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Beaver Creek restorative design using engineering in nature

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Beaver Creek restorative design using engineering in nature

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by Lindsay May Levatino

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Accepted by the faculty of the Engineering Department, James Madison University, in partial fulfillment of the requirements for the Honors College.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, in the 2020 Engineering xChange booklet on 4/27/2020.

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Abstract

Stream restoration work can be instrumental for the wellbeing of an ecosystem. Located in the Shenandoah Valley in Virginia is Beaver Creek, a well-known spot for fly-fishing due to its pristine water conditions and open surroundings. In order to maintain these conditions, a 100-foot stretch of Beaver Creek needed to be restored to prevent further erosion, stabilize the banks, and enhance the natural habitats. The project involved excavating a sediment island, filling in an eroded bank, building a cross vane, and adding stakes. Local stakeholders came together to complete this project contributing their expertise, equipment, and time. The construction was successfully completed in April 2020 and this site will continue to be monitored until around 2023. The work done at Beaver Creek looks natural and the stream is responding wonderfully to the changes.

Keywords: *Restoration, stream, channel, design, natural, engineering*

Introduction

Beaver Creek is a spring creek that runs through Rockingham County and is known as a popular fly-fishing location due to its pristine conditions. The spring-fed water flows at a consistent rate and maintains cool temperatures year-around suitable for trout ("Beaver Creek," n.d.). It is covered by large amounts of trees and other shrubbery providing shaded, cool areas for trout to hide and thrive in. The water is healthy and clean, leaving both Brook and Rainbow Trout with a comfortable home for feeding and reproduction.

The creek and its surroundings, however, need to be protected in order to contribute a healthy supply of water to the Chesapeake Bay. The landowners along Beaver Creek are taking great strides to preserve parts of the river that are vulnerable to or are already facing destruction and erosion. Erosion is a process in which geological structures are gradually being destroyed and worn away by a force over time. One major problem with erosion in rivers is that it leads to nutrient loading downstream, also known as eutrophication. Eutrophication is the process of excessive amounts of nutrients, especially phosphorus and nitrogen entering the water stream ("What is nutrient loading?" 2017). These nutrients can come from the weathering of soil and rocks around the watershed. This can be very harmful to the ecosystem, because it causes a spike in algae growth. Algae starts to cover the surface of the water, blocking the sunlight from getting through, and causing plant decay. Decaying plants and even algae consume a lot of dissolved oxygen, leaving an insufficient amount for the fish and other wildlife ("What is nutrient loading?" 2017).

There have been significant restorative and preventative efforts successfully implemented along this stream, however there is still more to be done. This project focuses on a 100-foot stretch of Beaver Creek, as shown in Figure 1 below.

Figure 1. 100-foot stretch of Beaver Creek
Photo by Brian Koerner, Engineering Solutions, PLC.

During high water events, especially following storms, the stream's energy dissipates substantially into this bank, threatening the fencing and taking land from the farmers, which is shown in Figure 2 below. This bank was used as a footpath for people to walk downstream, especially fishermen, which is now nearly impossible. The eroded land is falling into the river along with sediments that are harmful in large amounts, eventually making their way to the Chesapeake Bay and contributing to negative phenomena such as algae blooms. The goal of this project is to redesign this stretch of the creek using engineering techniques that mimic nature and help the ecosystem and surrounding area.

Figure 2. Walking path and fence adjacent to Beaver Creek where the bank has eroded
Photo by Dr. Bradley Striebig, James Madison University

This thesis will capture the process taken to restore this stream. It will describe the steps in a natural stream design process, lay out surveying procedures, and document the planning, construction, and results of the project. This report can be used as a reference point for future work on Beaver Creek, other parts of the watershed, or similar bodies of water. This report also includes a literature review to provide background on the topic of natural stream design and describe basic features and phenomena that make up a natural stream.

Plan of Work

To redesign this reach of Beaver Creek, a natural channel design approach was used, specifically the Geomorphic Rosgen method. The Rosgen design process uses "a combination of analog, empirical, and analytical methods" ("Rosgen Geomorphic Channel Design," 2007). It accounts for the variability of a creek using observational techniques rather than theoretical. It was applied to Beaver Creek's three-stage channel type meaning the flood-prone area, bankfull, and the low flow inner berm were all carefully analyzed when creating a new design. The ten phases of the Natural Channel Design that follow were used in this project ("Natural Channel Design," 2011):

Phase I. Define Restoration Objectives

Phase II. Develop Local & Regional Relations

Phase III. Conduct Watershed, River & Biological Assessments

Phase IV. Consider Passive Recommendations for Restoration

Phase V. Develop Conceptual Design Plan

Phase VI. Develop & Evaluate the Preliminary Natural Channel Design

Phase VII. Design Stabilization & Enhancement Structures

Phase VIII. Finalize Natural Channel Design

Phase IX. Implement Natural Channel Design

Phase X. Conduct Monitoring & Maintenance

Watersheds are constantly changing in water levels and contents, so streams will naturally adjust their shape and size, often leading to other problems and the need for more restorative efforts. This design process covers the necessary steps that needed to be taken for this project to be successful. The schedule of project milestones can be found in Table 1 below.

Table 1. Schedule of Project Milestones

Activity/Task	**Start Date**	**End Date**
Pre-project monitoring	04/2019	09/2019
Gather preliminary data, survey land	11/2019	02/2020
Design and plan for streambank stabilization	02/2020	03/2020
Acquire state and federal permits (USACE, VMRC, DEQ)	03/2020	03/2020
Bank restoration and Instream construction	03/2020	04/2020
Riparian planting	04/2020	05/2020
Evaluation	05/2020	05/2020
Monitoring and maintenance	05/2020	Ongoing

Literature Review

Natural stream and channel design have become an increasingly important process to prevent a stream from or recover from erosion and damage. The techniques used to restructure or stabilize the stream bed and banks are now designed to mimic nature as effectively as possible. A lot has been learned over the last few decades from trial and error, resulting in many changes and advancements being made to stream and channel design. The following pieces of literature explore ways to best practice river restoration and give insight through experience.

One of the biggest mistakes that can be made in stream restoration is fixing the obvious problems without considering the effects it can have upstream or downstream. The United States Department of Agriculture developed an engineering handbook for stream restoration design. One chapter focuses on establishing goals and objectives for the project. Historically, this proves to be a crucial step in the design process, because a large source of project failures is due to the lack of clear goals and future planning.

The Department of Agriculture states that objectives should be “specific, realistic, achievable, and measurable.” Boundaries and constraints should be established to determine whether the objectives meet those four standards. Designs must also protect existing infrastructure and refrain from causing harm to other areas while attempting to fix the focus area. The restoration projects should not increase flood profiles, and they should maintain water quality, protect riparian infrastructure, and have a low risk of failure (“Stream Restoration Design,” 2008). A compromise often has to be made between objectives and constraints. Simultaneously, the interests of stakeholders should be taken into account. These can help guide and narrow the scope of the project if refined properly. Once objectives are established, necessary data is collected, and correct methodology is identified, the designs to consider should become clear.

The Colorado Emergency Watershed Protection (EWP) Program published a paper discussing the restoration approaches used in recent projects. A main point of focus for the projects is to make the rivers more resilient in the event of major flooding. In order to do so, the program explores different approaches such as benches and bars, boulders, adjusting channel position, grade control structures, ripples, and riparian vegetation ("River Restoration Designs," 2013).

Dissipating a stream flow's energy is a significant part of restoration projects. Strategies such as building benches and bars are used to reduce and redistribute the channel's energy. These can also form naturally if a stream is unstable. In the case of low-flow conditions, it can be used to increase the depth by decreasing the width of the channel. Since benches are flat areas around the stream, this approach also makes space for planting, increases floodplain capacity, and allows the water to spread out. Point bars can form around a natural bend due to a buildup of sediment. These can be welcomed formations as they help to dissipate flow energy, as well. Sometimes, however, they are a sign of an instability in the stream if they were created naturally. It shows that sediment aggradation either due to an imbalance and could possibly be causing erosion in a nearby area. Stream flow could be too intense upstream and is plucking sediments from the streambed and carrying them to the bar. Aggradation in a stream is the process of sediment accumulating in an area (Fairbridge R.W., 1968).

Boulders are a generally simple way to reduce stream flow speeds and create habitats for organisms, because they are typically readily available materials and can be placed and positioned wherever necessary. This is one way to reposition the channel to stabilize it during transient phases where the stream is in the midst of changing locations along the floodplain. To control the elevation of a river, however, grade control structures can be used. This can help maintain the connectivity of floodplains and reduce the chance of erosion. Examples of these structures are “j-hook vanes” and “cross vanes” which help slow the river flow by changing the water elevation. They can also create pools immediately following the structure for wildlife to reside in. Another way to create small pools is to incorporate ripples using boulders, cobbles, and/or gravel. This also oxygenates the water, making it a better environment for wildlife (“River Restoration Designs,” 2013).

Finally, the EWP Program discusses the importance of riparian vegetation within and surrounding the river. While the vegetation can stabilize the structure and prevent erosion, it also enhances habitat diversity, filters pollutants, provides shade, and much more (“River Restoration Designs,” 2013). A table summarizing restoration techniques and their functionalities can be found in Appendix B. These techniques mostly use material that can be found naturally and methods that integrate into the environment without causing any destruction or damage.

The Ausable River Association wrote a piece of literature describing the different features of a stream such as a riffle, glide, run, pool, and more (“Stream Features,” 2012). Each feature is extremely important and depends on one another. Changing on feature will likely adjust one or more of the others. Natural streams have a repeating sequence of riffles, runs, pools, and glides in that order, as seen in Figure 3.

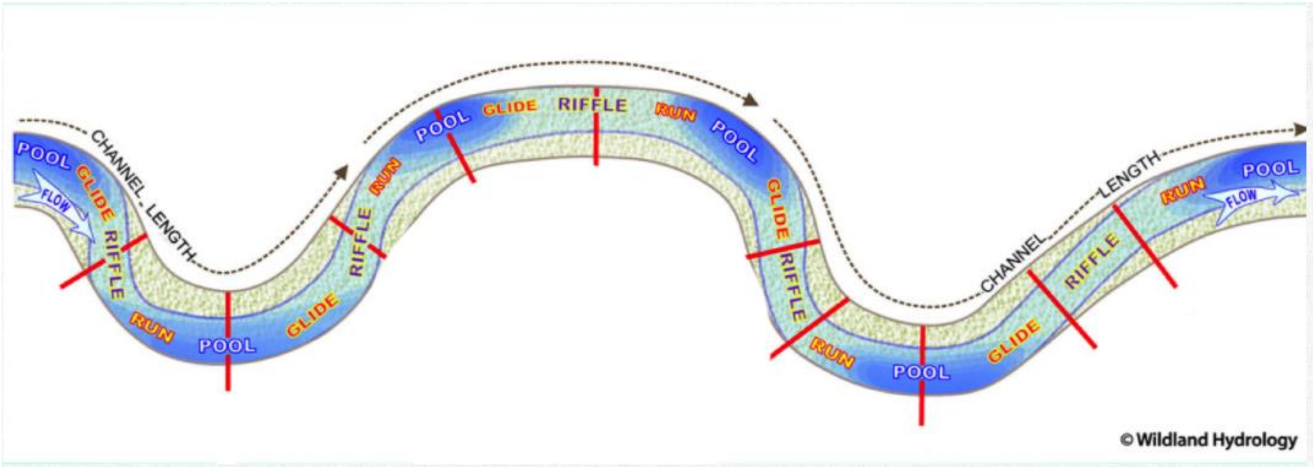

Figure 3. Stream feature sequence
Photo by Wildland Hydrology, ("Stream Features," 2012)

A riffle is a bed feature that is relatively shallow with a water surface slope steeper than the channel's average. It is usually a break in the water surface made of larger rocks forming rib-like structures between banks (Williams, 2010). Water moves faster through riffles, picking up small sediments and increasing oxidation. Following riffles are deeper and smoother areas called runs that generally flow rapidly. Pools, however, are slow and deep that form when water pours over boulders or logs into a flat surface ("Stream Features," 2012). Sediment is usually deposited into the pools at low flows and deposited into riffles during high flows. Finally, a glide follows a pool the streambed transitions from deep to shallow as the next riffle comes up.

Penn State University published a helpful document describing another important feature of a stream, which is the bankfull feature. Bankfull is the stage in the bank elevation where the water would spill over into the floodplain ("Guidance in Determining Bankfull"). The bankfull width is also an important measure, which is the width of the stream at the bankfull elevation, as seen in Figure 4 below. When locating the bankfull elevation, it can be helpful to identify changes in the bank slopes such as benches, the top of features such as point bars, or changes in vegetation and particle size. It is important to avoid any logjams, man-made impacts, bedrock outcroppings, braided channels, or hard meander bends (“Guidance in Determining Bankfull,” n.d.).

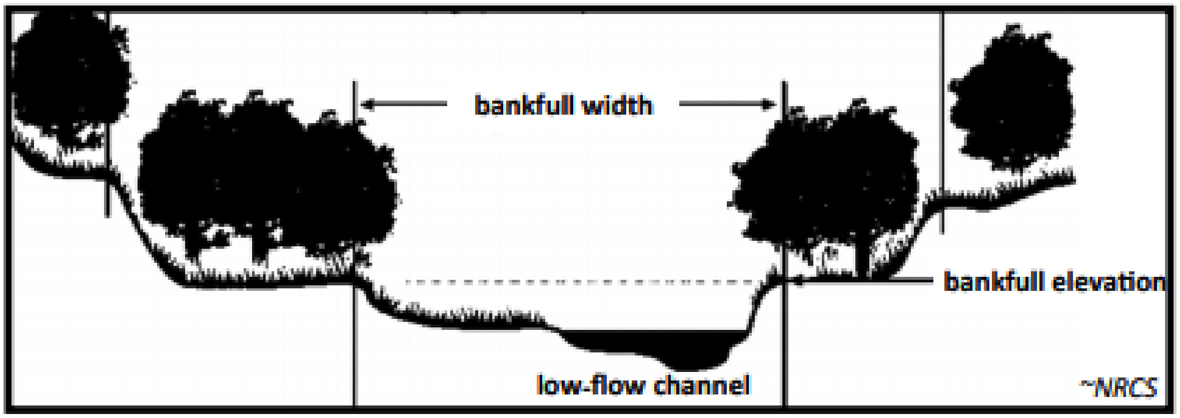

Figure 4. Bankfull measurements
Diagram by NRCS, (“Guidance in Determining Bankfull,” n.d.)

Some things to note about the bankfull features are that they are level across the channel and vegetation including trees can still exist below bankfull elevation. It is best to take five bankfull measurements and average them out. Always start to measure above the point where bankfull is believed to be and then look for indicators to get as close to the true bankfull elevation as possible (“Guidance in Determining Bankfull,” n.d.).

One of the first stages of stream restoration projects is to survey the land. An important piece to this process is capturing the elevation of the top and bottom of banks, the thalweg which is the deepest point of the streambed, and other surrounding features that will contribute to building a profile and topographic drawing. Finding the backsight and foresight measurements are based on whether the ground level is higher or lower than the instrument you are measuring from. Diagrams exemplifying these processes can be found in Figure 5 and Figure 6 (“Equipment Operator Basics,” n.d.).

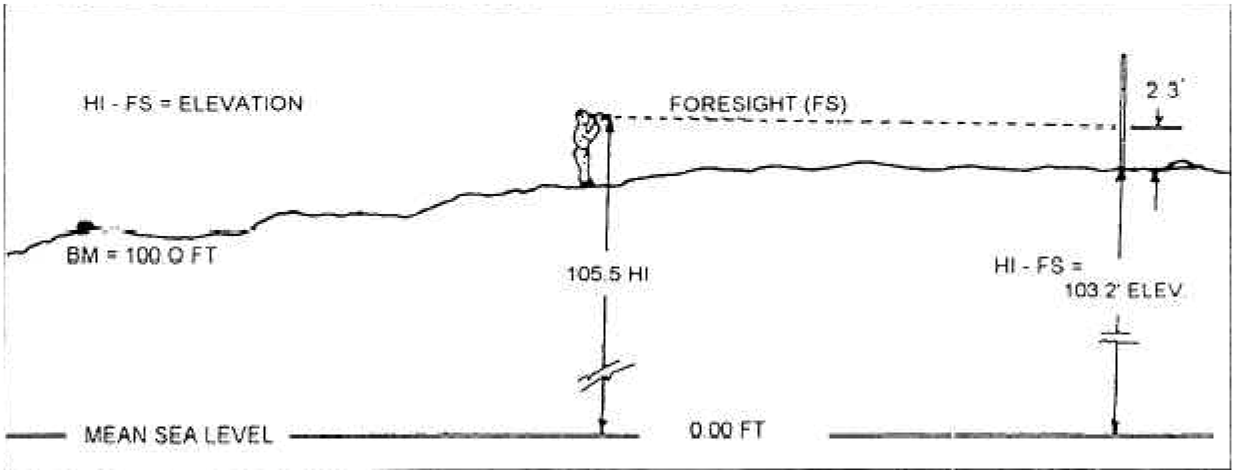

Figure 5. Foresight elevation measurement process
Diagram by Integrated Publishing Inc., ("Equipment Operator Basics," n.d.)

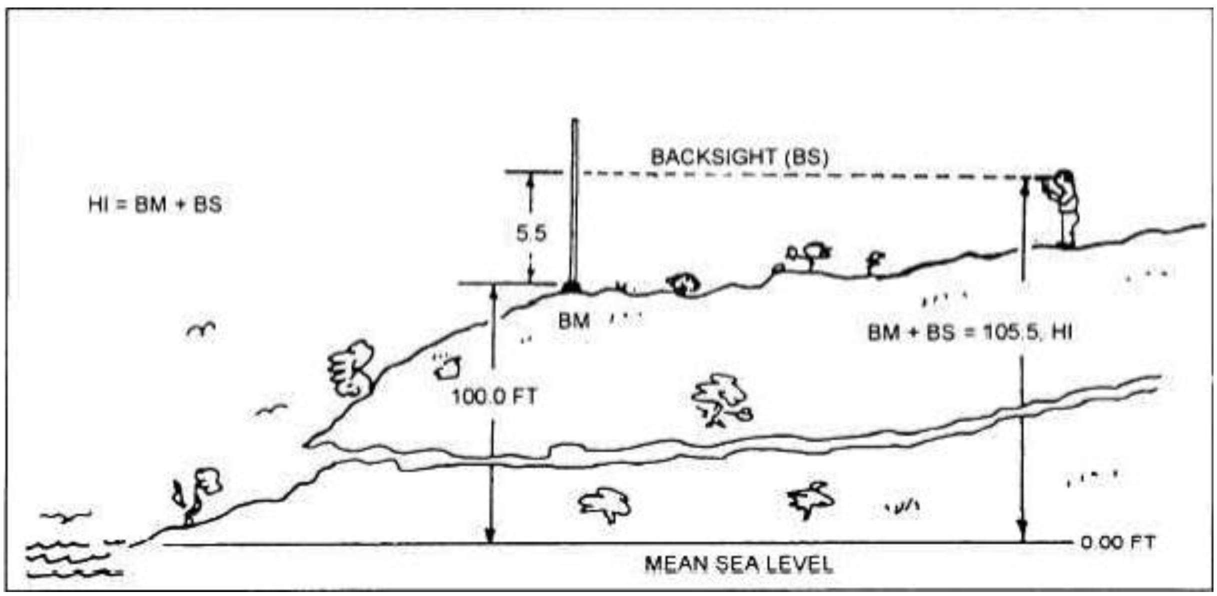

Figure 6. Backsight elevation measurement process
Diagram by Integrated Publishing Inc., ("Equipment Operator Basics," n.d.)

An effective starting point when calculating elevations would be to determine the height above sea level the site is. This can be done using a GPS or Google Earth, depending on how accurate the results need to be. The height above sea level will be the benchmark elevation. Table 2 below describes each term involved in elevation measurements.

Table 2. Surveying Abbreviations and Descriptions

HI	Height of instrument
BS	Backsight, the measurement on the leveling rod taken when the instrument is positioned from higher ground
FS	Foresight, the measurement on the leveling rod taken when the instrument is positioned from lower ground
BM	Benchmark, the elevation of the ground above sea level from where the instrument sits

When surveying is completed, engineers will enter the data into civil engineering software such as RIVERmorph and AutoCAD Civil. The software will typically perform the elevation calculations if given the right information. RIVERmorph is a stream restoration database and software that can assist in designing and assessing streams ("RIVERmorph," 2020). AutoCAD Civil is a computer-aided design software used for analysis and problem-solving ("Autodesk AutoCAD," 2013). AutoCAD works with Bing Maps so virtual design can be done directly at a known location on aerial imagery. It is known for the ease of creating cross sections and applying the 2D design to a 3D model ("Autodesk AutoCAD," 2013).

Natural Channel Design Process

Phase I. Define Restoration Objectives

The main objective of this project is to stabilize and restore a 100-foot stretch of Beaver Creek by implementing instream habitat structures and reinforcing the riparian zone to a condition that is healthy for brook trout to thrive in. The secondary objective of the project is to provide a framework for restoration projects to be done in the future on other parts of Beaver Creek or surrounding streams.

Phase II. Develop Local & Regional Relations

The restoration of Beaver Creek project involves a multitude of people from the local area. The landowner, Jerry Black and members of the Massanutten Chapter of Trout Unlimited are primary stakeholders. Dylan Cooper from Trout Unlimited is the lead engineer on this project under Seth Coffman, Shenandoah Headwaters Manager of Trout Unlimited. The civil engineering firm, Balzer and Associates, Inc. assisted by giving a tutorial on how to perform certain surveying techniques on the land in order to gather elevation data. Brian Koerner from Engineering Solutions and Construction Management, PLC consulted on the project and gathered drone photos for overhead views of the landscape. There was also existing watershed data from the engineering students at James Madison University retrieved during the summer of 2019. The funding for this project was provided by the Massanutten Chapter of Trout Unlimited along with a generous donation from the Virginia Eagle Distributing Company, LLC. Members from the Massanutten Chapter of Trout Unlimited and their family members volunteered to do the construction on the site. The TU members also obtained the necessary permits in order for the work to be done on this project. A detailed list of the stakeholders can be found in Appendix B.

Phase III. Conduct Watershed, River & Biological Assessments

Dylan Cooper from Trout Unlimited provided his engineering expertise and equipment to survey this reach of Beaver Creek. Most surveying practices are easiest and quickest when done with two or more people. A total station was used to shoot and save the coordinates of important points relative to a reference point. If enough points are taken along and around the stream, a profile can be built, and the site can be laid out in a software. The profile of a stream includes the origin, the end, and the decreasing gradient of the stream ("Streams," n.d.). The profile built from the surveying data done by Dylan Cooper and Lindsay Levatino can be found below in Figure 7. This graph displays each facet of the stream including where each pool, glide, riffle, and run are located. This helps pinpoint where problems may be occurring, such as a riffle that is much longer than the rest. Pictures taken during the surveying process can be found in Figures 8 and 9 below. See Appendix C for additional photos and the specific equipment used.

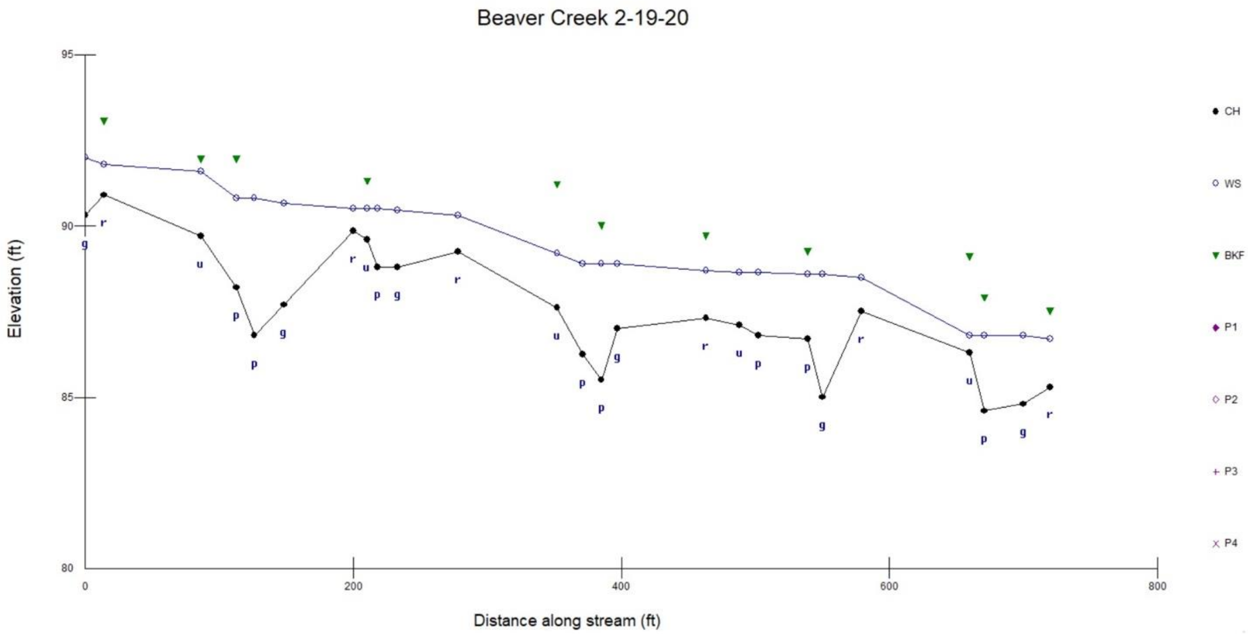

Figure 7. Graph generated by RIVERmorph showing the profile of Beaver Creek
Graph by Dylan Cooper, Trout Unlimited

Figure 8. Lindsay Levatino and Dylan Cooper using a total station at Beaver Creek
Photo by Dr. Bradley Striebig, James Madison University

Figure 9. Lindsay Levatino and Dylan Cooper using a digital laser level at Beaver Creek
Photo by Dr. Bradley Striebig, James Madison University

A digital laser level was used to capture elevations. If elevations are captured every few feet across a stream, a cross section can be built, similar to Figure 10 below. A cross section can explain a lot about a stream and give insight into where problems may be originating from. It can also be used to calculate characteristics such as streamflow and discharge.

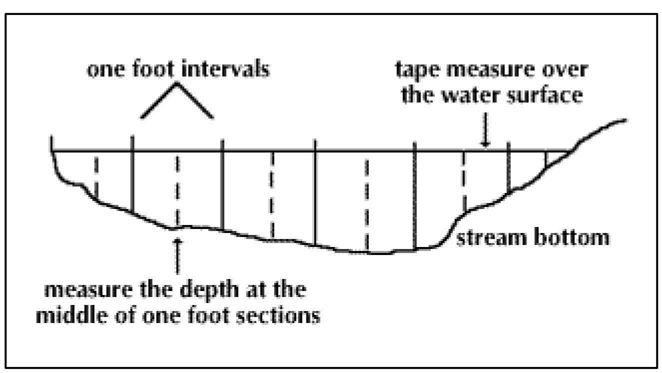

Figure 10. Diagram of a stream's cross section
Photo by Washington NatureMapping Program ("Data Collection Methods," 2008)

There are many different methods and equipment for surveying land, some of which can still be used in the same way as the equipment used in this project. The following general procedures were followed to survey the stretch of Beaver Creek and the surrounding landscape.

Profiling Procedure with Total Station

1. Gather total station equipment.
2. Establish a benchmark.
3. Set up a tripod directly over the benchmark.
    a. Adjust the tribrach and tripod legs so the bubble is directly over benchmark.
4. Secure total station on top of the tribrach.
5. Connect controller and power on.
6. Fine level the instrument with the controller.
7. Capture reference points with known coordinates (i.e. from Google Earth).
8. Begin capturing points along the stream.
    a. Have one person holding the reflector rod very still at the desired point, making sure the rod is facing the total station.
    b. Have another person at the total station looking out at the point and lining up the middle of the prism in the eyepiece to the circle on the reflector rod, use the dials on the front and side of the total station to zoom in and out and focus the lens, tighten the dials to hold the total station’s position and capture the point on the controller.

9. Capture major points along the stream including any significant trees/stumps/boulders, the top of bank points, bottom of bank points, thalweg, points outlining a bar/island if applicable, and anything else that may be important.
    a. Be sure to have different abbreviations for the points of different features along the stream.

Elevation Procedure with Laser Level

1. Set up a digital laser level station where it can be seen from all desired points.
2. Set a benchmark and gather known reference points.
3. Have a surveying notebook ready.
4. Lay out a surveying tape the length of the survey reach on one side of the stream, close to the water's edge
5. Determine a starting point and establish it as station zero.
    a. Measurements should be taken at stations along the tape at every stream facet such as glide, riffle, run, and pool.
6. Capture the water surface, thalweg, and bankfull elevations by holding the bottom of the rod at each point and expanding or compressing the rod until a steady beep is heard from the laser station.
    a. Bankfull does not need to be recorded at every station if an indicator is not present.

Cross Section Procedure with Laser Level

1. Set up a digital laser level station where it can be seen from all desired points.
2. Set a benchmark and gather known reference points.
3. Lay out a surveying tape perpendicular to bankfull flow in the channel and extend it to at least the highest elevation points you intend surveying to (typically at the edge of the floodplain).
4. Have a surveying notebook ready.
5. Record at what station along the tape this cross section is being measured from.
6. Take the elevation at set intervals across the stream, noting where bankfull, water surface, and thalweg are, or at other points of interest like major grade changes.
    a. Hold the bottom of the rod at each point and expand or compress the rod until a steady beep is heard from the laser station, read the measurement on the rod and record it in a surveying notebook with the station the point is at (distance across the stream).

The data acquired with the total station was saved in the controller which can be hooked up to a computer using a USB cable and the data can be transferred. The data can be uploaded to AutoCAD Civil to build the stream’s profile. Features will be labeled according to how they were saved when surveying, i.e. a tree saved as “TR.” This makes it easy to distinguish these points as the feature they represent in AutoCAD. The profile can be seen in Figure 11 below.

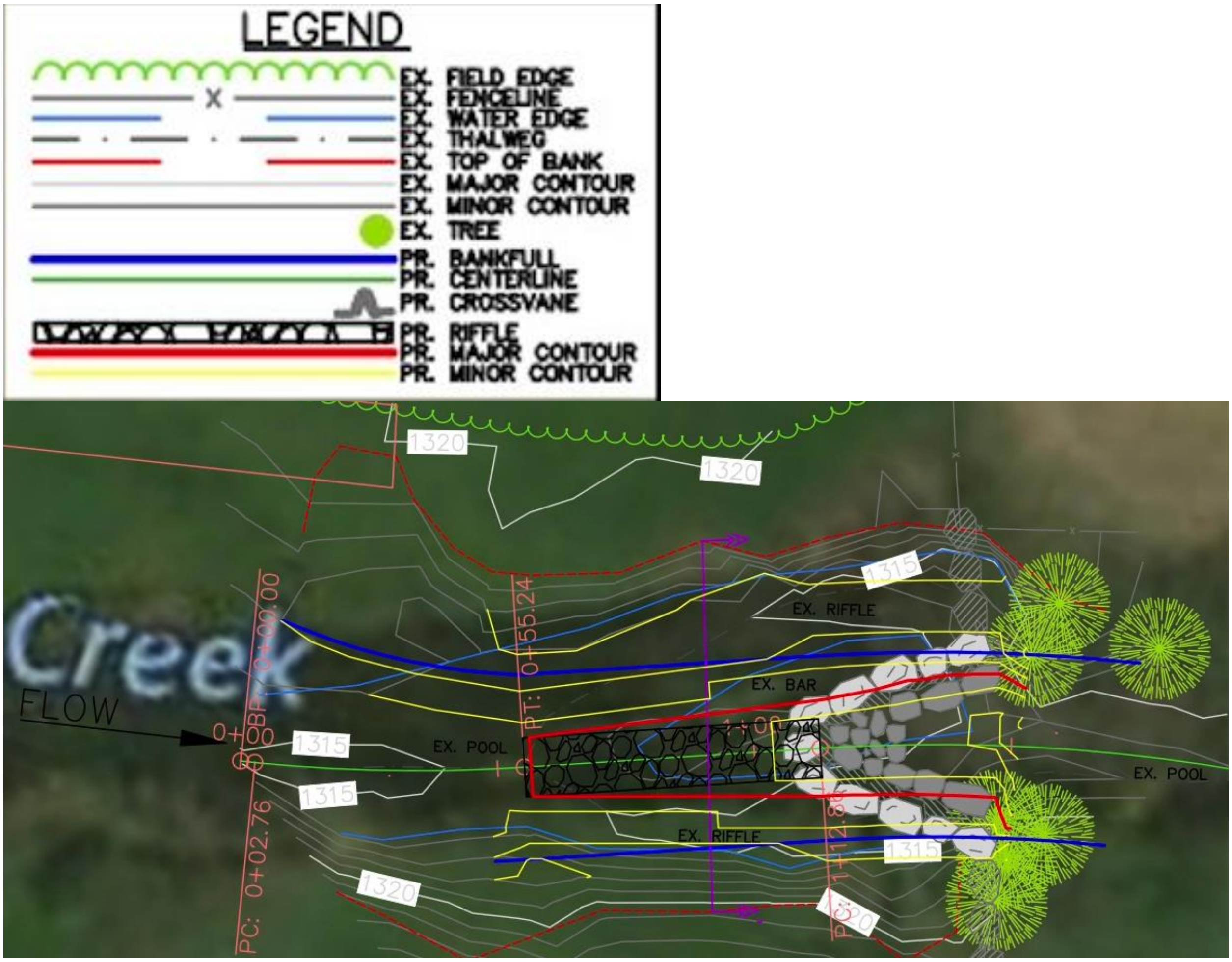

Figure 11. Profile of Beaver Creek generated with AutoCAD
CAD File by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Table 3 below contains a legend for surveying terms and the abbreviations commonly used. The elevation data acquired from surveying with a laser level can be found in Table 4 below. At each major stream feature such as pool, glide, riffle, or run, the elevation at the thalweg and water surface were taken with the occasional bankfull elevation measurement. The distance downstream from the datum is distinguished as a station. All of these measurements were entered into AutoCAD to help build the existing stream digitally.

Table 3. Legend for Surveying Data

Legend	
STA	Station
TW	Thalweg
WS	Water Surface
BFK	Bankfull
DSCR	Description
G	Glide
R	Riffle
U	Run
P	Pool

Table 4. Profiling Data from Laser Level

STA (ft)	TW (ft)	WS (ft)	BKF (ft)	DSCR
0	9.7	8	-	G
14	9.1	8.2	6.95	R
86	10.3	9.4	8.05	U
113	11.8	9.2	8.05	P
126	13.2	9.2	-	G
148	12.3	9.35	-	R
200	10.15	9.5	8.7	R
210	10.4	9.45	-	U
218	11.2	9.5	-	P
233	11.2	9.55	-	G
278	10.75	9.7	8.8	R
352	12.4	10.8	-	U
371	13.75	11.1	10	P
385	14.5	11.1	-	P
397	13	11	10.3	G
463	12.7	11.3	-	R
488	12.9	11.35	-	U
502	13.2	11.35	10.75	P
539	13.3	11.4	-	P
550	15	11.4	-	G
579	12.5	11.5	10.9	R
660	13.7	13.2	12.1	U
671	15.4	13.2	-	P
700	15.2	13.2	-	G
720	14.7	13.3	12.5	R

Table 5. Cross Section Data (at Station 86 of Table 4)

STA (ft)	EV (ft)	DSCR
5.5	5.5	-
8	6.2	-
11	6.4	-
14	6.4	-
17	6.3	-
19	6.45	-
22	7.45	-
24	8	BKF
25	9	WS
27	9.95	-
31	9.85	-
35	9.75	-
39	10	TW
42	9.8	-
45	9.7	-
47.5	9	WS
48	8.3	-
49	7.85	-
52	7.45	-
57	6.4	-

The data from Table 5 was uploaded to RIVERmorph to generate a graph of the cross section looking downstream as seen below in Figure 12. This was the original cross section before changes were made. From this graph, bankfull, water surface, and inner berm indicators can be determined, providing more crucial information about the stream. The ground points also help to outline the area.

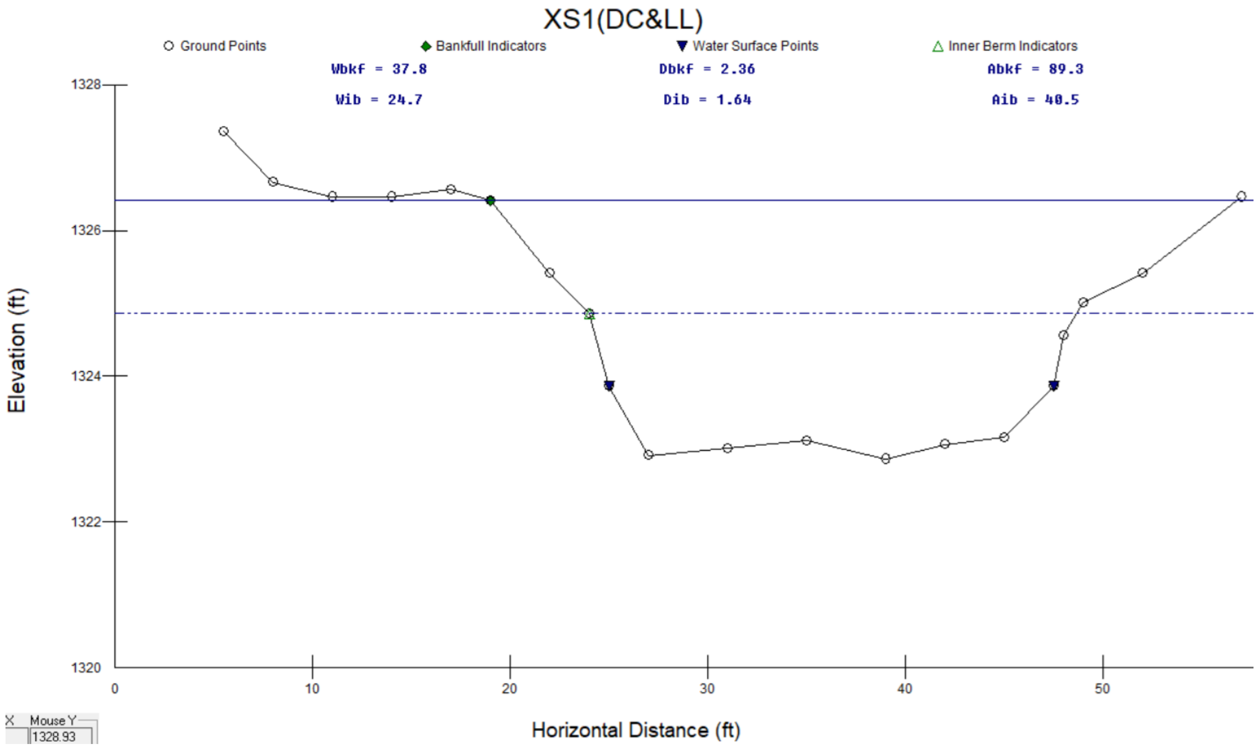

Figure 12. Graph of the original cross section of the site from RIVERmorph software
Graph by Dylan Cooper, Trout Unlimited

When cross section data is inputted, RIVERmorph automatically generates the bankfull width (Wbkf), depth (Dbkf), and area (Abkf), which are parameters that should be matched closely to reference data found in nature. Other parameters were also generated, as seen below in Table 6. These can be then uploaded to Microsoft Excel to set up calculations and manipulate data to get a desired cross section.

Table 6. Existing Channel Characteristics Generated by RIVERmorph

	Channel
Floodprone Elevation (ft)	1329.96
Bankfull Elevation (ft)	1326.41
Floodprone Width (ft)	51.5
Bankfull Width (ft)	37.76
Entrenchment Ratio	1.36
Mean Depth (ft)	2.36
Maximum Depth (ft)	3.55
Width/Depth Ratio	16
Bankfull Area (sq ft)	89.26
Wetted Perimeter (ft)	39.33
Hydraulic Radius (ft)	2.27
Begin BKF Station	19
End BKF Station	56.76

There have been various restorative projects done to Beaver Creek in the past, leaving existing data about the watershed found in Appendix D, such as cross sections that were used to make comparisons to the new surveying data as validation. The regional curve data taken by the USGS for the Valley and Ridge of Virginia was also used. Regional curves take data from all over an area and find trends that can be used for analysis and design, because these bodies of water tend to behave similarly in the same physiographic province.

A lot of data from the site was also gathered by James Madison University engineering students from a sustainability course. This data was used for further verification when making design decisions and can also be found in Appendix D.

Phase IV. Consider Passive Recommendations for Restoration

The need for this region of Beaver Creek to be restored became apparent from fishermen walking along the river and struggling to get past an area that eroded up to a fence protecting private farmland. The obvious response is to fill in the eroded corner and replace the walking path. This would be a temporary fix, however, because the problem would happen again over time. Other passive recommendations involved adjusting different parts of the river such as expanding the pool or redirecting the flow using various techniques such as the ones shown in Figure 13 below.

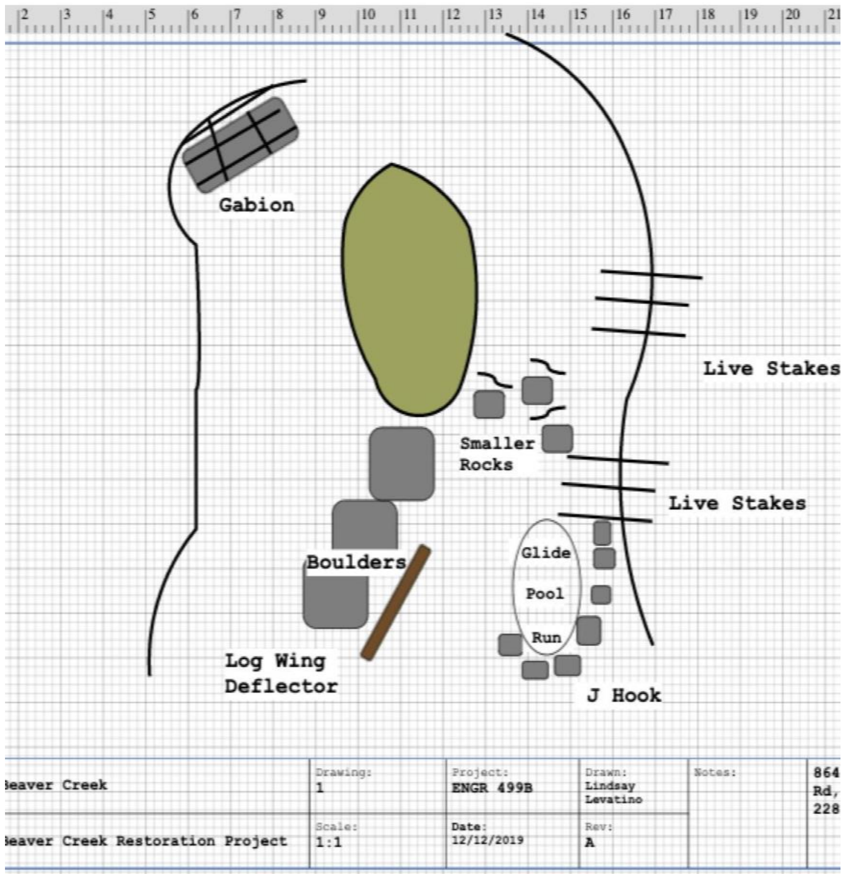

Figure 13. Passive design recommendation
Design by Lindsay Levatino, James Madison University

The techniques in the drawing were some ideas that could be implemented generally easily, however a more significant change needed to take place, which was later suggested by Dylan Cooper from Trout Unlimited. This involved modifying the riffle in question and implementing stabilization structures. Each design decision must be intentional and predict future consequences.

Phase V. Develop Conceptual Design Plan

After surveying the land, this riffle was found to be the longest one of the reach. The length and width of the riffle is likely causing the problems, making it unstable and forming the bar that splits the stream. Riffles are meant to transport material, however the instability of this specific one caused material to aggregate into an island, as seen in Figure 14 below. The longer the riffle, the greater increase to the flow's velocity, which leads to pebbles being plucked from the streambed and carried along. To mitigate this, a longer pool should be formed naturally from the stream readjusting. This way, the energy increase from the riffle will be dissipated over a longer pool. Unfortunately, slightly downstream of the reach is a shallow area of bedrock, preventing the stream from adjusting to a longer pool and causing it to widen out instead, as seen in the lower left corner of the stream in Figure 14. A plan was developed to dig out this bar and use the aggregate to fill in the eroded land approaching the farm fence.

Figure 14. An overhead view of the bar that splits the stream formed
Photo by Brian Koerner

It is important to build a riffle that represents what the stream wants, otherwise it will go back to the problematic state it was in or cause erosion elsewhere. The same goes for the general profile where the riffle lays. It should match the current profile of the stream in order to keep the stream acting naturally. In order to fix the problem of erosion in this location, the new riffle had to be moved about 20 feet upstream and shortened about 60 feet, creating room for a longer pool to follow. It cannot be too short, however, or the new riffle will want to elongate, and material will aggrade again. If the riffle is too long, the pool below will not be long enough, and it will eat away at the head of the next riffle. Finding the distance that the new riffle can be moved upstream while keeping the new pool in a desired range was done by Dylan Cooper using RIVERmorph and Microsoft Excel. Riffle length, pool length and radius of curvature can all be manipulated until desirable values appear. The existing data was used as a reference and the proposed data for the design can be compared in Table 7 below. The riffle lengths have been shortened to stabilize the area.

Table 7. Proposed Stream Pattern Data

		Riffle Length Ratio	Riffle Length (ft)	Pool Length Ratio	Pool Length (ft)	RC Ratio	Radius of Curvature (ft)
Existing Data	Min	0.7	26	1.6	60	-	-
	Max	1.7	64	2.3	88	-	-
	Max	2.2	82	3.0	113	-	-
Design Data	Min	1	36	1.2	43	2	72
	Mean	1.6	58	2.7	97	2.5	90
	Max	3.4	122	4.9	176	3.5	126
	Ideal	1.2	43	1.9	68	3	108

In Table 8 below are the proposed geometric characteristics of the stream cross-section using the ideal pool and riffle lengths. The new channel geometry can be compared to the existing problematic geometry mentioned earlier in Table 6.

Table 8. RIVERmorph-generated Data of Proposed Characteristics

	Channel
Floodprone Elevation (ft)	103.01
Bankfull Elevation (ft)	100
Floodprone Width (ft)	43.98
Bankfull Width (ft)	35.98
Entrenchment Ratio	1.22
Mean Depth (ft)	1.94
Maximum Depth (ft)	3.01
Width/Depth Ratio	18.55
Bankfull Area (sq ft)	69.9
Wetted Perimeter (ft)	36.96
Hydraulic Radius (ft)	1.89
Begin BKF Station	4
End BKF Station	39.98

The flood prone and bankfull elevations and bankfull width have been greatly decreased to consolidate the area and shape the new structures. The mean depth was also made shallower, so the riffle does not create too much scour.

Phase VI. Develop & Evaluate the Preliminary Natural Channel Design

In order to hold grade at the end of the proposed riffle at the end of the site, create a deeper pool, and correct the channel width, a cross vane was designed. The point of curvature, PC, of the new stream alignment is where the new pool is started and its end is the point of tangency, PT. On the straight section of the channel's alignment is where the riffle should be located, from the PT to PC.

The current riffle is too narrow, which causes the stream to go deeper, creating more shear stress on the pebbles, leading to more scour downstream. Scour is when the streambed elevation changes due to sediment eroding or being carried away with the flow. It is important to have some scour to keep material flowing to a degree, but not too much that the streambed is being eliminated and sediment is building up in other places where it is not supposed to. The proposed cross vane designed by Dylan Cooper will hold the downstream elevation of the new riffle and create scour to maintain the pool. To do so, various calculations had to be done using Microsoft Excel. First, Manning's n had to be established, which is the roughness coefficient in channel velocity calculations. The lower the n value, the less resistance a channel has to flow and thus it should have higher velocity. It is based on the characteristics of the bank and pebble size on the streambed. For this site, a short grass-covered bank condition was used and from Table 9 below, Manning's coefficient corresponding with this stream (a main channel that is clean, winding, with some weeds and stones) is about 0.043.

Table 9. Manning's n for Channels ("Manning's n Values," 2006)

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Next, the size of grain needs to be determined from the majority of the streambed. 130-millimeter grain size was determined based on data from previous projects at Beaver Creek. Furthermore, a D84 pebble count will be used to represent the maximum moveable particle size. This means that 84% of the particles in the streambed are smaller than 130 millimeters and 16% are larger. By using a D84 pebble count, the Rosgen Curve can be used to estimate a corresponding shear stress. This curve uses a mixed bed of sediments to determine shear stress as opposed to Shield's Curve that uses all of the same sized particles as reference data. The graph showing both Rosgen and Shield's Curves can be seen in Figure 15 below.

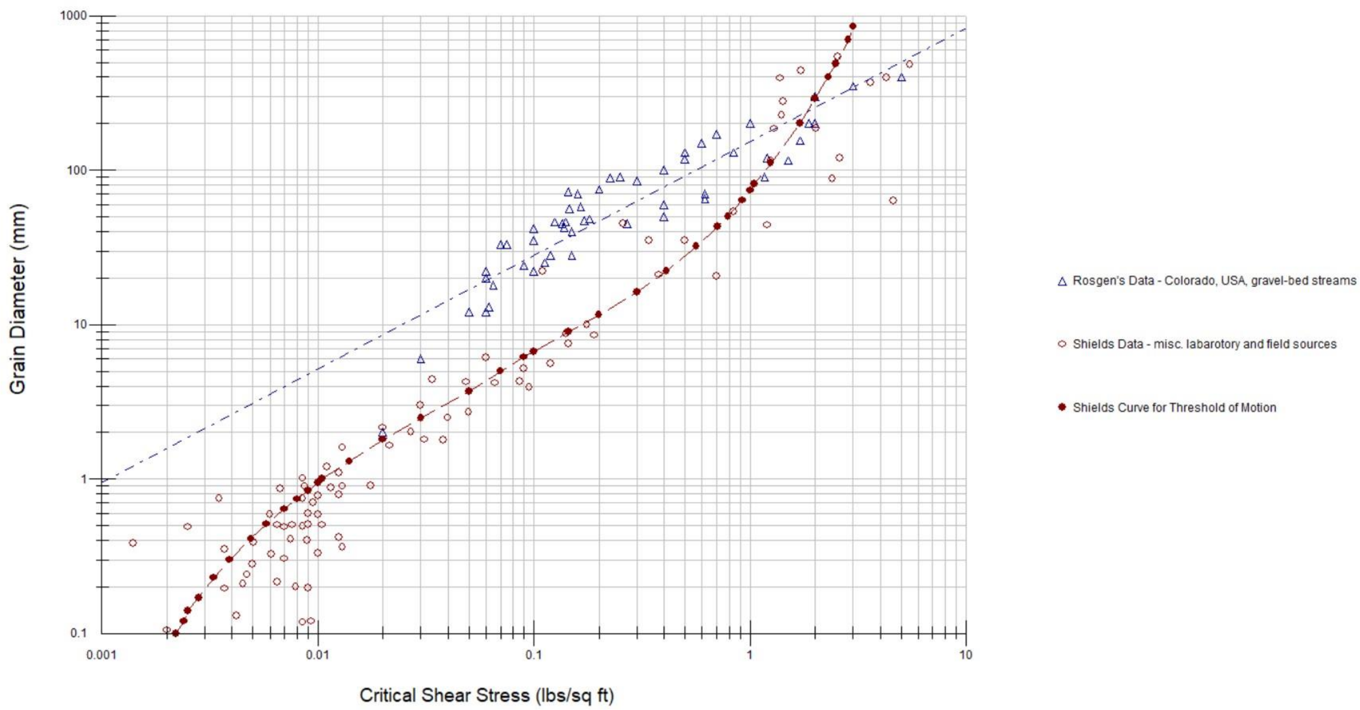

Figure 15. Graph of grain diameter vs. critical shear stress comparing Shield and Rosgen Curves
Graph by Dylan Cooper using RIVERmorph

The graph outlines both curves as grain diameter versus critical shear stress. As the size of the sediment increases, the more stress is needed for the water flow to pick it up and move it along the stream. Since the grain diameter was determined based on past projects, the Rosgen Curve can be used to find the critical shear stress, another important parameter used for design.

The Manning's n value can then be used to find channel velocity by using Manning's equation found in Figure 16 below. The hydraulic radius and water surface slope were found from the RIVERmorph data generated by the cross-section geometry and longitudinal profile.

$$V = \frac{1.49 * R^{2/3} s^{1/2}}{n}$$

V	= Avg. velocity (length/time, usually ft/s)
s	= Water surface slope (unitless)
R	= Hydraulic radius (length, usually ft)
n	= Roughness coefficient
1.49	= English units conversion factor, set to 1.0 for metric

Figure 16. Manning's Equation for velocity of stream flow
Photo by the Comet Program ("Basic Hydrologic Science," 2006).

The channel velocity can then be used to calculate the discharge by multiplying it times the bankfull area. The discharge is the driving force of all stream processes and the cross section can be designed based on this value. If the design bankfull discharge is too low, too much sediment will be carried away, and if it too high, there will not be enough sediment movement in the stream and it will aggrade. The riffle cross-section and cross vane were designed based on these parameters.

Due to the straightness of the pool downstream of this site, a tangent cross vane was chosen as opposed to an offset cross vane. Offset cross vanes work best when the project area is meandering. The vane arm lengths were set to equal the design bankfull width of 36 feet. The throat of the structure was set to be about a third of the bankfull width, or 11.5 feet. The angle of the arms off of the bank was set to be 22.5 degrees. This particular angle allows for the cross vane to funnel the water away from both banks back into the center of the channel without creating an obstruction, which protects the banks from high velocities and creates a deeper pool for the trout. This information and more are all detailed in the plans in Figure 17 below.

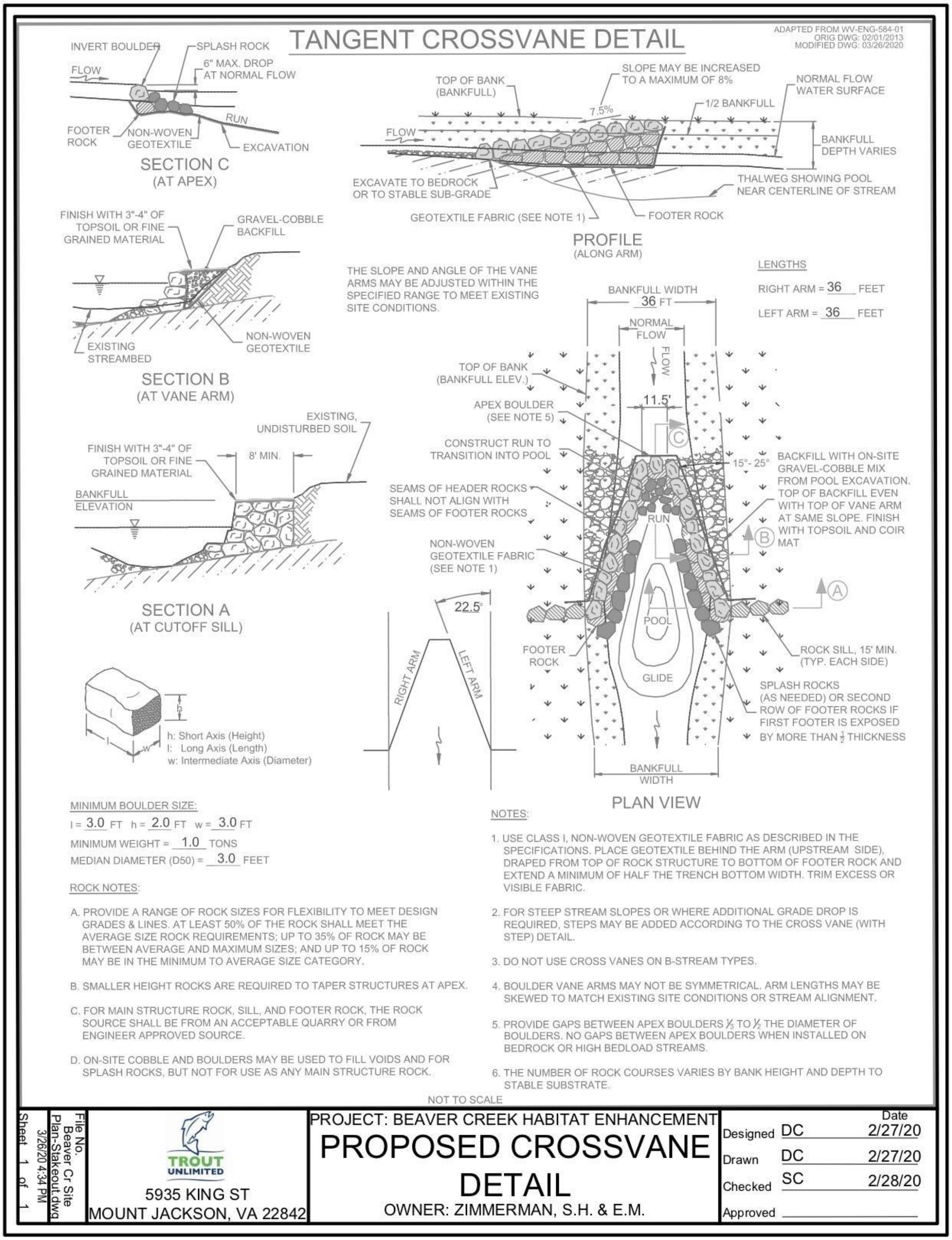

Figure 17. Cross vane plans
Design by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Other information needed to build this structure properly include the boulder sizes that should be used and the amount of topsoil to finish the construction with. A detailed plan such as the one above will help the implementation process go quickly and smoothly and prevent or postpone the need of future maintenance.

Phase VII. Design Stabilization & Enhancement Structures

In order to stabilize the new instream structures and stream banks, a few measures were designed and implemented. These include matting, stakes, and live stakes. Matting enhances soil preservation and control. Coir is coconut fiber that is woven into mats that come with different sized openings. The sized holes should be based on the stream velocity to control how much sediment passes through. The guidelines for choosing the right coir mat can be found in Appendix E. The coir mats used on the new banks were CM700. One roll was used on the right bank and two were used on the left bank, each roll being about 6.6 feet wide and 164 feet long. These coir mats are 100% biodegradable and will gradually release nutrients into the soil overtime, enhancing vegetation and growth (“Coir Mats for Stream,” n.d.). Most coir mats will last around four to six years before fully biodegrading. A N060 nonwoven geotextile matting was also used on cross vane structure. To protect the boulders used from being undermined, this matting was laid on the upstream faces of the boulders to contain the cobble fill, but in a way that is not visible to visitors. About 100 feet of geotextile was used out of a 15-foot-wide by 300-foot-long roll. The specifications for both matting types can be found in Appendix E.

Wooden takes were used to hold the matting in place. Dylan Cooper mentioned that the angle of the stakes pointing upstream is important to give them the best chance at holding the matting down during high water events. Wood stakes that are 18 inches long and one by two inches thick were driven into the ground with mallets, leaving about four inches sticking out from the matting. Live staking is an effective way to reintroduce plant life to the stream (Fetter, Jennifer R., 2015). The live stakes should be cut from trees right before the buds begin to bloom in the spring. This will improve the likelihood of the cuttings turning into trees in the stream. The stakes should eventually grow a root network to enhance the soil life in the stream and prevent soil loss (Fetter, Jennifer R., 2015). Black Willow or Red Osier Dogwood are some of the best species of trees for live staking. Two-foot Black Willow live stakes will be used at this site and should be implemented by the end of May 2020. The stakeout plans can be found in Figure 18 below. This shows where the stakes will be placed relative to the new cross vane.

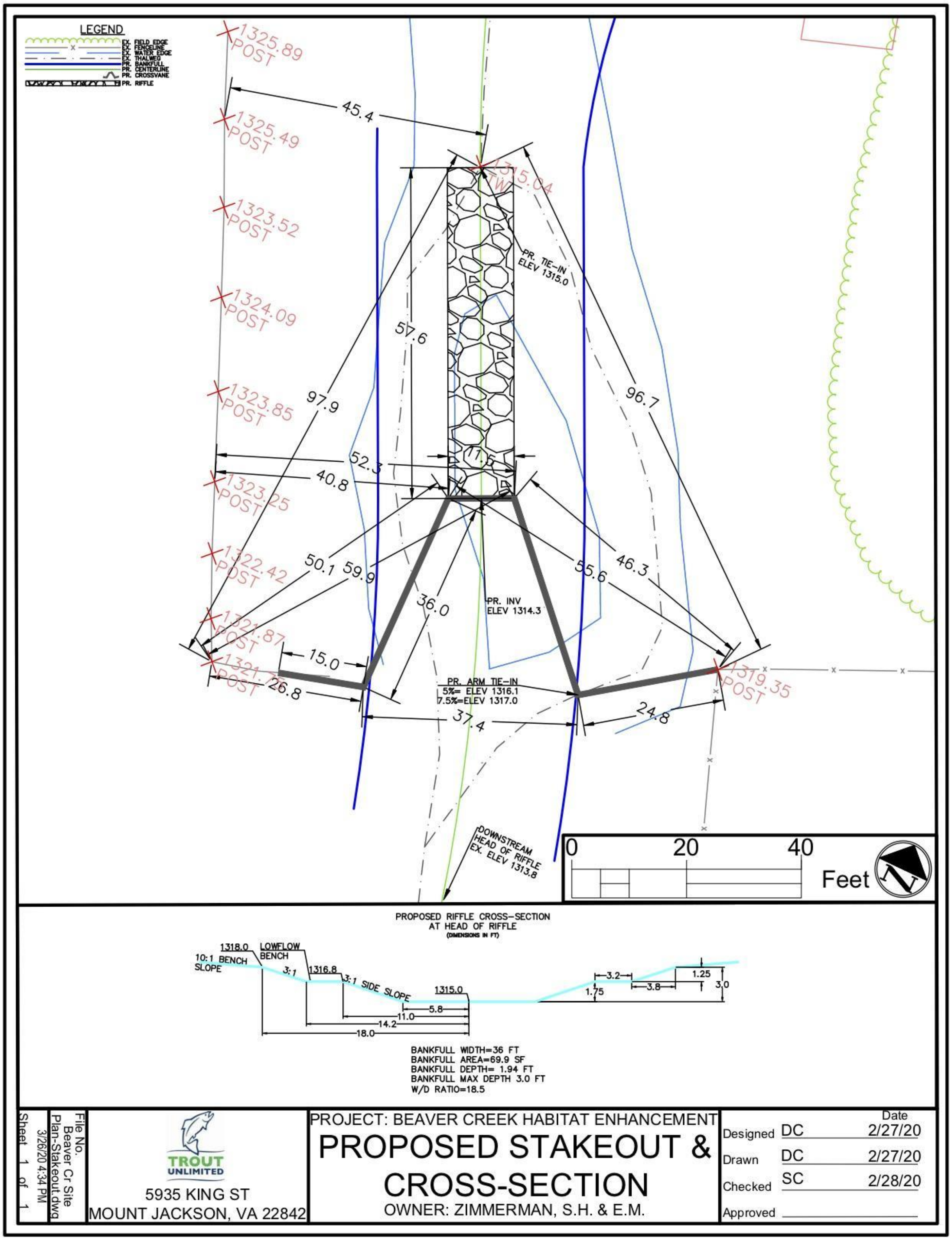

Figure 18. Stakeout plans
Design by Dylan Cooper, Trout Unlimited

Phase VIII. Finalize Natural Channel Design

The full final design can be found in Appendix F. The new cross section found in Figure 19 below shows where the existing top of the bank lays and where the new bankfull should be located. This final cross section was designed using the characteristic data from Table 8 in Phase V.

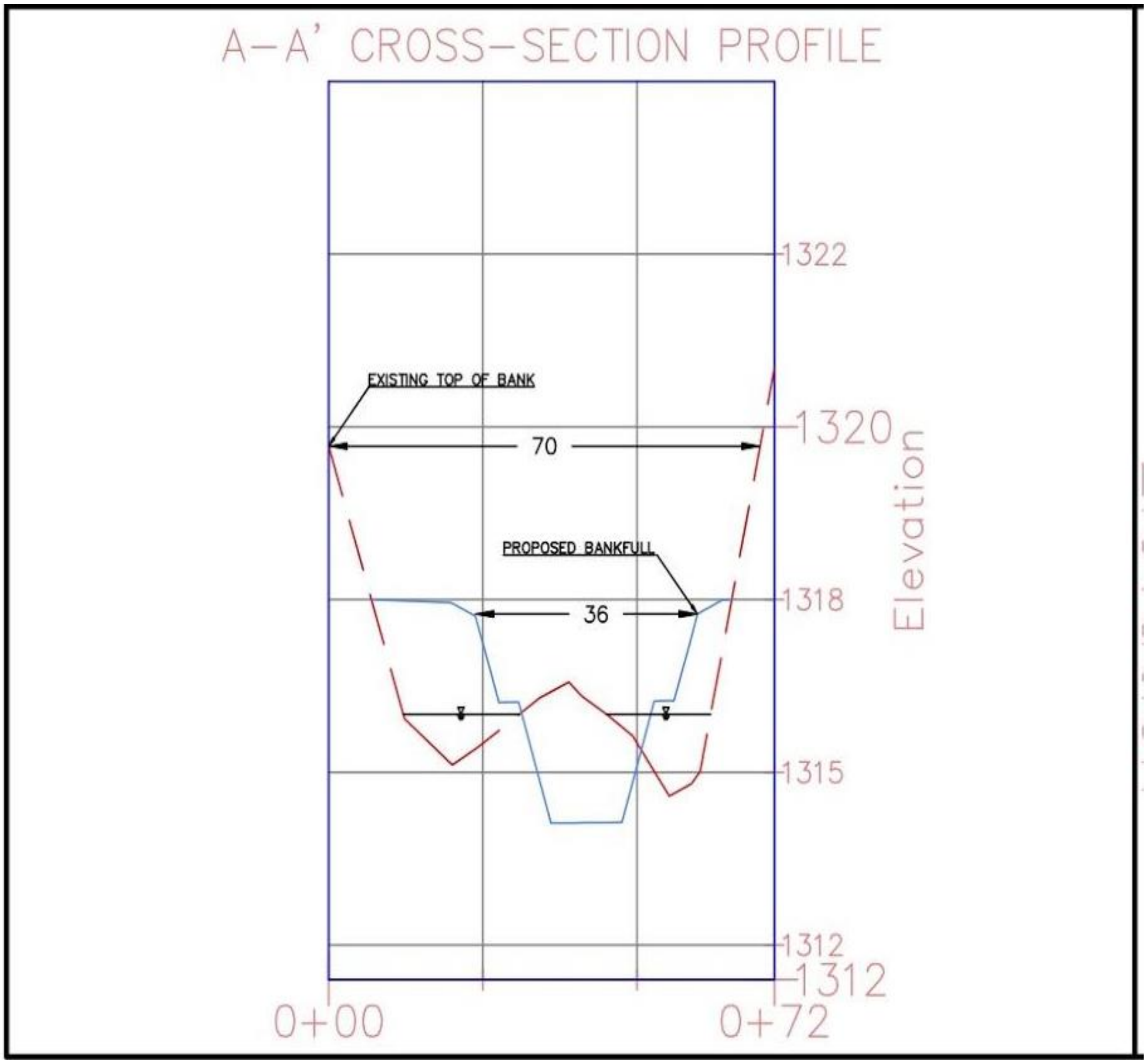

Figure 19. Zoomed-in view of finalized cross section looking downstream
Drawing by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Figure 20 below shows the cross section to the proposed riffle with specific dimensions for ease of construction. The view is facing downstream, so the new banks can be seen on either side. The new banks are broken down by side slope, low-flow bench, bankfull bench, and bench slope. The plan also lays out the finalized bankfull width, area, depth, max depth, and width-to-depth ratio.

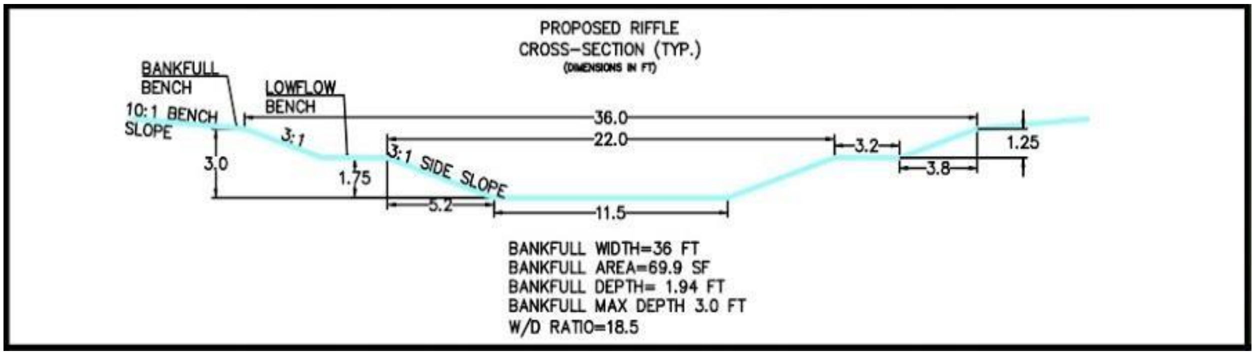

Figure 20. Zoomed-in view of finalized riffle cross section
Drawing by Dylan Cooper, Massanutten Chapter of Trout Unlimited

The centerline profile in Figure 21 below shows the stream from a sideview, revealing the significant change from the existing grade to the proposed grade. It also displays the new bankfull from the side, as well as the rock vane, which signifies the end of the proposed riffle.

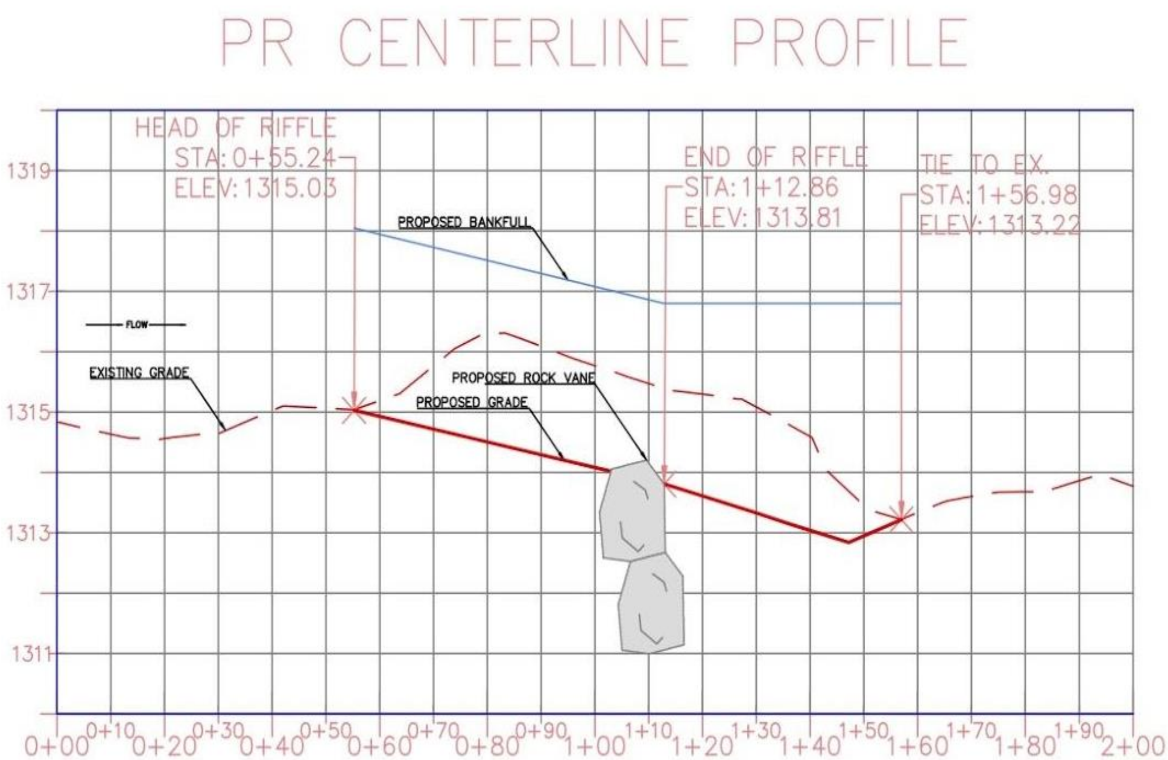

Figure 21. Zoomed-in view of finalized centerline
Drawing by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Phase IX. Implement Natural Channel Design

The final natural channel design was implemented by the Massanutten Chapter of Trout Unlimited and Trout Unlimited employees from the Shenandoah Headwaters region in Virginia. The construction of this project took roughly two weeks. There was an existing pile of boulders next to this stretch of Beaver Creek donated by the landowner for restorative work that was able to contribute to this project. Furthermore, the sediment that made up the stream-splitting bar was excavated and used to fill in the largely eroded corner. The filling can be seen in Figure 22 below and a photo of the stream without the bar can be found in Appendix G.

Figure 22. Sediment from excavated bar to fill eroded banks
Photo by Dylan Cooper, Massanutten Chapter of Trout Unlimited

The cross-vane structure can be seen in Figure 23 and 24 below. After carefully following the design plans shown earlier, the cross vane was constructed with precision and accuracy. This structure will affect how the stream adjusts to the changes of the stream features, so it is important that it was implemented exactly as planned. The existing boulders from the site were used in the cross vane, forming a beautiful drop at the end of the new riffle, followed by a new pool.

Figure 23. Implemented cross vane structure looking upstream
Photo by Dylan Cooper, Trout Unlimited

Figure 24. Cross vane implementation side-view
Photo by Dylan Cooper, Trout Unlimited

The remainder of the existing boulders were used to stabilize the newly filled bank that also serves as a footpath. This should protect the farmer's fence that is located right next to it and eliminate excess nutrients from flooding the waters. Figure 25 shows the cut-off sill made of the excess boulders extending from the end of the cross-vane arm to the edge of the old bank. This feature ensures that at any overflows (above bankfull) from high water events do not flank the structure. Water cannot go around the arm, which would result in cutting down through the soil if this structure was not in place.

Figure 25. Stabilization of the previously eroded bank
Photo by Dylan Cooper, Massanutten Chapter of Trout Unlimited

This is also where the nonwoven geotextile is used on the upstream face of the boulders in order to retain all of the soil and cobble fill, as mentioned earlier.

Phase X. Conduct Monitoring & Maintenance

Members of Trout Unlimited will monitor the restoration sites and inspect the riparian annually. The Virginia Department of Forestry recommends that these inspections include replacing any damaged tree stakes, controlling weeds and invasive species, and adding bird netting if necessary (“What is a riparian buffer?” 2020). Members of the TU will also perform routine walks after big storms during the first year and notify and consult with the landowner about any major changes. There are also cameras continuously recording the site from two trees, one facing downstream and the other facing upstream. These can be referred to when needed to review any changes.

To evaluate the success of this project, the following metrics found in Table 10 on the next page can be used to measure or monitor the site. These were established by the members of the Trout Unlimited and agreed upon by the other stakeholders.

Table 10. Maintenance Measures

Metric	**Methodology**	**Person Responsible**	**Frequency**
Increase in brook trout abundance in Beaver Creek	Sample the restored section of Beaver Creek using backpack electro-fishers Record number of brook trout collected as well as length and weight of individuals	Dr. Tim Kreps, Bridgewater College	Continue annually for 3 years
Increase in gravel permeability and a reduction in streambed fine sediment	Conduct pebble counts	Dr. Bradley Striebig, James Madison University	Conduct sampling on an annual schedule
Decrease in summer peak temperatures in the restored stream section	Deploy HOBO temperature loggers in the stream	Dr. Bradley Striebig, James Madison University	Each summer following the restoration activities until sufficient temperatures are recorded
Increase stabilization of streambanks and improved channel geomorphology	Conduct photo monitoring along the restored stream reach Measure physical habitat characteristics such as stream width and depth	Dr. Bradley Striebig, James Madison University, Massanutten Regional Governor’s School (Regional selective high school project)	Established stations annually for 3 years

Conclusion

Stream restoration is an important, positive contribution from humanity, as we continue to interfere with nature by building new infrastructure and affecting the environment. Although streams have the tendency to adjust themselves to rebalance, sometimes the changes can take decades to occur, threaten a landowner's property or infrastructure or have negative effects downstream. Using engineering to improve the situation from the standpoints of both society and the environment can be very rewarding. As long as the project attempts to mimic natural occurrences and predict the reactions of nature, the restoration should have positive results. The work done on Beaver Creek in this project should significantly decrease the amount of harmful contributions to the water quality downstream and it will stop the erosion to the bank approaching the farmer's fence. Specifically, the designed riffle should stop the stream from widening in this stretch and prevent another bar from aggrading. The cross vane should slow the stream's flow along the banks and redirect it towards the center of the channel. Ultimately, the restoration work, and the natural stream channel design process can be used as a reference point for future work on Beaver Creek or nearby streams.

Appendix A

Potential Restoration Techniques

Table A.1 Stream Restoration Techniques ("The Virginia Stream Restoration," 2004)

Technique	**Description**	**Functionality**
Brush Layering	A revegetation technique, which combines layers of dormant or rooted cuttings with soil to revegetate and stabilize both stream banks and slopes	Slow flow/pooled reaches, limited backwater effects, silt or fine sand bed, high bedload transport
Brush Mattresses	A combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize streambanks	Slow flow/pooled reaches, limited backwater effects, silt or fine sand bed, high bedload transport
Fascines	Dormant branch cuttings bound together into long cylindrical bundles and placed in shallow trenches on slopes to reduce erosion and shallow sliding	Slow flow/pooled reaches, limited backwater effects, silt or fine sand bed, high bedload transport
Live Crib Walls	A wooden log cabin-type structure built into a streambank which is filled with rock, soil and cuttings of willow	Limited backwater effects, silt or fine bed
Live Stakes	Long hardwood cuttings, used to stabilize erosion control fabric	Creates a root mat to stabilize the soil by reinforcing and binding soil particles together
Natural Fiber Rolls	A toe and lower bank protection technique using fiber rolls made from coir (coconut) fiber and netting	Stabilizes the toe of the bank in areas of low stress
Deflectors	Generally wooden or rock structures installed at the bank toe and extending towards the center of the stream, in order to concentrate stream flow away from the banks	Allow for the concentration and conveyance of lower flows without losing channel capacity for the transportation of larger discharges

Gabions	Cage or box filled with sand, soil, or rubble used to stabilize a slope, build a retaining wall, build a foundation, or direct flow of water, especially to prevent erosion	Stabilizes incised channels in place
Rootwad Revetment	Consists of the lower trunk and root fan of a tree (rootwad), a footer log, and large boulders or graded riprap. Individual rootwads are placed in series along the outer meander bend in the lower portion of the streambank	Provides immediate bank protection, protects the toe-of-slope and provides excellent fish habitat, especially for juveniles
Boulder Placement	Placing a boulder or boulders in the toe of the streambank	Provides rigid toe protection
Rock/Cross Vanes	Linear structure made of large rocks, upstream-angled lines of boulders with smaller rocks between	Deflects near-bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools
Log Vanes	Linear structure made of large logs, upstream-angled lines	Deflects near bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools
J-Hook Vanes	The structure is identical to a rock vane with the addition of several gapped rocks placed in the middle third of the channel in a parabolic arc	Deflect near-bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools, the additional "J-rocks" create a scour pool with moderate to high fish habitat value
Vortex Rock Weirs	A rock vortex weir consists of footer and vane rocks	Accumulates sediment behind the weir arms and creates a

	arranged to provide grade control, provide scour hole, and reduce bank erosion. The form of the rock vortex weir is parabolic and spans the channel width	scour pool downstream of the structure

Appendix B

Stakeholders

1. Bradley Striebig, Ph.D.: Engineering Professor at James Madison University, thesis adviser and the Massanutten Chapter of Trout Unlimited Treasurer.
2. Dr. Bradley Newcomer, Ph.D.: Dean of the Honors College at James Madison University and thesis reader.
3. Dylan Cooper, EIT, AED: Stream Restoration Specialist at Trout Unlimited, project's lead engineer and reader.
4. Seth Coffman: Shenandoah Headwaters HRI Manager at Trout Unlimited and project manager.
5. James A. Patton, LS: Vice President at Balzer and Associates and project survey workshop instructor.
6. Brian Koerner, PE: Founder and Partner at Engineering Solutions and Construction Management, PLC and project consultant.
7. Sam Zimmerman: Project property landowner, farmer, and operator of grading equipment, and donated time and materials to the project.
8. Jerry Black: Adjacent property landowner and the Massanutten Chapter of Trout Unlimited chairman.
9. Virginia Eagle Distributing Company, LLC.: Anheuser-Busch wholesaler and donors to this project.
10. James Madison University Engineering Department: Students who took the Sustainability course and did field work to gather data at Beaver Creek.

Appendix C

Surveying Equipment

Figure C.1 Total Station- Sokkia iM 101 (“Sokkia IM-101,” 2020)

Figure C.2 Data Logger- Carlson Mini Data Collector (“Carlson MINI 2 Data Collector,” 2020)

Figure C.3 The total station used to survey Beaver Creek and Lindsay Levatino
Photo by Dr. Bradley Striebig, James Madison University

Figure C.4 Lindsay Levatino writing and Dylan Cooper capturing elevation data
Photo by Dr. Bradley Striebig, James Madison University

Figure C.5 Lindsay Levatino capturing profile data with a prism rod pointing at a total station
Photo by Dr. Bradley Striebig, James Madison University

Appendix D

Existing Watershed Data

Table D.1 Reference Cross Section & Bankfull Data from Previous Projects

Cross Sections		Bankfull Characteristics									
Reach Name	XSEC Name (Surveyor Initials)	W/D Ratio	Bkf Width	Bkf Depth	Bkf Max Depth	Max Depth Ratio	Bkf Area	Hydraulic Radius	Wetted Perimeter (ft)	D84	n
Beaver Creek	Riffle1(JF)	31.3	55.4	1.77	3.32	1.88	98.06	1.74	56.28	130	0.043
	Riffle2(JF)	13.0	31.35	2.41	3.24	1.34	75.42	2.29	32.86	130	0.041
	Regional Curve(V&R)	18.0	36.7	2.04	NA		75.3	NA	NA	130	#VALUE!
	Ref XS(DJ&SC)	19.8	35.7	1.8	2.7	1.50	64.5	1.7	37.6	130	0.043
	Ex XS(DJ&SC)	37.5	56.3	1.5	2	1.33	84.1	1.5	57.1	130	0.044

Table D.2 Regional Curve Data from USGS Valley & Ridge for VA

Drainage Area (Sq. Miles)	
Dimension	**USGS Valley and Ridge for Md, Va, and WV**[7]
$Q_{bkf\,(cfs)}$	308.8
$A_{bkf\,(sf)}$	75.3
$W_{bkf\,(ft)}$	36.7
$D_{bkf\,(ft)}$	2.04

Table D.3 Beaver Creek Stream Characteristics from Summer 2019

Date	**Air Temperature (F)**	**Cross Section (in^2)**	**Stream Width (ft)**	**Stream Flow (in^3/s)**		
Summer 2019	60	4268	30	13450.9		
						Average
Distance from Left Bank (ft)	6	12	18	24	30	18
Depth (in)	11	19	19	20	9	15.6
Velocity (raw) (314)	508	684	945	1096	1112	869
Velocity (counts/time)	194	176	216	151	16	150.6
Velocity (in/s)	205.5	176	228.3	167.2	18.3	159.06
Velocity Depth	2260.5	3344	4337.7	3344	164.7	2690.18
DO (mg/L) upstream	9.7	9.75	9.78			
DO (mg/L) downstream	9.8	9.77	9.75			
Turbidity	6.73	6.93	5.9	7.08	17.48	6.98
Total Dissolved Solids (mg/L)	46					
pH	7.6	7.5	7.4			

Appendix E

Coir Mat Information

Table E.1 Coir Mat Type Properties ("Erosion Control Mats," 2019)

Mat	Opening Area	Weight
40	65%	400 g/m²
70	50%	700 g/m²
90	39%	900 g/m²

Table E.2 Coir Mat Guidelines ("Coir Mats for Stream," n.d.)

Mat	Slope	Flow
40	3:1	8 fps
70	2:1 or 1:1	12 fps
90	1:1	16 fps

Table E.3 Woven Coir Matting Specifications for New Banks ("Earthshield Natural," 2015)

SPECIFICATIONS:

The CM700 open-mesh woven fabric will utilize the following characteristics:

PROPERTY	TEST METHOD	MACHINE DIRECTION	CROSS MATCH DIRECTION
Tensile Strength (Dry)	ASTM D4595	77 lb/in	86 lb/in
Tensile Strength (Wet)	ASTM D4595	78 lb/in	87 lb/in
Grab Elongation	ASTM D4632	26%	26%
Elongation at Failure (Dry)	ASTM D4595	26%	26%
Elongation at Failure (Wet)	ASTM D4595	27%	27%
Apparent Opening Size (AOS)	ASTM D4751	0.59" x 0.67"	
Percent Open Area		49%	
Mass	ASTM D5261	700 gsm	
Thickness	ASTM D5199	0.36	

Table E.4 Nonwoven Coir Matting Specifications for Cross Vane Structure ("N060 Technical Data," 2015)

SPECIFICATIONS:

The N060 polypropylene nonwoven fabric will utilize the following characteristics:

PROPERTY	TEST METHOD	MIN. AVG. ROLL VALUE
Grab Tensile Strength[1]	ASTM D4632	160 lbs
Grab Tensile Elongation	ASTM D4632	50%
CBR Puncture	ASTM D6241	410 lbs
Trapezoid Tear Strength	ASTM D4533	60 lbs
UV Resistance @ 500 hrs	ASTMD4355	70%
Apparent Opening Size (AOS)	ASTM D4751	70 US Sieve
Permittivity (sec^{-1})	ASTM D4491	1.6 (sec^{-1})
Flow Rate	ASTM D4491	110 gpm/ft^2

Appendix F

Finalized Design

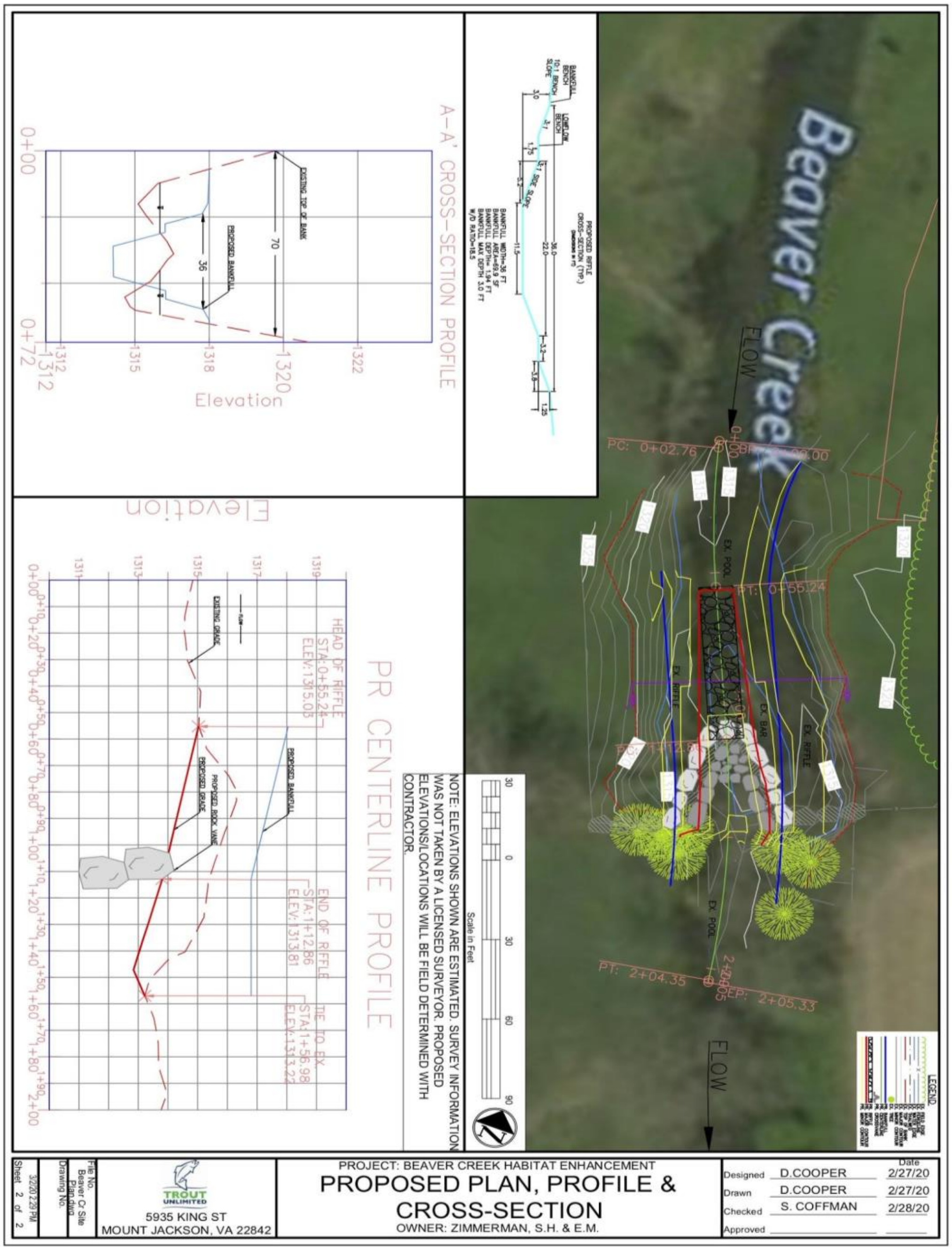

Figure F.1 Full finalized plan, profile, and cross section for Beaver Creek
Drawing by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Appendix G

Implementation

Figure G.1 Former bar location (looking upstream) that was excavated
Photo by Dylan Cooper, Massanutten Chapter of Trout Unlimited

Figure G.2 Downstream view of sight
Photo by Dylan Cooper, Massanutten Chapter of Trout Unlimited

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