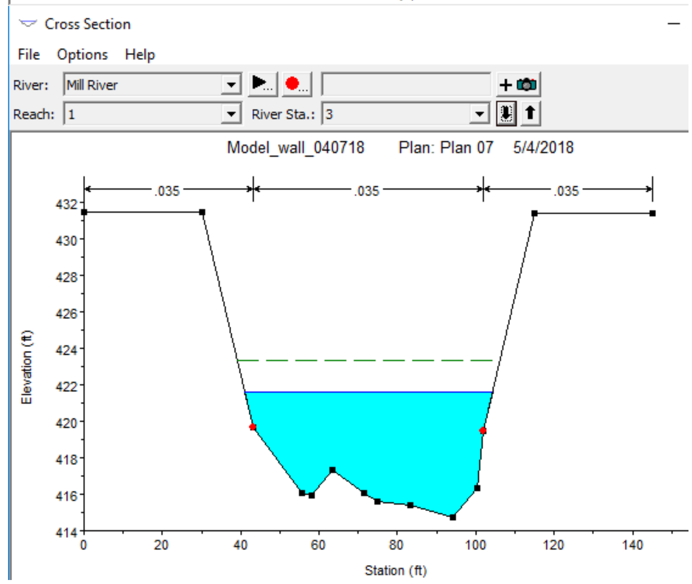


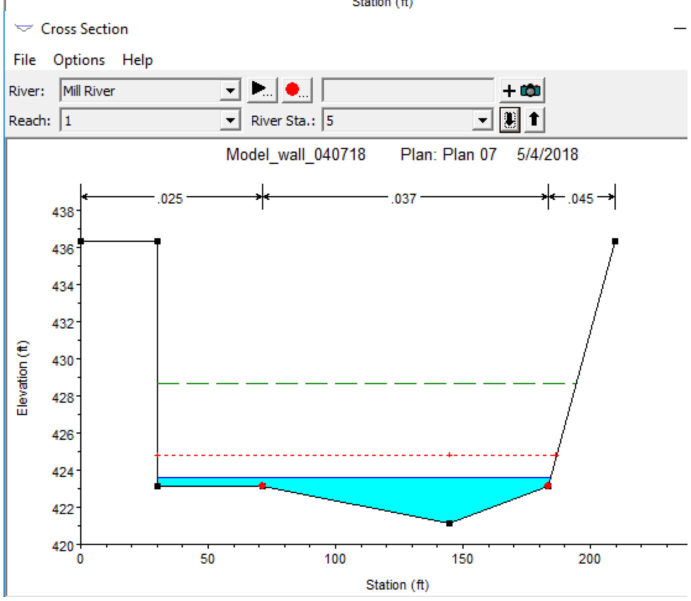
BP-V-03

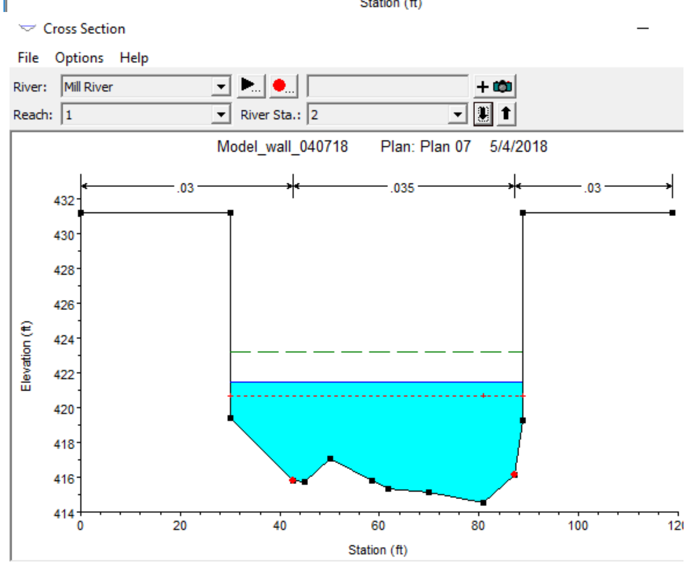

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 7
Model_wall_040718 Plan: Plan 07 5/4/2018
.012
.035
.2
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 4
Model_wall_040718 Plan: Plan 07 5/4/2018
.05
.035
.055
Elevation (ft)
Station (ft)

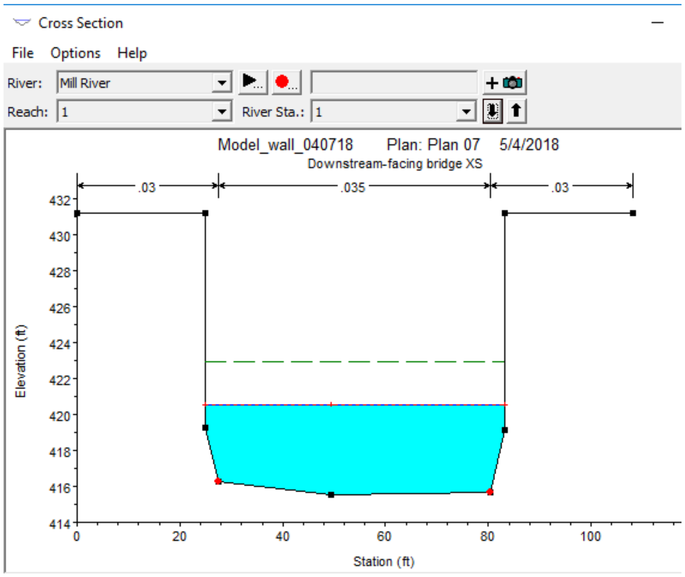

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 6
Model_wall_040718 Plan: Plan 07 5/4/2018
.05
.03
.06
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 3
Model_wall_040718 Plan: Plan 07 5/4/2018
.035
.035
.035
Elevation (ft)
Station (ft)

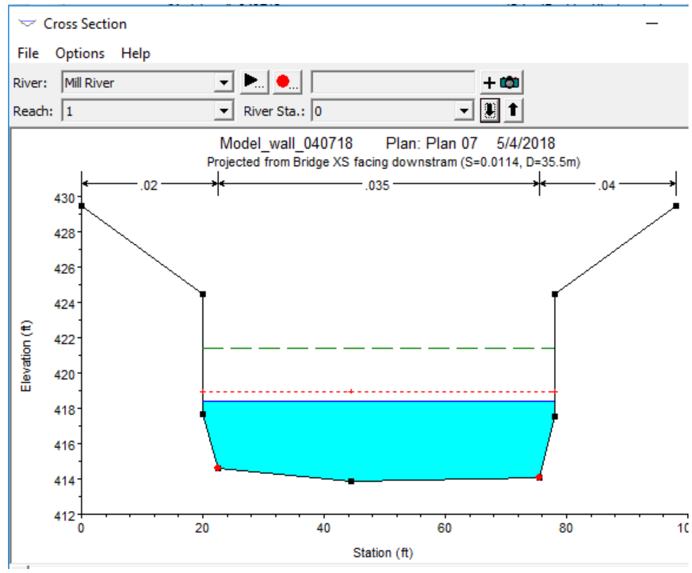

Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 5
Model_wall_040718 Plan: Plan 07 5/4/2018
.025
.037
.045
Elevation (ft)
Station (ft)


Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 2
Model_wall_040718 Plan: Plan 07 5/4/2018
.03
.035
.03
Elevation (ft)
Station (ft)

BP-V-03



Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 1
Model_wall_040718 Plan: Plan 07 5/4/2018
Downstream-facing bridge XS
.03
.035
.03
Elevation (ft)
Station (ft)



Cross Section
File Options Help
River: Mill River
Reach: 1
River Sta.: 0
Model_wall_040718 Plan: Plan 07 5/4/2018
Projected from Bridge XS facing downstram (S=0.0114, D=35.5m)
.02
.035
.04
Elevation (ft)
Station (ft)

BP-V-04 – Figure 15 from Final Report

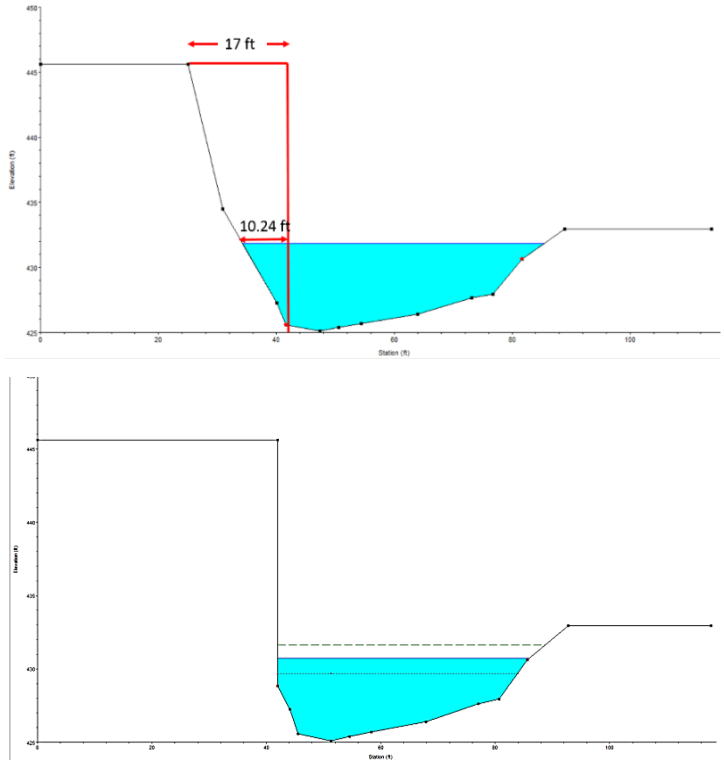


Figure 15. A 17ft Road Extension Intrudes a Total Distance of 10.24ft into the River at XS7 (Top) and the Riverbed is Shifted 10.24 away from Route 9 (Bottom)

Appendix 14: Calibrating Manning's Roughness Coefficient to Account for Bend Head Losses

Following method documented in "Accuracy Of HEC-RAS To Calculate Flow Depths And Total Energy Loss With And Without Bendway Weirs In A Meander Bend (2005)"

The following method was developed by the Engineering Research Center at Colorado State University for the Internal Bureau of Reclamation. It aims at adjusting Manning's Roughness coefficient in HEC-RAS to account for the energy losses in meander bends

Prepared by: Maya Sleiman
For: WMRGC DC Project
Last Updated: 03/27/18

Background

HEC-RAS contains built-in tools that account for two sources of head loss: friction (through Manning's roughness coefficient n), and expansion/contraction (through coefficients of expansion and contraction at each cross-section).
Bends, however, undergo additional head losses due to secondary currents in the flow. With no tools to account for these losses, HEC-RAS underestimates the total head loss in bends.
This method adjusts manning's roughness (n) to account for additional bend-related losses.

Conclusion

Using the method below, it was determined that the 0.035 initial guess for channel roughness was an overestimation at XS11 and XS10 (two of the four bend cross sections), but a good estimation for XS12 and XS9.

It was thus decided that it would be best to perform the model calibration based on the W.S. Level values measured by Brett Towler at different flows.

List of Symbols and Abbreviations

h_f = *head loss due to friction* (ft)

h_{bend} = *head loss due to bend* (ft)

h_T = *total head loss* (ft)

r_c = *radius of curvature* (ft)

S_f = *friction slope* = *slope of the energy grade line* = dH/dL (ft/ft), *where H is total head*

$S_{fManning}$ = *friction slope calculated using one of Manning's equations* (ft/ft)

TW = *Top Width* (ft)

Δx = *downstream reach distance*

Premise of procedure

It was empirically determine that there exists a strong correlation between the ratio h_{BEND}/h_f and a dimensionless parameter π_5 equal to the ratio TW/r_c through the following equation:

$$h_{BEND}/h_f = 4.0e^{(-0.45\pi 5)} \qquad \text{(Eqn. 14-1)}$$

Procedure

1. Use a map to approximate the radius of curvature of the bend r_c.
2. Use HEC-RAS's output table to find TW of each cross section
3. Using the average TW and r_c of the bend, $\pi 5$ is calculated using the following equation:

$$\pi_5 = TW/r_c \qquad \text{(Eqn. 14-2)}$$

4. Using the calculated $\pi 5$ term, the ratio h_f/h_{Bend} is calculated using the following empirically derived relationship:

$$h_{Bend}/h_f = 4.0e^{(-0.45\pi 5)} \qquad \text{(Eqn. 14-3)}$$

5. Using the calculated h_f/h_{Bend} ratio and h_f values output by HEC-RAS, h_{Bend} is calculated using the following equation:

$$h_{Bend} = (h_{Bend}/h_f) * h_f \qquad \text{(Eqn. 14-4)}$$

6. Total head loss is then calculated by definition as follows:

$$h_T = h_{Bend} + h_f \qquad \text{(Eqn. 14-5)}$$

7. The friction slope S_f is calculated by definition as follows:

$$S_{fi} = (h_i - h_{i+1})/\Delta x \qquad \text{(Eqn. 14-6)}$$

8. The friction slope $S_{fManning}$ is calculated using HEC-RAS's manning's roughness as follows:

$$S_{fManning} = (nQ^2/\phi AR^{2/3})^2 \qquad \text{(Eqn. 14-7)}$$

9. Use the Solver Excel Add-in to minimize the difference between S_f and $S_{fManning}$ by changing n.

II. Manning's Calibration for our Model

1. A snapshot from Google Maps of the Bend was imported into AutoCAD (Fig.14-1a) and a circle was approximately fitted to the bend curve. The center of the circle was located. The real distance between the center of the circle to the edge was found to be 380ft using the measure tool in Google Maps. (Fig. 14-1ba)

a

b

Figure 14-1. (a, above) is a screenshot from AutoCAD showing a circle fitted to the bend curve. Google Maps measuring tool was used to measure the distance from the located center to the curve edge (b, below).

2. The Top Width of the each bend cross section was imported from HEC-RAS Output Table

3. The above TW values were averaged out in Excel, and used with r_c to calculate $\pi 5$.

4. The friction loss h_f is imported from HEC-RAS (left), and the ratio h_{BEND}/h_f was calculated using $\pi 5$.

5. The ratio h_{BEND}/h_f is calculated using $\pi 5$, and h_{BEND} is calculated using the ratio.

6. Total loss h_t is calculated by summing the columns h_{Bend} and h_f.

7. The downstream reach length is imported from HEC-RAS and used to calculate the friction slope.

8. Flow (Q), Flow area (A), Hydraulic Radius (R), and HEC-RAS's Manning's roughness coefficient are used to calculate $S_{fManning's}$.

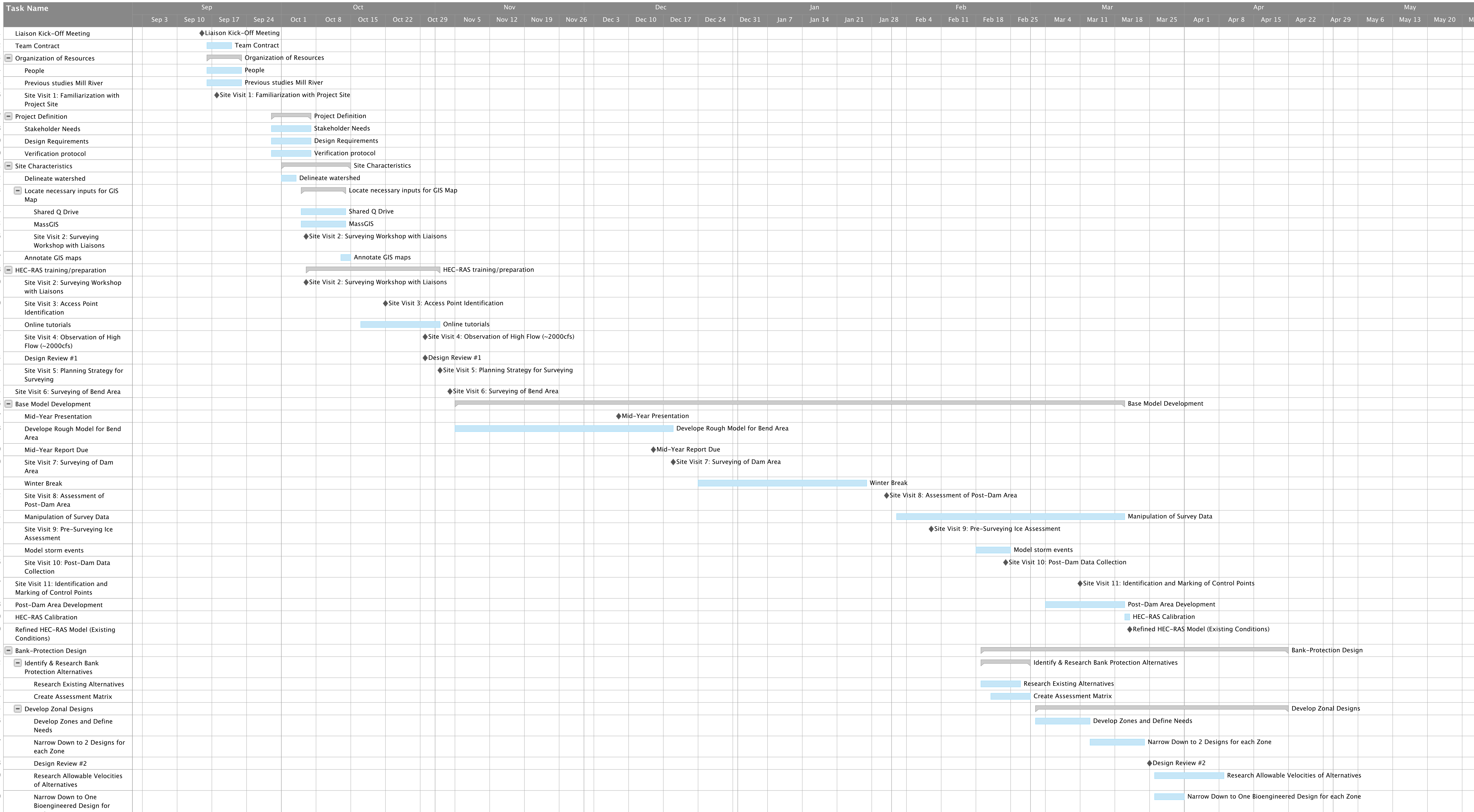
9. Excel's Solver Add-in was used to minimize the square difference between S_f and $S_{fManning}$ for each of the cross sections by adjusting n.

Appendix 15: Gantt Chart

This Gantt Chart represents the timeline of our project.

MRGC Gantt Chart

smartsheet



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	Task Name
51	Size Optimal Bioengineered Design for Each Zone
52	Eliminate designs using HEC-RAS velocities
53	Finalized Recommendation for Each Zone
54	Design Review #3
55	Model Development with Bank-Protection
56	Integrate Wall into Model + Channel Adjustment
57	Refined HEC-RAS Model (adjusted channel with wall)
58	Class Deliverables
59	Write Proposal
60	Project Proposal Due
61	Proposal Presentation
62	Design Review #1
63	Mid-Year Presentation
64	Mid-Year Report Due
65	Design Review #2
66	Final Poster
67	Design Review #3
68	Final Presentation
69	NCEES Due
70	Final Report for Grading
71	Final Report for Archiving