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Natural Channel Design for a Degraded Stream in Sparta, Tennessee

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ABSTRACT

The objective of this project is to design a restoration plan to restore function to 1,100 feet of stream in Sparta, Tennessee. The body of water in question is a small headwater stream that flows through a subdivision development project. A hydrologic study was conducted to determine the range of flow rates expected in the stream for use in the design parameters. Natural streams have features such as riffles and pools as well as a meandering pattern in plan form. These features sustain a diverse aquatic habitat by creating variable hydraulic conditions in the stream. A new stream channel was designed that included riffle and pool cross sections, a meandering planform geometry, and a longitudinal profile. Statistical relationships from a headwater stream characteristic database were used to determine channel geometry for riffle and pool sections. This geometry was then compared to survey data from an undisturbed section of the stream. A hydraulic analysis of the final stream design was completed to verify it functioned as designed and would be stable during flood events. Following this analysis, the design was ready to be implemented.

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NATURAL CHANNEL DESIGN FOR A DEGRADED STREAM IN SPARTA TENNESSEE

PROJECT INTRODUCTION

1.1 PROBLEM DESCRIPTION

A housing development project was set to be constructed in Sparta, Tennessee. This development would include several single-family home lots as well as a retention lake for aesthetic purposes. The plan set for these lots and lake is in Appendix A. During the construction process a 1,100 ft section of stream was degraded without proper permits. This included excavating several sections of the stream, degrading the flood plain, as well as improperly damming the lower stream section. Shown in Figure 1 is the altered floodplain and degraded stream. State governments require various permits when performing these activities, as the hydraulics of the stream are greatly altered during this process. These codes are in place to ensure these processes are done correctly, as an improper design could lead to multiple issues for the areas surrounding the stream. These issues include flooding and erosion, which can cause problems for the residents and the environment.

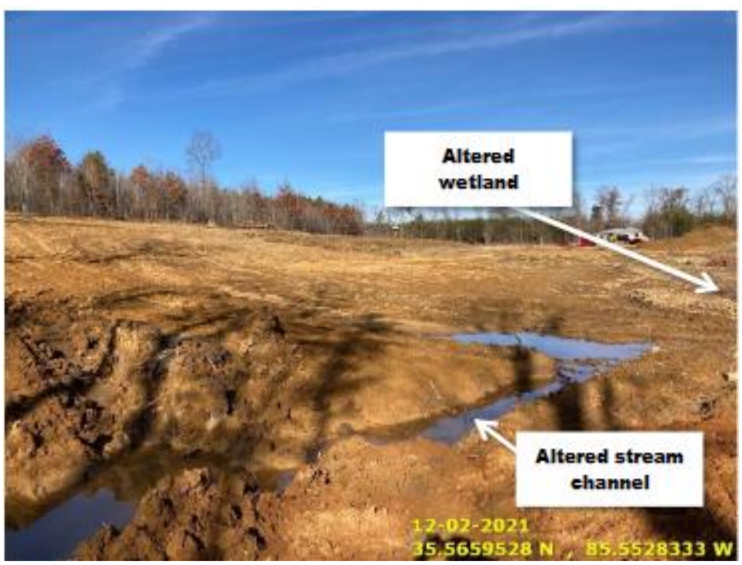


Figure 1: Altered Stream Section

These unpermitted changes eventually caught the attention of a Tennessee government agency, that launched an investigation into the violations occurring at the site. The agency ultimately ruled that the development company would need to prepare a corrective action plan to lay out the steps that would be taken to rehabilitate the stream and surrounding wetland. This plan would need to have a detailed description of the new design for the stream pattern and channel, as well as what vegetation would be used to reforest the surrounding wetland.

The objective of this project is to design a restoration plan for the impacted 1,100 foot of stream. This design will employ natural stream design principles and will include a full hydrologic and hydraulic analysis.

1.2 Features of a Natural Stream

In completing a design for a natural stream, it is important to understand the different features of a stream and how they interact with each other. A stream follows the thalweg which is the deepest point on the of the cross section of the channel, which acts as the corridor of the stream. The main components of a natural stream are the riffles and pools that make up the structure of the stream (Jennings & Harman, 1999). They are the mechanism for flow and sediment conveyance as well as habitat for various organisms that live in the stream. Riffles are stream reaches that are shallow and have higher velocities. As these sections have higher flow velocities the bed materials in the riffles are typically coarse such as gravel and larger stones (Jennings & Harman, 1999). These sections support insect and invertebrate life as they are capable of clinging to these rocks and reproducing in an oxygen rich environment.

The other main component of the stream structure are the pools. These are deep sections that are naturally made from scours that excavate the sediment. In natural streams these pools typically form at changes in slope or when the thalweg undergoes a large elevation drop such as after natural dams. Pools have low flow velocities and as such have fine bed materials like silt and clay (Jennings & Harman, 1999). These areas make habitat for fish, amphibians, and reptiles that use the deeper water to find food and reproduce. Riffles and pool work together to reach a state of stability in the stream that keeps it from degrading or filling itself in with the sediment load from the watershed. The stream must have a high enough discharge to move the sediment through the stream while at the same time not having too high of a flow velocity that would erode the banks and destroy the pattern of the stream (Jennings & Harman, 1999). Riffles work to increase the flow velocity of the stream to move sediment while the pools slow the velocity to keep it in check. An example of a natural pool and riffle section can be seen below in Figure 2.

Figure 2: Riffle and Pool Section

Along with these two features, another common feature in a natural stream is a log sill. These often occur in natural streams due to large woody debris forming natural dams and can serve multiple purposes. One of the main functions of a log sill is providing cover for aquatic life. Small species of fish often congregate under these log sills because they offer protection and provide a place for them to feed on insects being swept over the logs. To add to this, the turbulence created by these logs helps add oxygen to the stream, which is necessary for plant and animal life to thrive. Log sills also act as a dam to slow the water down and control the water level in certain parts of the stream.

2 SUMMARY OF METHODOLOGY

The first step of the design process was to create a design schedule for the project. This included identifying issues that needed to be addressed and scheduling the timeframe for designing each aspect. The full project schedule can be seen in Appendix C. Before starting the design, a hydrologic analysis of the area was conducted. This included delineating the watershed for the stream and using the TR-55 method to calculate the runoff. This involved calculating a curve number based on the different soil conditions and land uses in the watershed area. Once the curve number was calculated, the runoff for the watershed area could be calculated.

Once this was completed, the next phase of the design was to calculate the bankfull dimensions. Because every stream is different, there are a variety of equations that can be used to find these dimensions. Because of this, three different methods were used, with values being chosen that fell within the range of these numbers. All three of these methods involved using regression equations that were developed in slightly different ways. Once calculated, the bankfull dimensions could be used to lay out the cross section of the channel.

Moving on to the stream pattern the values for sinuosity, belt width, radius of curvature, and wavelength needed to be determined. These values would ensure the stream was laid out with a natural design that would not have erosion issues. It was very important that these values be calculated correctly, or else the stream could have issues with banks collapsing and erosion on the bends during heavy rainfall events. In order to calculate these values survey data from an unaffected section of the stream was used so that the values would match pre-violation conditions.

Once the design parameters were determined the design was constructed in Civil3D. This allowed for plan views of the design and elevation profiles for the project. Once the final design was completed it was necessary to complete a hydraulic analysis to ensure the design works as intended. This analysis determined the water level during a typical storm for the area as well as the stress on the stream from the water. This stress was then used to size the rock used to protect the stream.

3 ANALYSIS OF WATERSHED AREA

The first step in starting this design is conducting a hydrologic study of the stream's watershed. A watershed is an area of land in which all surface water flows to a water outlet. Watersheds vary in size from as small as half an acre to entire countries. The size and conditions in the watershed are what informs the parameters chosen for the stream design. Because of this several characteristics of the watershed needed to be found such as watershed area, soil type in the watershed, and time of concentration of the watershed.

3.1 Delineation of Watershed

The watershed first needed to be delineated or defined so that it could be studied. To delineate the watershed a United States Geological Survey (USGS) website called StreamStats was used to give an outline of the watershed and a rough report of some of the basin characteristics. Shown in Figure 3 below is the watershed provided by StreamStats and the full report can be seen in appendix F.

Figure 3: Delineated Watershed

The watershed area came out to 0.054 square miles or 34.7 acres. This area covers most of the planned housing project as well as some of the surrounding forest. However, as this is a small watershed area for a perineal stream very little data from similar streams is available for comparison in making the design.

3.2 SOIL CONDITIONS

Now that the watershed area and shape had been provided by StreamStats the next step is to find out the soil types in the watershed. To accomplish this another USGS website was used that provides a soil survey of a given area. Given the outline of the watershed and its coordinates the website produces a soil map of the site with various soil engineering properties. Shown below in Figure 4 is the soil map for the project watershed with each region of soil labeled over an aerial picture of the site.

Figure 4: Soil map of project watershed showing the soil series mapped by the USDA. See Table 1 for definition of map symbols.

As this is a small watershed not many different soils are represented in the site. The majority of the site is made up of a Ramsey loam. Which has coarser sandy grains while the rest of the stie is made up of silt loams with finer particles. Along with the soil map of the site a table of relevant engineering soil properties of the present soils was provided in the report. The main property that is needed from the report is the hydrologic soil group of the different soils. Shown below in Table 1 is a description of the soils on the site as well as their engineering properties.

Table 1: Soil Engineering Properties Table

Engineering Properties–White County Area and Van Buren County, Tennessee														
Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Pct Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				L-R-H	L-R-H	L-R-H	L-R-H	L-R-H	L-R-H	L-R-H	L-R-H
LdC—Lonewood loam, 5 to 12 percent slopes														
Lonewood	94	B	0-9	Loam, silt loam	CL, CL-ML, ML	A-4, A-6	0- 0- 0	0- 0- 1	92-98-100	83-95-100	76-94-100	48-60-72	30-32-40	12-13-17
			9-28	Silt loam, loam	CL	A-6	0- 0- 0	0- 0- 1	93-96-100	84-93-100	77-92-100	48-59-73	27-33-37	12-16-18
LoC—Lonewood silt loam, 5 to 12 percent slopes														
Lonewood	86	B	0-9	Loam, silt loam	ML, CL, CL-ML	A-4, A-6	0- 0- 0	0- 1- 6	88-97-100	87-97-100	77-90-100	61-75-86	27-34-42	9-13-18
			9-28	Silt loam, loam	CL	A-6	0- 0- 0	0- 2- 5	89-95-100	88-95-100	80-94-100	51-60-73	27-33-37	12-16-18
RfD—Ramsey-Lily complex, 5 to 20 percent slopes, very rocky														
Ramsey	63	D	0-5	Sandy loam, gravelly loam, loam, gravelly sandy loam	CL-ML, CL	A-2, A-4	0- 0- 0	0- 1- 13	84-97-100	69-94-100	63-93-100	35-61-74	20-30-38	4-10-17
			5-10	Loam, gravelly sandy loam, gravelly loam, sandy loam	CL, SC-SM	A-2, A-6, A-4	0- 0- 0	0- 0- 5	80-93-100	59-86-100	52-85-100	33-57-72	19-29-35	4-12-17

With 2 of the 3 soils present in the site being classified as hydrologic soil group B this simplifies the calculations needed to find the time of concentration using the TR-55 overland flow method (United States Department of Agriculture, 1986). The full report provided by StreamStats is located in Appendix F.

3.3 TIME OF CONCENTRATION

The main goal of the hydrologic study of the watershed is to calculate the time of concentration of the watershed and use it to calculate the peak flow the stream could expect. The time of concentration of a watershed is the time it takes for water that falls in the most distant point in the watershed from the outlet to reach the outlet as surface runoff. The peak flow expected through the stream is the flow that will be used to test the stream design after completion to ensure that the stream handles the rainfall event without leaving its banks.

3.4 LAND USE

In order to calculate time of concentration a weighed curve number needs to be found. A curve number is a numeric representative of the type of land present in the watershed. It relies on the hydrologic soil group of the soil paired with what the land is being used for as well as the hydraulic condition of the land. (United States Department of Agriculture, 1986) Each of these conditions are then compared to a table in the USDA journal *Urban Hydrology for Small Watersheds*. The equation for weighted curve number is shown below.

Equation 1: Weighted Curve Number

$$CN_{aw} = \frac{\sum_{i=1}^{n}(CN_i * A_i)}{\sum_{i=1}^{n} A_i}$$

To get a true representation of the site every unique pairing of soil group and land use needs to be accounted for and their individual areas. In order to accomplish this the soil map provided by the USGS site was overlayed on a Civil3D drawing so that aerial photographs could be used to determine land use and indicate the layout of the previously proposed site. Shown below in Figure 5 is the Civil3D drawing used to determine the groupings of soil group and land use.

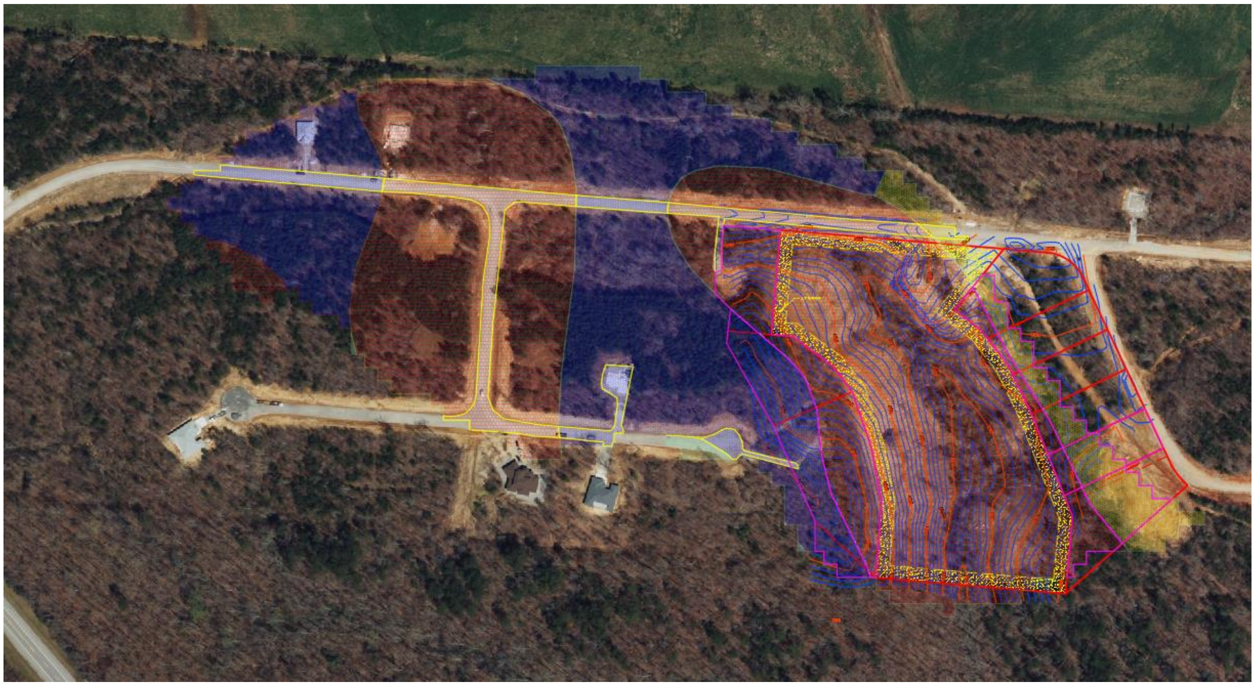


Figure 5: Land Use and Soil Map. LoC is shown in blue, RfD shown in red, and LdC in yellow.

Because the area of each unique pairing of soil and land use is required each section was traced and then measured with Civil3D's measurement tools. As the watershed is relatively small only 3 land uses were considered for this portion: Impervious roadways, developed residential land, and forested area. Roadways were outlined in yellow for each soil group and the area of the existing residential lots were used for residential land with the rest being considered as forested. This works to cover a large variety of curve numbers while also simplifying the work necessary to get a weighted curve number.

3.5 *TIME OF CONCENTRATION CALCULATION*

Once all the areas and curve numbers were processed a weighed curve number of 73 was calculated. This number is on the high side of curve numbers meaning that the watershed is less permeable and allows water to move quickly to the outlet. The time of concentration in hours was able to be calculated using the following equations.

Equation 2: Time of Concentration

$$T_c = \frac{l^{0.8}(S+1)^{0.7}}{1140y^{0.5}}$$

$$S = \frac{1000}{CN} - 10$$

The equations use curve number, CN, length of flow path in feet, l, average vertical slope of the watershed in percentage of relief, y, and maximum potential retention in inches, S. The time of concentration came out to 1.02 hours. This is relatively high for a watershed of this size; this could be contributed to the very small overall slope and long slender watershed. The NRCS velocity method was also applied to determine time of concentration and yielded nearly identical results.

3.6 *SSA MODEL*

In order to determine the flows that would occur through the area a computer model of the watershed was created using Autodesk Storm and Sanitary Sewer Analysis. By inputting several of the characteristics found in the hydrologic analysis such as the time of concentration, curve number, and watershed area the simulation will accurately determine peak flows during certain storms. Shown below in Figure 6 is the computer model as well as a screen showing the flow for a rainfall event with a 2-year reoccurrence rate.

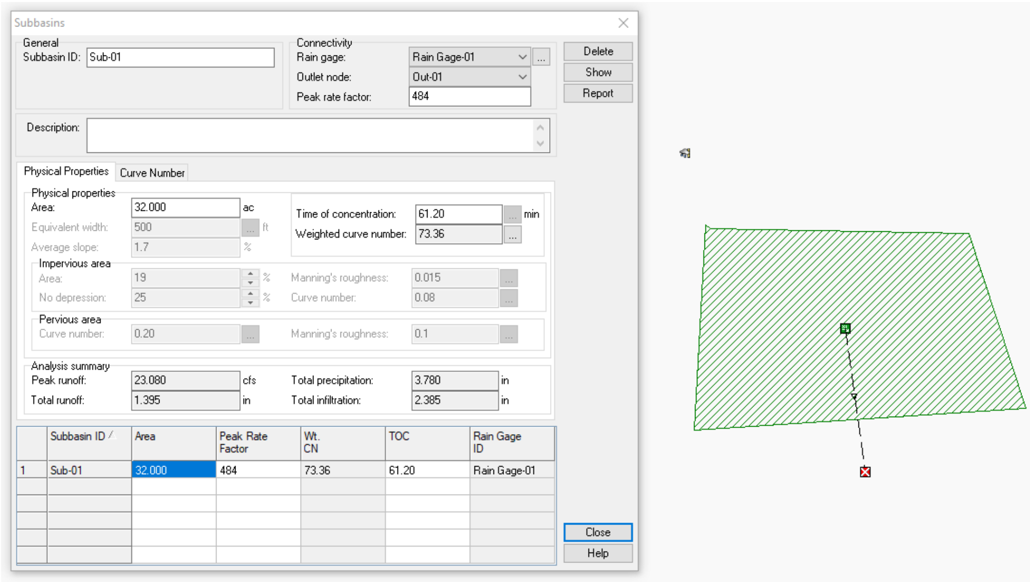


Figure 6: SSA Watershed Simulation

4 CHANNEL DESIGN

4.1 BANKFULL GEOMETRY

Bankfull geometry refers to the water depth, top width, channel area, and discharge when the channel is in a bankfull stage. The bankfull stage is defined as the water level, or stage, at which a stream, river or lake is at the top of its banks and any further rise would result in water moving into the flood plain. An illustration of these dimensions can be seen in Figure 7. In order to obtain the bankfull dimensions for channel that was being designed, three different sets of

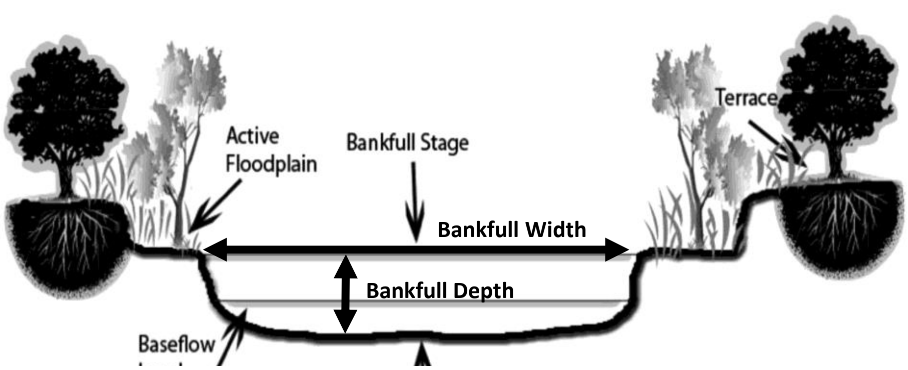


Figure 7: Bankfill Stage with Dimensions

regression equations were used. The equations give values with the parameter being the drainage area of the stream. These equations all provided values based on approximately a 1.5-year reoccurrence rainfall event. Meaning that this storm will impact the watershed on average once every 1.5 years.

The first set of these equations came from a published database of streams with small watersheds throughout Tennessee. This database divided Tennessee by its various ecoregions and provided equation sets for each of them. The ecoregion that this stream fell into was eco-region 71g, which can be seen in Figure 8. By surveying the dimensions of the streams in this region, the values were able to be combined and graphed. Regression equations were then generated based on the slope of the graphed data. Shown below in Figure 8 is the ecoregion map of eastern Tennessee.

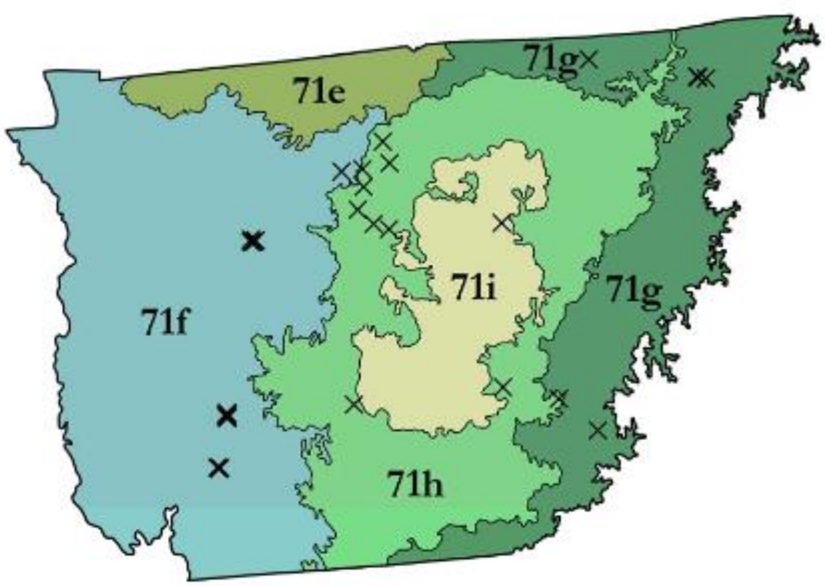


Figure 8: Ecoregions throughout middle-Tennessee (Tennessee State Government, 2017)

While this method was useful because it pertained to small streams in the same region as the one being designed, there was one major drawback. The smallest stream that was sampled had a watershed area of 0.06 square miles, while the stream being designed had a watershed area of 0.05 square miles. Because of this, a second set of revised equations that are based on smaller watersheds was used. This led to values that were slightly different than what were obtained using the first set of regression equations.

The final set of equations used were development by *The Journal of American Water Resources Association*. Much like the first set, these equations were based on different regions, with the difference being they were country-wide rather than statewide. In this case, the equations for the interior low plateau (IPL) region were used. While the first and second set yielded similar results, the data gathered from the third set had a larger deviation from those two. Overall, the values obtained from this method were smaller than those of the other two methods. Once these values were obtained, they were all compared to survey values from the actual stream in order to further verify their legitimacy. The summary of the data points can be seen in Table 1 below.

Table 2: Summary of Bankfull Stream Geometry Calculated with Four Different Techniques

	DA (sq mi)	A_{bkf} (sqft)	W_{bkf}(ft)	d_{bfk} (ft)	Q_{bkf} (cfs)
Graphical Method	0.05	2.40	6.96	0.498	11.65
Revised Graph	0.05	2.33	5.71	0.469	8.51
JAWRA	0.05	2.03	4.33	0.470	N/A
Survey Data	0.05	2.64	3.00	0.79	N/A

4.2 CHANNEL SLOPE DESIGN

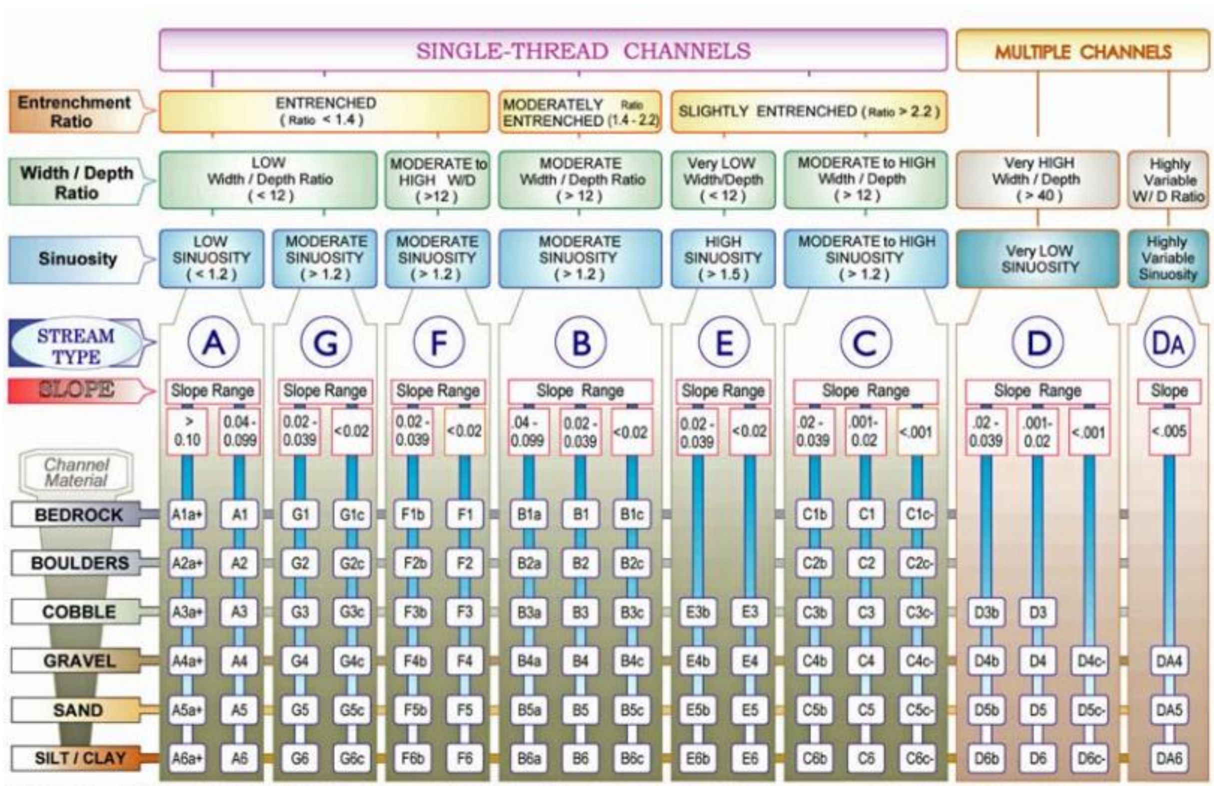
In order to design the channel with the appropriate slope, the Rosgen stream classification was used. This method involves using the streams entrenchment ratio, Width to depth ratio, and sinuosity to find a range of slopes for that given channel. The classification diagram can be seen in Table 3. In the case of the stream being designed, the entrenchment ratio was found to be 8.7. This put the stream in the slightly entrenched category. The width to depth ratio was the next value that was calculated. The channel dimensions produced a ratio of 12.2, putting it into the moderate to high category. The final dimension that was considered was the sinuosity.

The design calculations called for a sinuosity of approximately 1.1. This put it outside of the two ranges that were given for a single thread channel with the previously discussed ratios.

For this reason, the category of moderate to high sinuosity was used as it was closer to the calculated value than that other option.

With these categories defined, the stream was determined to be Type C. Given that the soil was mainly Ramsey Loam, it was given a further classification of C5. This means the appropriate slope range for the channel was 0.01-0.02. Shown below in Table 3 is the Rosgen Classification table.

Table 3: Rosgen Classification Table



4.3 *Channel Bank Slope*

Along with the overall slope of the channel, the slope of the channel banks had to be calculated as well. Given that the soil surrounding the stream was mainly loam, guidelines published by the *Iowa Department of Natural Resources* recommend a slope of 2:1 – 3:1. Because of this, a slope of 2.5:1 was used.

4.4 *Riffle Design*

As stated previously, all natural stream channels consist of consecutive pools and riffles. These two different sections require different dimensions as the pools are deeper and often wider than the riffle sections. For riffles, the channel will simply have the dimensions that were calculated using the regression equations. This is because the regression equations are meant to model a riffle section of channel.

4.5 *Pool Design*

Because the bankfull dimensions were used to model the riffle sections, a different method had to be used to size the pool. There were two methods used in order to find the pool depth. One involved an equation and one involved using common riffle to pool depth ratios for small streams in Tennessee. Equation 3 below related was developed using geomorphic data for streams in Kansas and relates the pool depth to the dimensions of the riffle sections. (Shelley, 2012)

Equation 3: Pool Sizing

$$\frac{D_{pool}}{D_{Riffle}} = 1.5 + 4.5\left(\frac{W_{bkf}}{R_c}\right)$$

Using this equation, the pool depth was calculated to be approximately 1.4-2.2. This value is represented as a range because the radius values vary. This range was then compared to the expected value from the second method. Data from the reference stream database indicated a pool to riffle depth ratio of approximately 2 was reasonable. The ratio of 2 was used since it is based on regional data.

The final consideration for the pool design was the spacing between the pools. A typical textbook value for pool spacing is approximately 5 channel widths, so this design utilized a spacing of 25ft.

5 STREAM PATTERN DESIGN

The pattern of a stream refers to the dimensions when seen in plan view. These dimensions deal with the overall shape of the stream and can vary largely throughout different parts of the stream. A visualization of these dimensions can be seen in Figure 9 below.

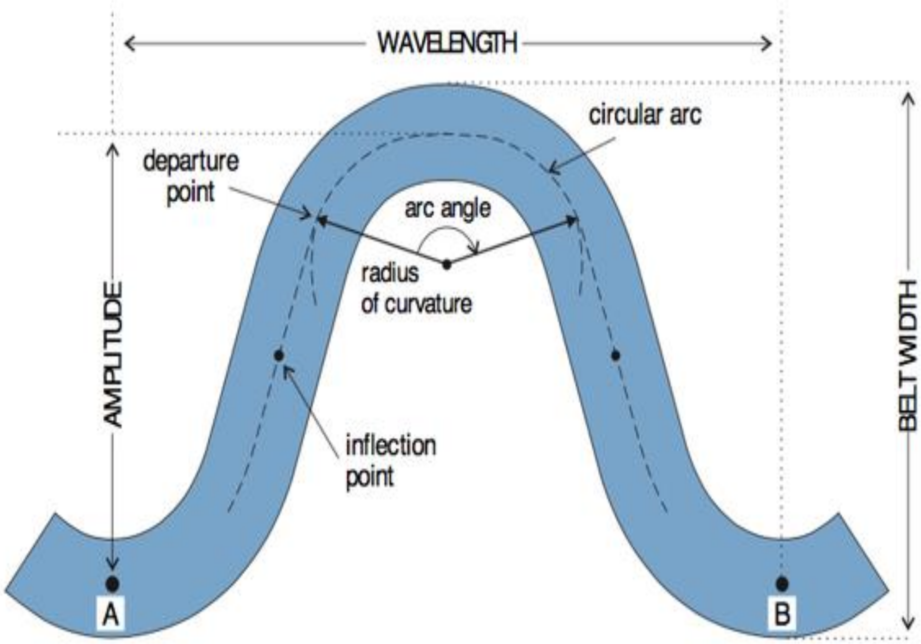


Figure 9: Stream Pattern Dimension Diagram (*NC state*)

5.1 *SINUOSITY*

Sinuosity refers to the ratio of the total channel length to the straight-line length of a stream. For most small streams, this value is somewhere in between 1 and 2. Faster moving streams will have much smaller values, while slower moving ones generally have higher values. This is because channels with faster conveyance tend to erode the banks of curves, which straightens out the stream over time and lowers the length ratio. When considering the sinuosity for the proposed stream design, the first step was to study the sinuosity of the existing stream. Survey data showed that the sinuosity was approximately 1.21.

Due to the steeper slope of the upper reach of the stream, it was decided that there would be no bends in the design for the upper part of the stream. This would lead to a sinuosity for the final design that was less than 1.21. Because of this, a target value of 1.08 was used when laying out the plan form of the stream.

5.2 BELT WIDTH

Belt width refers to the width of the channel from bend to bend, measured from the outer edge of the channel. Unlike sinuosity, a range of values is used for the design process. A range of values is needed because the belt width varies throughout the stream. Certain sections have larger belt widths than others depending on multiple factors such as slope of the channel. For this design, a range of 16-25ft was used. This range was determined using reference points from the original stream.

5.3 RADIUS OF CURVATURE

The radius of curvature for streams is defined as the inner radius of the stream bends. Much like the belt width, a range of values is used for the design. This is because the bend radius changes depending on the velocity of the stream. Faster velocities usually create tighter turns because the current erodes the bank, whereas slower velocities create wider turns. Because the velocity is different throughout the stream, there will be varying radius lengths throughout the stream. For this design, the range was determined to be 8-14ft based on survey points collected from the original stream.

5.4 WAVELENGTH

The final stream pattern parameter that needed to be considered in the design was the wavelength. Wavelength refers to the straight-line length between two separate bends in the stream. This design involved using a wavelength of 6-15ft, which is once again determined from survey data from the original stream. The wavelength will vary throughout the stream based on the values for other parameters such as the radius and belt width.

6 NATURAL STREAM FEATURE DESIGN

6.1 LOG SILLS

As mentioned previously, log sills are a naturally occurring feature that serves multiple purposes in the stream. When designing a stream, these natural features were mimicked in order to have a well-functioning stream. For this design, the main function of the added log sills was to help drop elevation. In order to accomplish this, the logs are laid across the width of the channel. This creates a dam-like structure with the log. An example of how this was useful would be in the watershed profile was dropping too far below the proposed stream profile. In this case, a log sill was used to make a large drop into a pool. This would allow for the stream profile to be dropped substantially without increasing the channel slope to an unreasonable value. Shown below in Figure 10 is an example of a log sill in a stream.

Figure 10: Log Sill in Natural Stream

6.2 VEGETATED SOIL LIFTS

One of the key issues that can occur with streams is bank failure. This can occur when the bank is too steep, not protected enough, or various other reasons. Because of this, it is important to make sure banks are designed to be stable. For this design, vegetated soil lifts were used to mimic the natural look of a stream bank, while also providing support and stability. Vegetated soil lifts consist of staggered layers of soil that are embedded with seeds. When those seeds grow, the roots stretch into the soil and help to strengthen and stabilize the lifts. This provides a durable and natural looking bank for the stream. These lifts were utilized in this design in areas where the water velocity would be high, and erosion could occur. Shown below in Figure 11 is an example of a vegetated soil lift. The locations of these lifts can be seen in Figure 17.

Figure 11: Fresh Installation of a Vegetated Soil Lift

7 STREAM DESIGN WITH CIVIL3D

Civil3D was used to create and layout the natural stream design. This was done because plan sets would be used to eventually construct the stream meaning that the designed needed to have control points and dimensions. In order to accomplish this an elevation surface of the project site needed to be created. Using survey data collected after the destruction of the stream and a contour map of the project site before the violation occurred two surfaces of pre and post-violation could be created. This would provide elevation data which would assist in laying out the stream as well as having the pre-violation surface act as a target to match with the design. Shown below in Figure 12 is the contour map created for the project site.

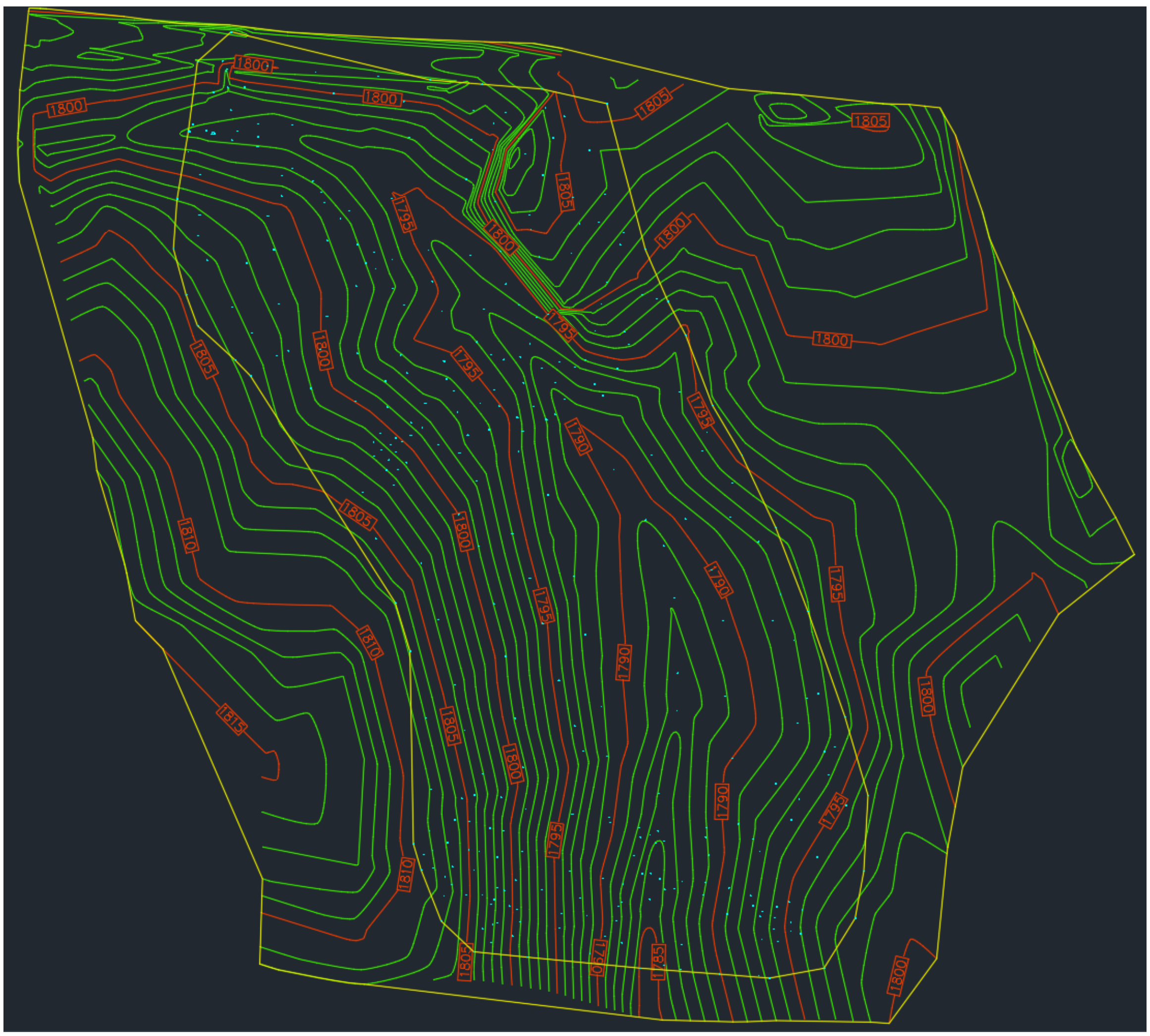


Figure 12: Contour map with a contour interval of 5 feet and elevations relative to a NGVD88 datum.

This would serve as the basis for the rest of the design. In the light blue post-violation survey points it is possible to see the unpermitted dam at the bottom of the site as well as the pile of backfill from the excavation in the middle of the valley.

7.1 LAYING THE ALIGNMENT

In order to create an initial path that the stream would follow an alignment connecting the lowest points of the contour lines through the project site was needed. This was done using the alignment tools on Civil3D and connecting points at the top of each contour line. These points would indicate the bottom of the valley and the path water runoff would naturally take if no stream was present. This alignment would allow the overall slope of the valley and distance to be calculated assisting in the time of concentration calculation. Below in Figure 13 is the drawing with the original alignment laid out.

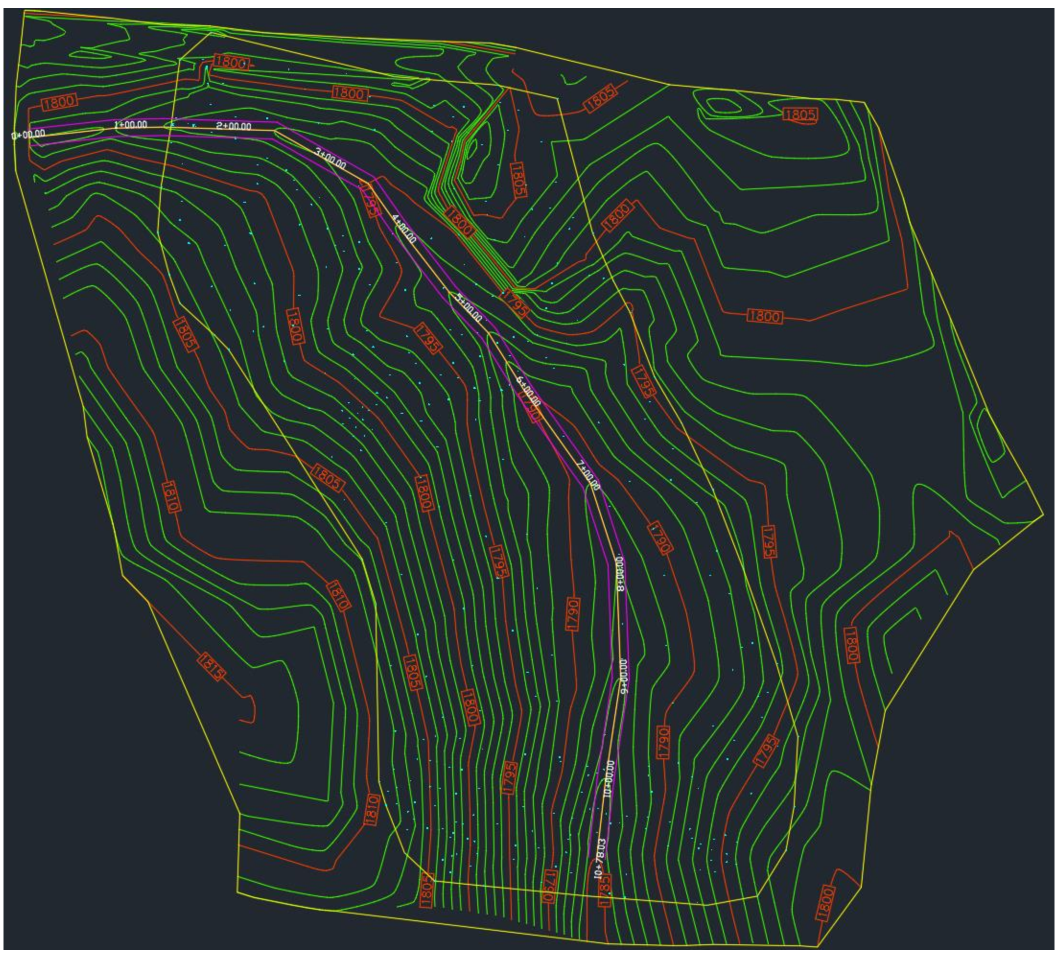


Figure 13: Contour map with a contour interval of 5 feet and elevations relative to a NGVD88 datum. The overall stream alignment is also shown with approximate bankfull limits.

This would also provide an elevation profile that would then be used as the target profile for the stream design. By matching the original profile as closely as possible this would help match the conditions of the original streams and floodplain as well as eliminate any unnecessary excavation or filling in of portions of the site. Shown below in Figure 14 is the elevation profile of the valley before violation in green and after violation in red.

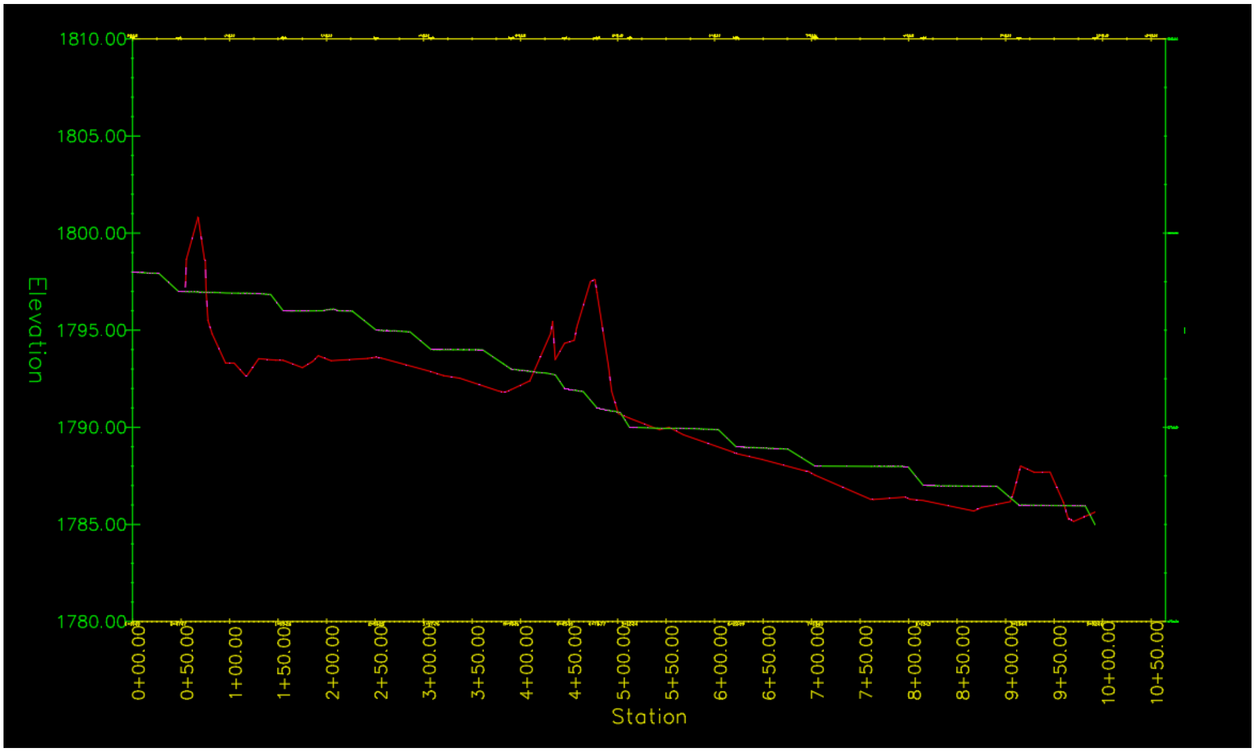


Figure 14: Elevation (in feet) Profile of Channel Thalweg

7.2 DESIGNING THE UPPER REACH

Before laying out the design of the stream it was decided that the stream would be divided into an Upper and Lower Reach. This decision was made as the upper section of the stream has a higher average slope than the lower portion which would require a different approach to the design. Due to these higher slopes, velocities and shear stresses would be high because of this it is not advisable to add meanders to the upper section as they would most likely be eroded away and cause the design to fail. Therefore, for the Upper Reach the designed stream would follow the path of lowest elevation with smooth curves to create a flowing channel with minimal sharp changes in direction to keep it stable. Shown below in Figure 15 is the plan view of the Upper Reach channel.

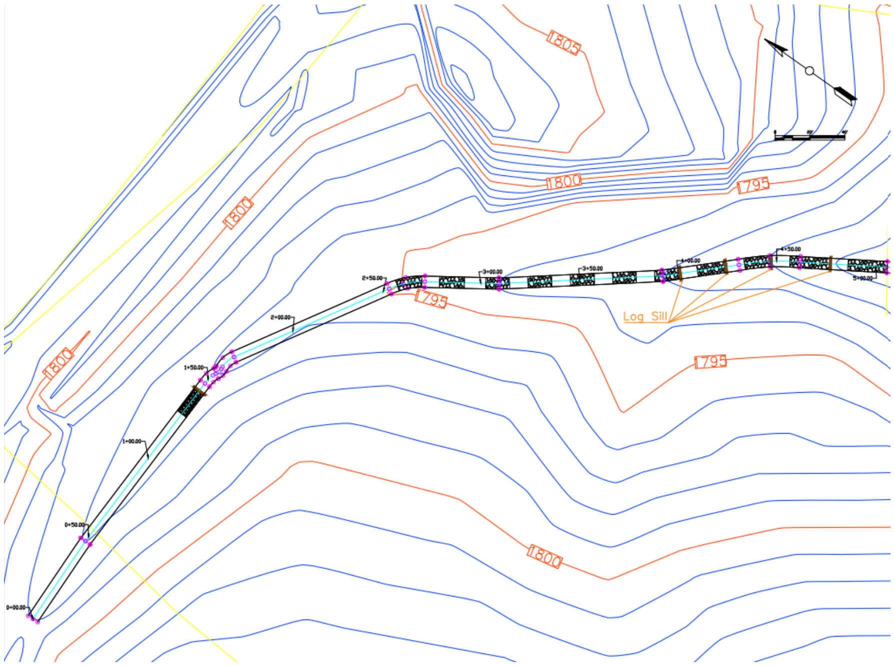


Figure 15: Upper Reach Plan View

With no meanders to shallow the slope of the channel and slow the water down the channel needed to be protected by adding riprap rock to several of the riffle sections to prevent erosion and scouring. These are shown as the rock hatching on the plan view. It was also necessary to slow the water as much as possible in other ways by decreasing the pool spacing and adding several log sills. These log sills help slow the water down as it reaches the end of the upper section and keep the stream's elevation profile closer to the pre-violation profile. Below in Figures 16 & 17 is the elevation profile of the Upper Reach as well as a riffle and pool section.

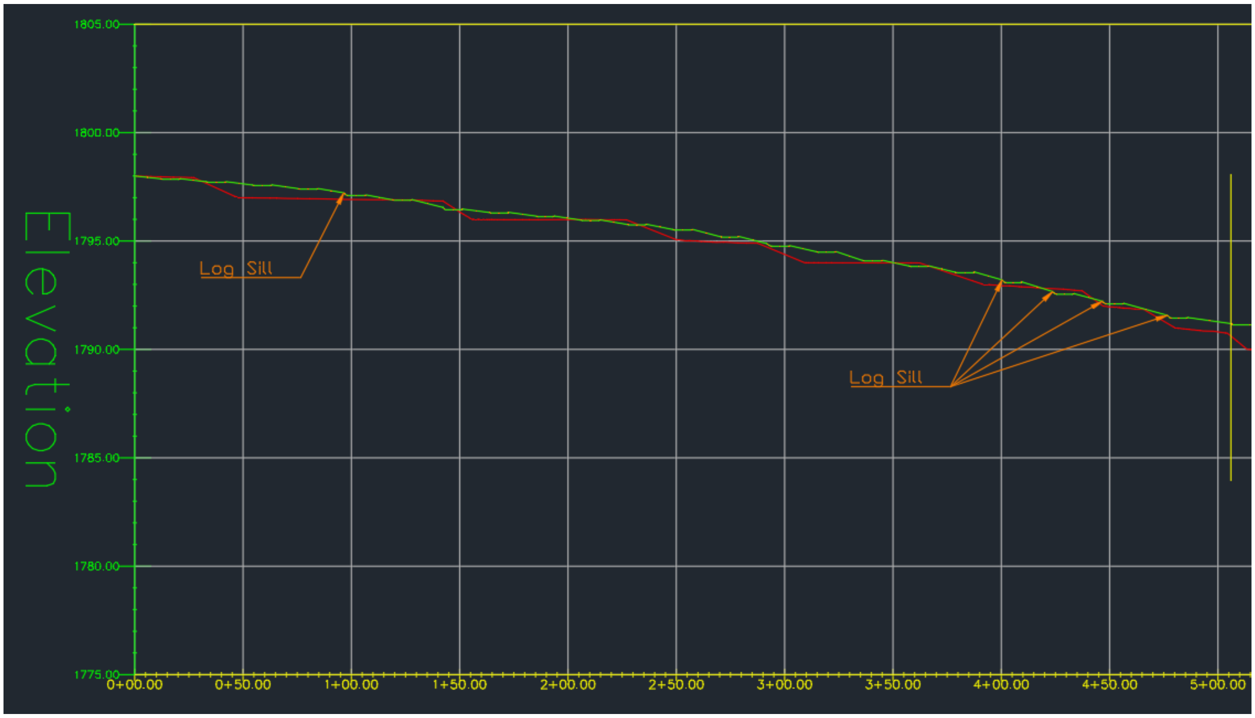


Figure 16: Elevation Profile of Upper Reach. Design stream is shown in green, pre-violation surface is shown in red.

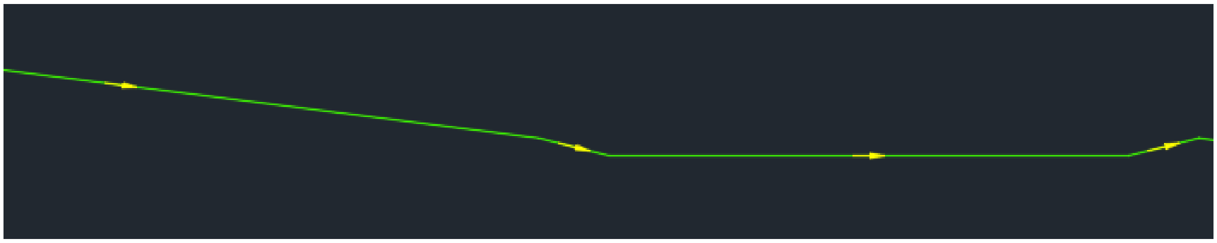


Figure 17: Riffle and Pool Section

7.3 DESIGNING THE LOWER REACH

Given that the Lower Reach had a much shallower slope it could be designed with a meandering stream pattern using the parameters calculated for streams of this size. However, since water would have a higher velocity entering the lower section from the steep upper section it was important to sufficiently slow the water before bending the stream channel. This was accomplished by starting the lower section off with a long and deep pool to handle the velocity of the water followed by a straight section before starting in the meanders. Shown in Figure 18 is the beginning of the lower section.

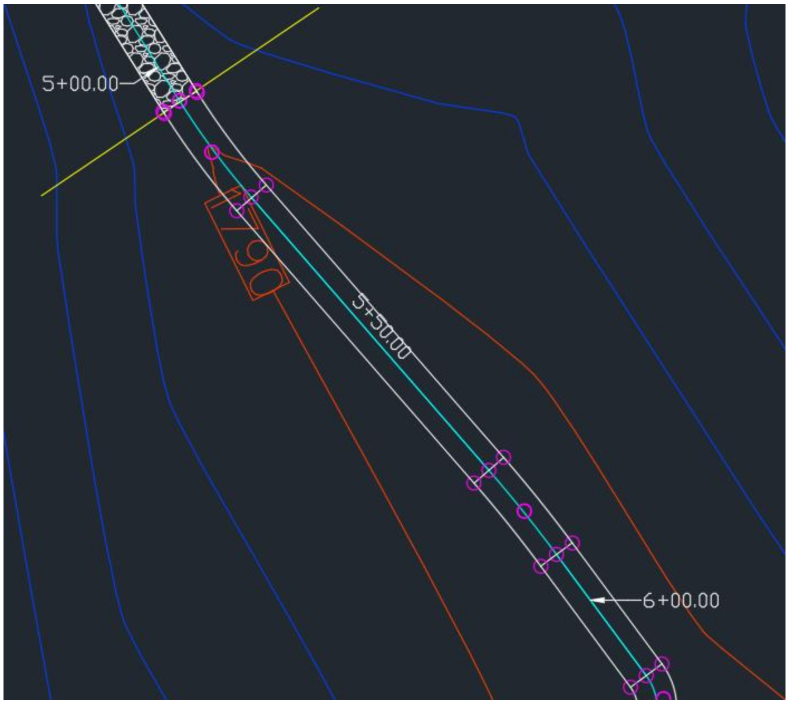


Figure 18: Lower Reach Beginning

For the meander pattern it is important to start off with short and tight bends as the water still has relatively high velocity. This is also justified by the range of values found for bend radius, wavelength, and belt width. The stream would start with tight bends before widening as the stream moves further down the lower section and the velocities decrease. Laying out the bends in Civil3D is an iterative process requiring the use of the alignment geometry editing tools to create multiple versions of the bends until a design is created that looks natural and matches the parameters set. This is difficult as these tools are meant to be used to layout roadways not the complex bends of a natural stream. In order to construct these bends in the installation process points that are tangent to the channel before and after the bend must be used to lay out the bend. Therefore, each bend must be made of one continuous curve while maintaining a natural look avoiding uniformity. Shown below in Figure 19 is the plan view of the Lower Reach.

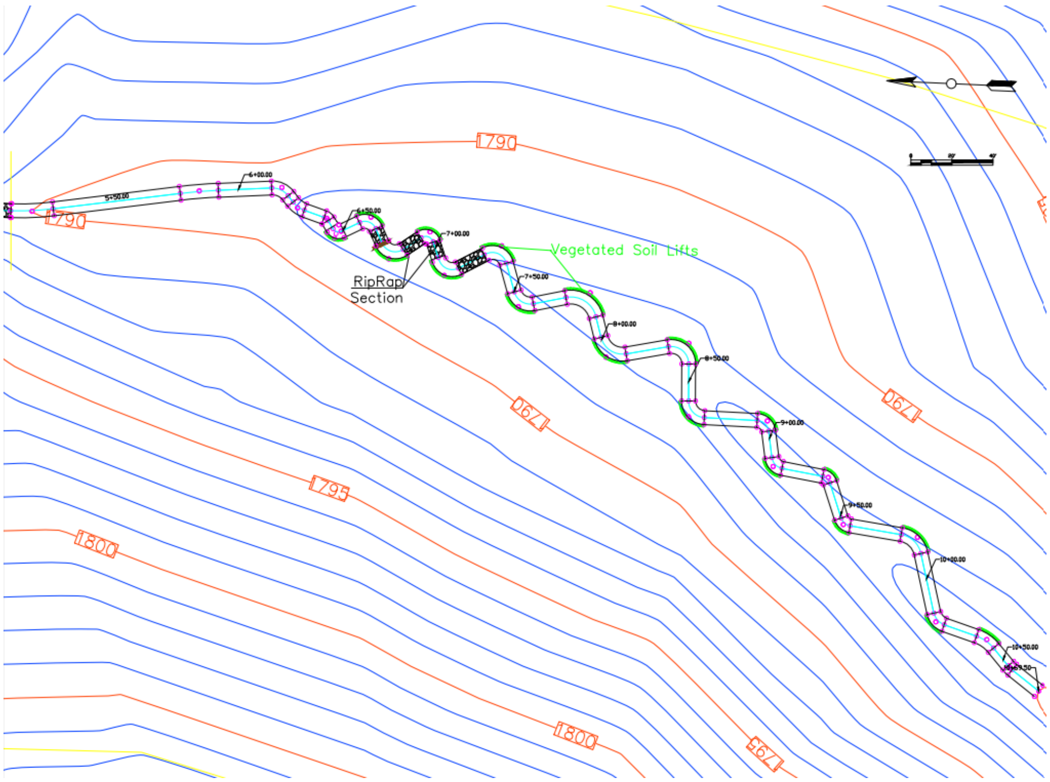


Figure 19: Lower Reach Plan View

Called out in the plan view is the use of vegetated soil lifts to add protection to the bank of the bends. These would normally be installed only on bends that may deal with faster water and high shear stress but to be conservative in the design it was decided that they would be required on every bend. Also visible is the meander pattern lengthening as the stream progresses down the section.

Pools in a meandering stream naturally occur in the bends of the channel so the spacing of these pools vary with the size and frequency of these bends. This also presents a unique challenge in laying out the pools in the elevation profile as the station of the beginning of each pool must be measured out on the profile in order to lay them out properly. These pools are created using the profile geometry editing tools to create points of vertical intersection or PVIs to create an outline of the pool. Below in Figure 20 is the elevation profile of the Lower Reach of stream once again the pre-violation surface is in red while the designed channel is in green.

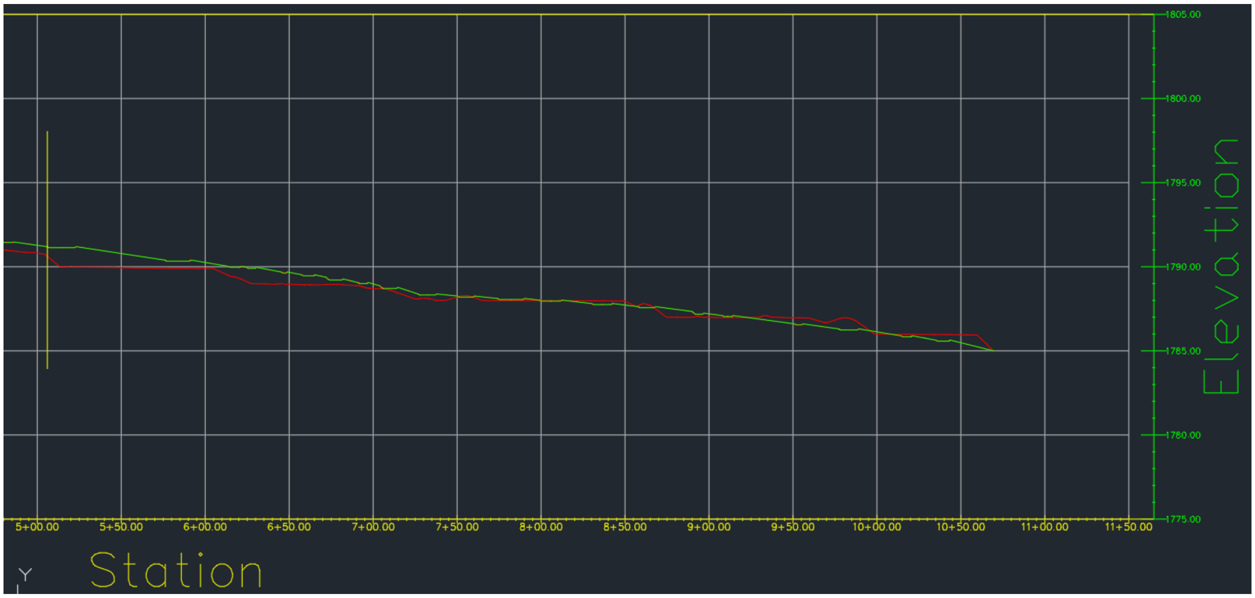


Figure 20: Elevation Profile of Lower Reach. The designed stream is shown in green, pre-violation surface is shown in red.

8 HYDRAULIC EVALUATION WITH HEC-RAS

Now that a design for the stream was completed it needed to be tested and evaluated to ensure the stream would work properly and be able to withstand high rainfall events. The main priority for this evaluation is to calculate what the highest shear stress is on the stream and the water level during a rainfall event comparable to the flows used to size the channel. As the bankfull dimensions are calculated based off the flow from a storm with a 1.5-year reoccurrence rate it was decided that a storm with a 2-year reoccurrence rate would be used for the baseline evaluation. The stream's ability to handle a major rainfall event would also be tested by running a 100-year storm.

Using the same SSA model of the watershed, the peak flows for both the 2-year and 100-year storms were found. Then the cross-sectional geometry of the stream is laid out in HEC-RAS using the Hydraulic Design Uniform Flow simulation. This allows for different storms to be ran through the representative cross-section to determine the water level. Shown below in Figure 21 is the water level graph for a 2-year storm.

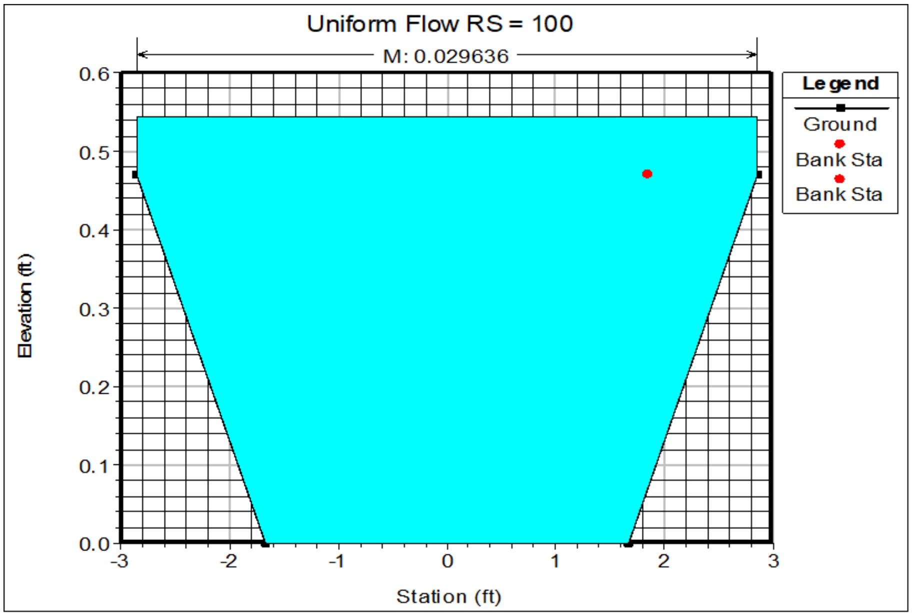


Figure 21: 2-year Storm Simulation

Given that the dimensions of the channel were calculated based off a storm of 1.5-year reoccurrence overtopping the banks by a small amount during a 2-year event is consistent with a good channel performance.

From this result the size of the riprap used in the channel would be calculated. It is important to accurately size the rock in the stream to ensure that the rock will not be washed away in typical rainfall events while also not being oversized to the point of impeding flow through the stream and causing flooding. Using Shields Diagram, a relationship can be formed between the shear stress on a channel and the size of the rip rap in the stream. The following Equation 4 relates sediment size, d, to a dimensionless Shields Parameter, Ψc*.

Equation 4: Shield's Formula

$$\Psi_c * = \frac{load}{strength} = \frac{\tau_c d^2}{(\rho_s - \rho_w) g d^3},$$

Equation 5 below then allows the shear stress to be related to the water level resulting from the 2-year storm and the slope of the stream, I.

Equation 5: Shear Stress

$$\tau = \rho_w g h I,$$

By inputting both equations into an Excel spreadsheet the size of the rip rap could be found by using the Goal Seek function to find an iterative solution. Shown below in Table 4 the Excel spreadsheet and the size of the biggest 50% of the rip rap, d50.

Q cfs	13.285	τ_c lb/ft^2	1.213
K	1.486	τ lb/ft^2	1.190
A ft^2	2.706		
R ft	0.422		
P ft	6.405		
n	0.031		
b ft	3.350		
S	0.034		
z ft	2.5		
y $\%$	0.567		
d_{50} ft	0.227		
d_{50} in	2.719		

Table 4: Rip Rap Sizing Spreadsheet

This gives a rip rap size of 2.72 inches for the top 50% of the rock as there will still be a gradient of sizes smaller than this to create a natural pattern. To be conservative a size of 3 inches will be used in construction of the stream.

The final step of the hydraulic analysis was to evaluate how much flooding would occur during a major rainfall event. For this a 100-year storm was used to simulate worst possible conditions. This event was once again run through the HEC-RAS cross-sectional model to determine the water level during a peak flow of 78.38 cfs. The cross-sectional water level diagram is shown below in Figure 22.

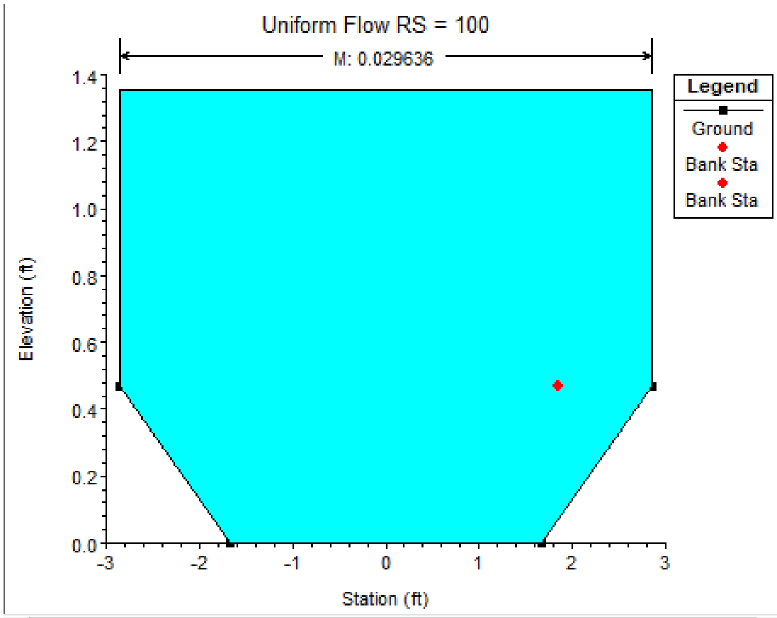


Figure 22: 100-year Storm Simulation

As shown in the graph the channel would experience just under 1 ft of flooding beyond its banks which can easily be handled by the floodplain. Overall, the stream performed well in the analysis by keeping shear stresses relatively low and flooding to a minimum.

9 CONCLUSIONS

A design was created that utilized bankfull dimensions and natural stream features to create a replacement design for a degraded stream. The plan view and elevation profile of the final design is located in Appendix B and D. After completing multiple design iterations and analyzing the final design using HEC-RAS, the design was completed. Overall, the design was meant to be conservative in order to ensure the stream would function properly and not experience any failures. Certain design choices such as sizing up the bed rock and using a wider stream channel were just a few of the decisions made in order to ensure the stream could endure normal conditions. The software analysis verifies the validity of these choices and shows that the design would function properly. A summary of the chosen dimensions can be seen below in Table 5.

Table 5: Summary of Design Parameters

Stream Pattern			
Sinuosity	**Wavelength (ft)**	**Belt Width (ft)**	**Radius (ft)**
1.08	6-15	16-25	8-14

Channel Dimensions				
$Depth_{pool}$ (ft)	**$Depth_{riffle}$ (ft)**	**Width (ft)**	**Bank slope (ft)**	**Spacing (ft)**
0.97	0.47	5.7	2.5:1	~25

References

Bengtson, H. (n.d.). CE-089 Manning Equation for Open Channels. *PDHstar*, 10-13.

Bieger, K., Rathjens, H., Allen, P. M., & Arnold, J. G. (2014). Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States. *Journal of the American Water Resource Assoication*, 2-13.

Harman, W. A. (2011). *Natural Channel Design Review Checklist.* Annapolis: US Fish and Wildlife Service.

Jennings Environmental, LLC. (2017). *Tennessee Reference Stream Morphology and Large Woody Debris Assessment.* Nashville: Tennesse Department of Environment and Conservation.

Jennings, G., & Harman, W. (1999, June 1). *Natural Stream Processes*. Retrieved from NC State Extention: https://content.ces.ncsu.edu/natural-stream-processes#:~:text=Streams%20have%20left%20and%20right,meanders%2C%20floodplains%2C%20and%20terraces

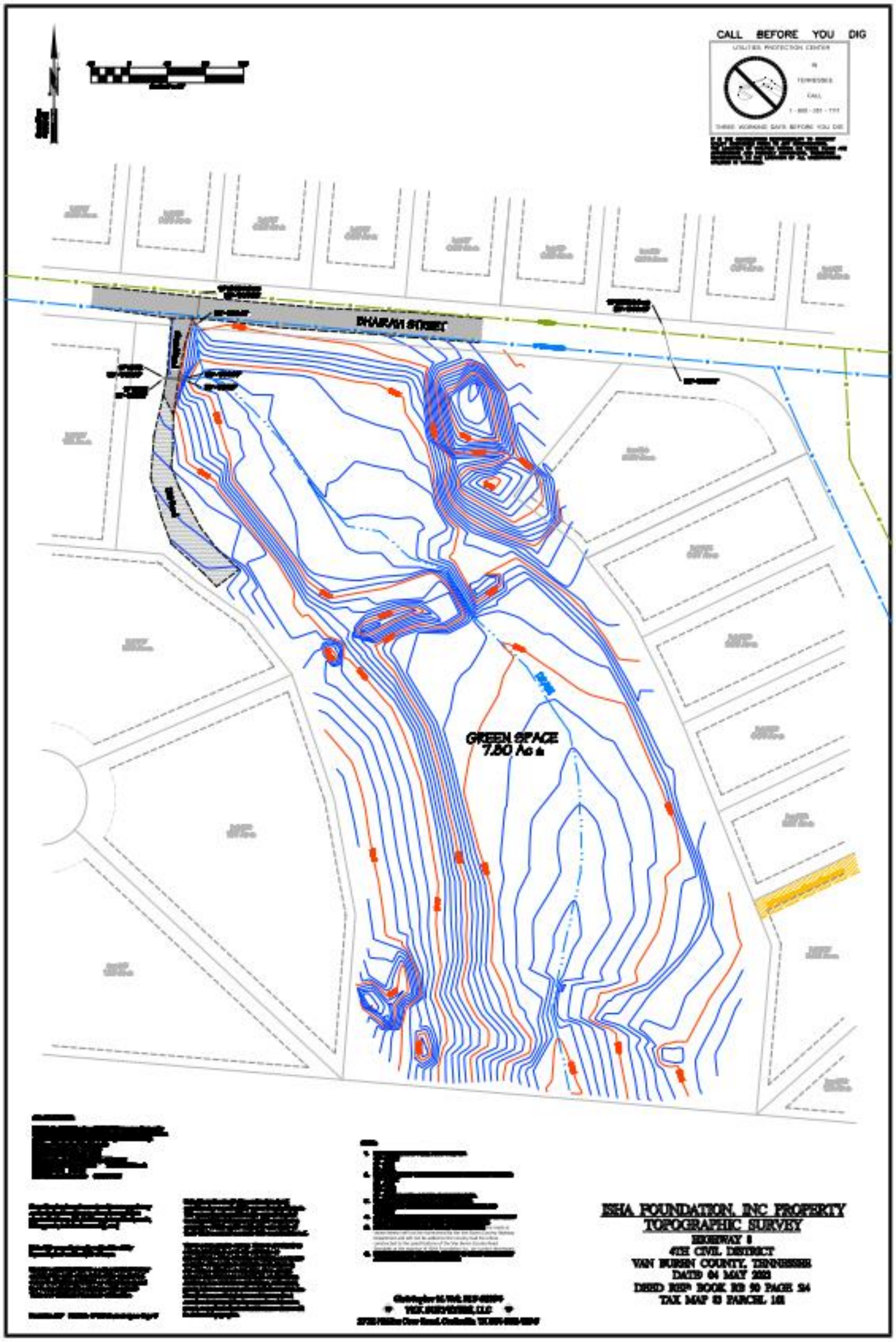
Shelley, J. E. (2023, feburary 28). *Geomorphic Equations and Methods for Natural Channel*. Retrieved from https://core.ac.uk/download/pdf/213398577.pdf

Tennessee State Government. (2017). *Morphological Stream Design and Assessment Tools for the Interior Plateau (Ecoregion 71) of Tennessee.* Nashville: Tennesse State Government.

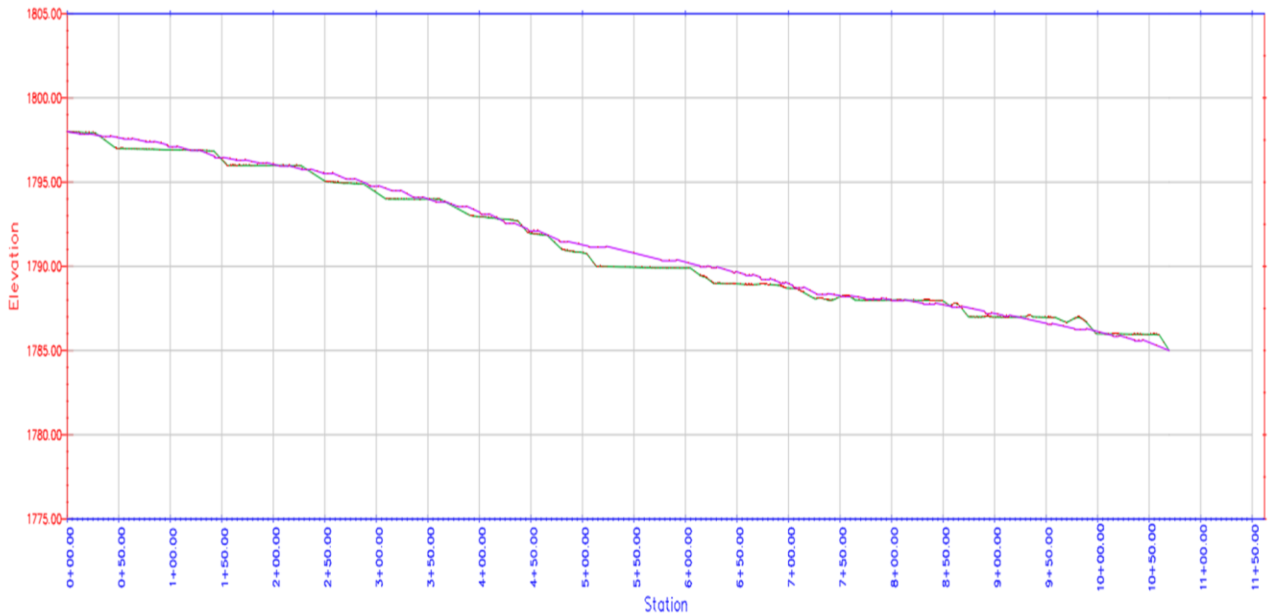
United States Department of Agriculture. (1986). Urban Hydrology for Small Watersheds. *Conservation Engineering Division Technical Release*, 30-40.

APPENDIX

APPENDIX A


CALL BEFORE YOU DIG
GREEN SPACE
ISHA FOUNDATION, INC PROPERTY
TOPOGRAPHIC SURVEY
4TH CIVIL DISTRICT
VAN BUREN COUNTY, TENNESSEE

APPENDIX B



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1790.00
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1775.00
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1+50.00
2+00.00
2+50.00
3+00.00
3+50.00
4+00.00
4+50.00
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6+50.00
7+00.00
7+50.00
8+00.00
8+50.00
9+00.00
9+50.00
10+00.00
10+50.00
11+00.00
11+50.00
Station

APPENDIX C

Cookeville Stream Restoration

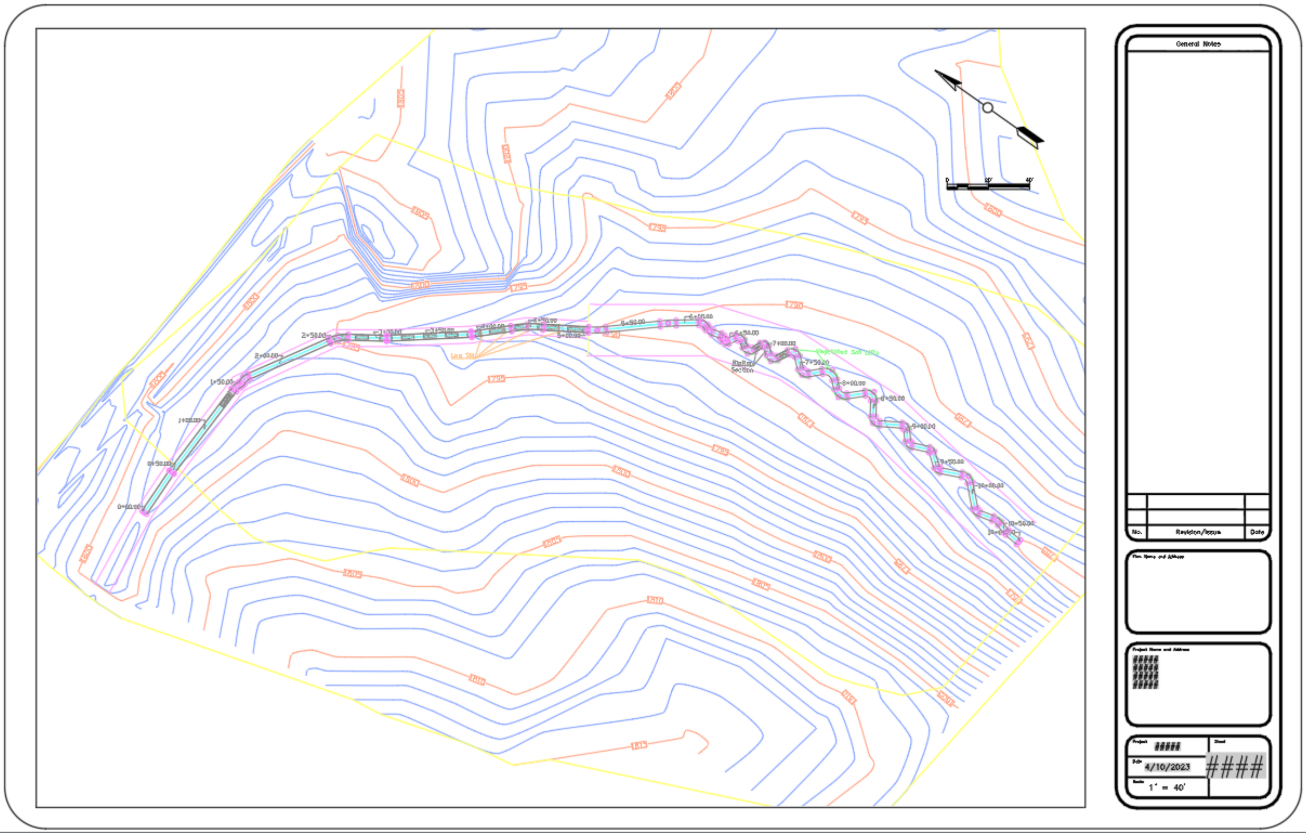
Brayden Wicks & Michael DeMeyer
Advisor: Dr. Hill

Project Start: Fri, 9/23/2022

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Planning				
Study post-development site plans to understand development issues	Michael & Brayden	100%	9/23/22	9/24/22
Review violation documents and identify issues	Michael & Brayden	100%	9/24/22	9/25/22
Create list of tasks pertaining to the project	Michael & Brayden	100%	9/25/22	10/2/22
Develop list of deliverables based on provided documents	Michael & Brayden	100%	9/25/22	9/25/22
Study stream geometry journal from JAWRA	Michael & Brayden	100%	9/23/22	9/23/22
Define the scope of the project	Michael & Brayden	100%	9/25/22	9/25/22
Design				
Review provided auto-cad drawing and use it to create a topo-map	Brayden	100%	10/1/22	10/24/22
Begin calculating channel dimensions for stream	Michael	100%	2/1/23	2/15/23
Design geometry for bends in the stream	Brayden	100%	2/15/23	3/17/23
Determine Environmental Control (rip-rap, geotextiles, etc.)	Brayden	100%	2/16/23	2/18/23
Create HEC-RAS model to analyze flow throw the channel	Brayden	100%	3/17/23	3/21/23
Begin calculations for flood plain design	Brayden	100%	3/21/23	3/28/23
Design and test flood plain using HEC-HMS	Brayden	100%	4/7/23	4/21/23
Report				
Create concetual outline of topics that should be included	Michael & Brayden	100%	1/11/23	1/14/23
Use provided template to start inserting topics into report	Michael	100%	3/10/23	3/14/23
Format template and create first draft	Brayden	100%	3/20/23	3/26/23
Review draft and add data and findings	Michael & Brayden	100%	3/26/23	3/29/23
Finalize rough draft to prepare for final changes	Brayden	100%	3/29/23	4/17/23
Create final draft that includes data suggestions for solving issue	Michael & Brayden	100%	4/19/23	4/22/23
Present report for review	Michael & Brayden	100%	4/22/23	4/25/23
Presentation	Michael			
Formulate ideas for presentation style	Michael	100%	3/20/23	3/22/23
Create outline for presentation	Michael	100%	3/24/23	3/31/23
Create rough draft for presentation	Michael	100%	3/31/23	4/5/23
Edit presentation and polish design, keeping slides informative but concise	Michael & Brayden	100%	4/5/23	4/10/23
Creat final draft for presentation	Michael & Brayden	100%	4/12/23	4/17/23
Practicing giving presentation to prepare for final presentation	Michael & Brayden	100%	4/18/23	4/20/23
Give final presentation for review	Michael & Brayden	100%	4/21/23	4/21/23

APPENDIX D



APPENDIX E

Design Factor	Page number, or reason not applicable
Public health safety, and welfare	Section 2.1
Global	N/A: Being that this is a small stream, the impacts are limited to a local region.
Cultural	N/A: The small scale of this project means it does not have any notable cultural impacts.
Social	Section 2.1
Environmental	Section 2.1
Economic	N/A: The economic factors were outside of the scope of this project. This project solely focused on the design of the stream as that was what was needed for the corrective action plan.
Ethical & Professional	Section 2.1
Reference for Standards	Section 2.1

APPENDIX F

StreamStats Report Cookeville Stream

Region ID: TN
Workspace ID: TN20230119170159134000
Clicked Point (Latitude, Longitude): 35.56545, -85.55307
Time: 2023-01-19 11:02:36 -0600

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CLIMFAC2YR	Two-year climate factor from Lichy and Karlinger (1990)	2.338	dimensionless
CONTDA	Area that contributes flow to a point on a stream	0.05	square miles
CSL10_85	Change in elevation divided by length between points 10 and 85 percent of distance along main channel to basin divide - main channel method not known	90.81	feet per mi
DRNAREA	Area that drains to a point on a stream	0.05	square miles
HA1PCT	Percent of area within Hydrologic Area 1	100	percent
HA2PCT	Percent of area within Hydrologic Area 2	0	percent
HA3PCT	Percent of area within Hydrologic Area 3	0	percent
HA4PCT	Percent of area within Hydrologic Area 4	0	percent
PERMGTE2IN	Percent of area underlain by soils with permeability greater than or equal to 2 inches per hour	9	percent
RECESS	Number of days required for streamflow to recede one order of magnitude when hydrograph is plotted on logarithmic scale	32	days per log cycle
SOILPERM	Average Soil Permeability	3.31	inches per hour
TNCLFACT2	Tennessee climate factor, 2-year interval	2.338	dimensionless
TNSOILFAC	Tennessee soil factor, percentage of area underlain by a soil permeability greater than or equal to 2 inches per hour	9	percent