TSEGI WASH DESIGN REPORT

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Acknowledgements

The Tsegi Wash Group would like to thank Mark Lamer, Renee Benally, and the Western Navajo Agency of the Bureau of Indian Affairs for their guidance and support with this project.

1.0 Project Description

1.1 Purpose

The purpose of this project is to determine the feasibility of a stabilization method to minimize soil erosion and stream scour of a channel headcut. A headcut is an abrupt vertical drop in the channel, resembling a waterfall. The following image is a visual representation of what’s occurring at the site.

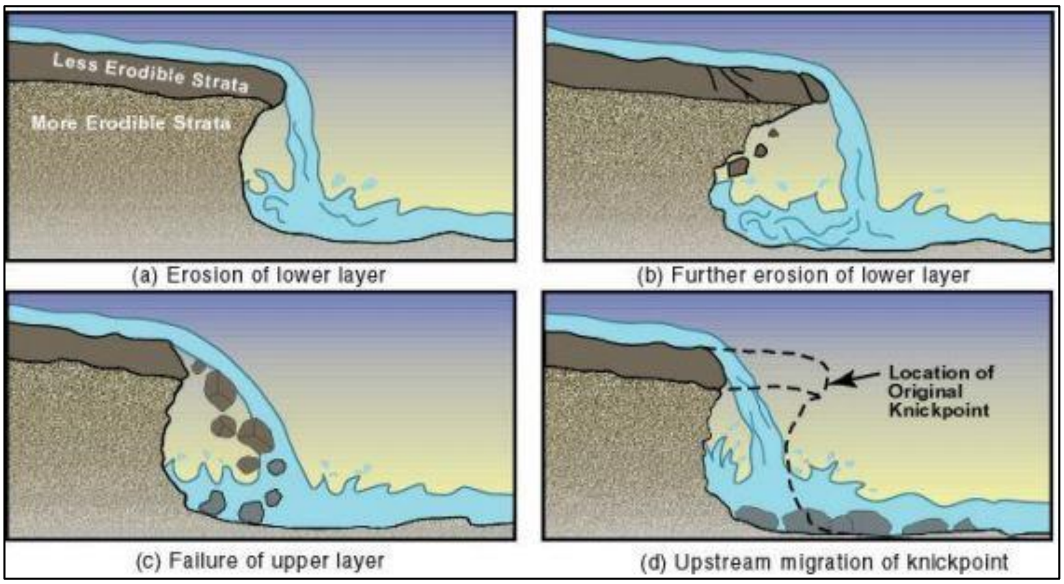

Figure 1. Erosion of a Headcut (Iowa DOT)

As seen in the figure above, during the rainy season when water is flowing a plunge pool is formed at the bottom of the headcut, eroding the bottom layer causing the top layer to fail. As a result, the headcut continues to migrate upstream.

The existing site consists of a 23-foot high by 30 foot wide headcut, composed of sandstone. The site location’s coordinates are 36°40'04.4"N 110°48'52.2"W. The stabilization alternative chosen will act as a conceptual design and will not result in construction plans.

1.2 Project Understanding

Tsegi Wash is located in Nitsin Canyon, west of the Navajo National Monument. Navajo National Monument is divided into three units, the designated unit for this project will be the Inscription House unit, which is comprised of 40 acres. Inscription House has been closed to the public since 1968 to preserve the site. About 50 years ago the canyon consisted of farmland and housing structures, but around 40 years ago the headcut began spreading along the canyon reducing the available farmland. The current land user inside the canyon owns the cattle contributing to the soil erosion problem due to their grazing.

As the cattle graze they uproot the grass, removing one of the sources of stabilization for the canyon.

The lack of soil stability near the site may be due to the cattle grazing and lowering of the water table. The vegetation at the site includes cottonwood trees, willow trees, and shrubbery. The bed material at the headcut is composed of a sandy soil. Currently, the only source of stabilization at the headcut comes from the roots of the nearby cottonwood trees. The headcut is located a quarter mile upstream from the point water source at the canyon. The canyon drains 30 miles downstream into Lake Powell. Below is an aerial view of the canyon where the site is located and a closer overhead view of the headcut.

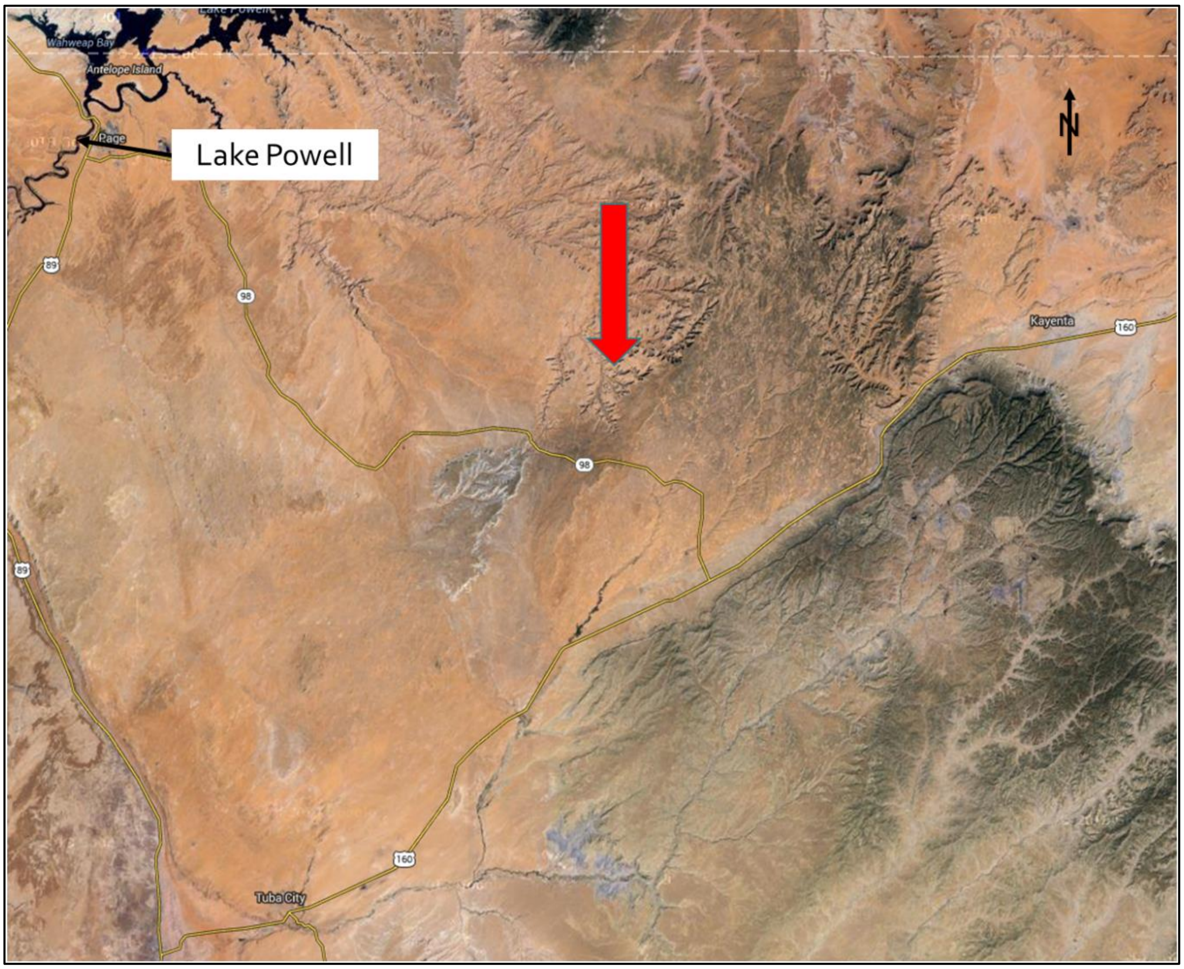

Figure 2. Aerial View of Nitsin Canyon (Google Maps)

As seen in Figure 2, the site location is indicated by the arrow, it is west of Kayenta.

Figure 3. Site Location (Google Maps)

The image in Figure 3 presents a close up view of the headcut located beneath the tree denoted by the arrow.

2.0 Design Alternatives

The following section details the three types of design alternatives best suited for the project.

2.1 Live Vegetation

Live vegetation is the process of planting suitable vegetation along the shorelines of a channel to prevent erosion. The plant roots provide a base of stabilization for the soil. Plants that haven't established deep roots can be washed away during high velocity flows. Possible native plants of consideration for the project are: Russian olives, cottonwood, and/or willow trees.

2.2 Bioengineering

Bioengineering is the combined use of live vegetation with structural materials to provide stream bank stabilization and erosion control. The practice applies engineering techniques while maintaining the natural environment around the project site. An example of bioengineering would be a geotextile system that combines layers of encased vegetation to create successive layers to reduce flow.

2.3 Hard Armoring

Hard armoring is the technical placement of various sized rocks along a channel slope or streamline, reducing the flow energy of the stream and stabilizing the headcut. An example of hard armoring is a rock chute spillway that prevents erosion at the lower layer of the headcut, as can be seen in the image below.

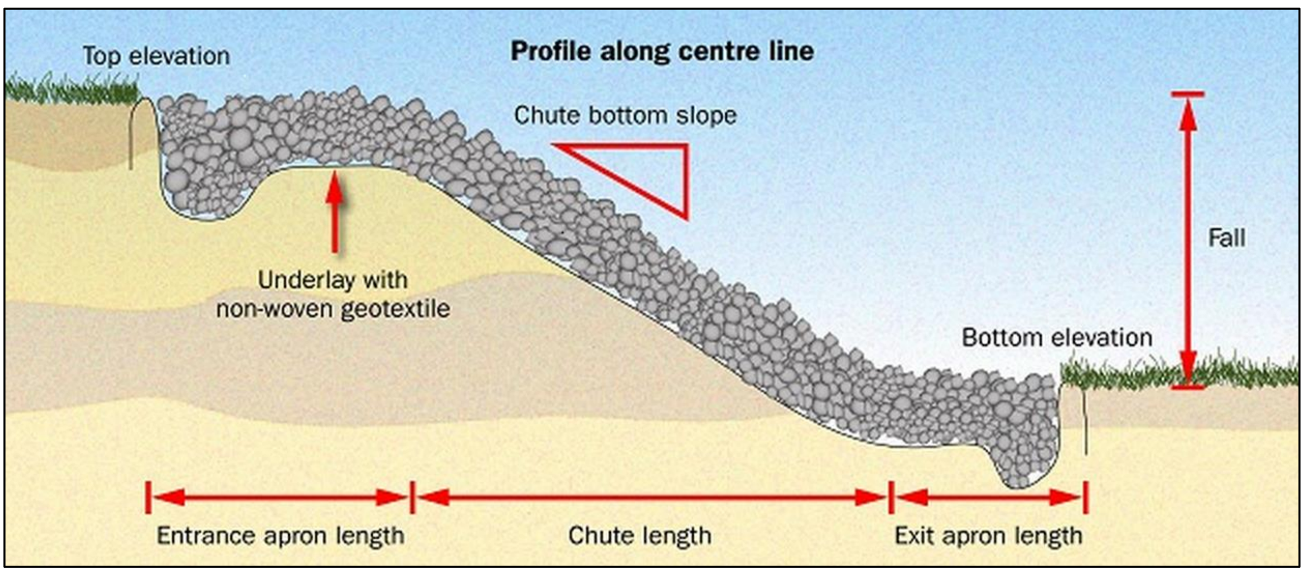

Figure 4. Rock Chute Spillway (Ontario Ministry of Agriculture and Food)

Rocks line the slope to decrease the velocity of the flow and decrease erosion at the headcut.

3.0 Testing/Analysis

3.1 Manning's Coefficient

After assessing the bed material of the channel during the site visit a Manning's Coefficient of 0.0235 was selected using the table below.

Table 1. Manning's Coefficient (Engineering Toolbox)

Earth, smooth	0.018
Earth channel - clean	0.022
Earth channel - gravelly	0.025
Earth channel - weedy	0.030
Earth channel - stony, cobbles	0.035

The final factor was determined by averaging coefficients for "Earth channel – clean" and "Earth channel – gravelly" as the reach mainly consists of sandy soil with intermittent rocks spaced throughout. The image below shows the composition of the channel bed material at the time of the site visit.

Figure 5. Bed Material (Tsegi Wash Group)

As seen in the figure above, the channel composition is mostly soil with tree litter and relatively little shrubbery is present.

3.2 Watershed Delineation

A watershed delineation of the site was performed using United States Geological Survey (USGS) StreamStats program. USGS StreamStats for Arizona was developed by the U.S. Dept. of the Interior, Bureau of Reclamation, Navajo County, U.S. Forest Service and various other reputable government entities, it is widely used by engineers to map floodplains and aid in the design of bridges and culverts. The basic concept of watershed delineation is to start at a point source, which for this project was the location of the headcut. Then from each side of the stream a line is formed working its way to the highest point in the area by crossing contour lines perpendicularly until both lines connect forming the area. Figure 6 on the following page displays the final delineation.

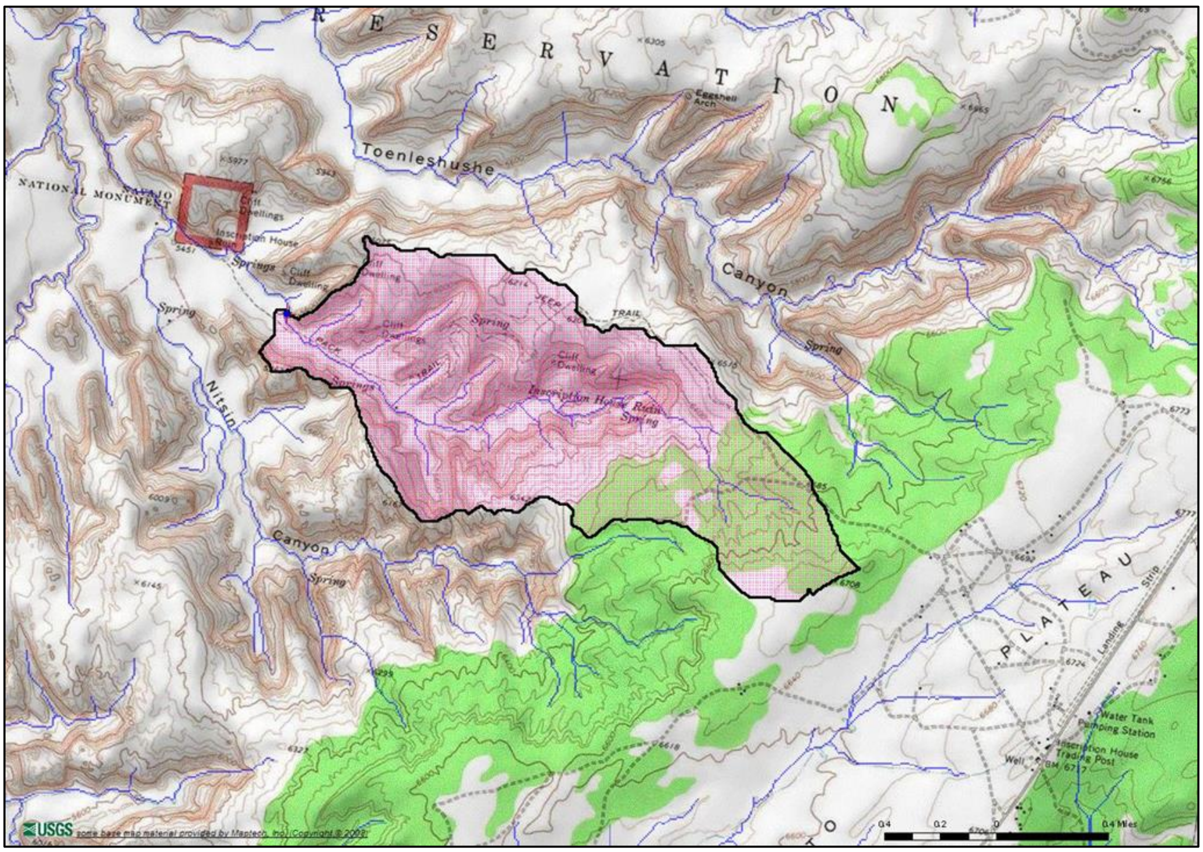

Figure 6. Watershed Delineation (USGS StreamStats)

The area outlined in black is the delineated watershed. The watershed was delineated from the point source located at the headcut, in the image above. The final watershed encompasses 1.32 square miles with an average basin elevation of 6080 ft.

3.3 Survey Data

The raw survey data was taken from the survey of the headcut during the second site visit. The headcut was surveyed using a total station in which 207 points were collected and uploaded as a Comma Separated Value(CSV) file into excel containing the point, northing, easting, and elevation data, which can be seen in Appendix B.

3.4 AutoCAD

Using the CSV file with all the survey data, the points were inserted into AutoCAD and a topographic map of the area was created, which can be seen in Appendix C. An alignment was drawn along the channel and cross sections were created. The cross sections can be viewed in Appendix C. A channel profile was also formed and is attached in Appendix D. An excel spreadsheet containing the station, elevation, and distance to the right and left bank for each cross section was created to be inputted into the Hydrologic Engineering Centers River Analysis System (HEC-RAS) software, which can be seen in Appendix E .

3.5 Flow

The flow of the channel was obtained using National Streamflow Statistics (NSS). The region where the headcut is located was selected and the watershed area and average elevation were entered into the program. The headcut is located in Four Corners Region 8, which was determined from the hydrologic flood regions for Arizona map. The watershed area of 1.32 square miles and mean elevation of 6,080 feet were obtained from the basin characteristics determined in USGS StreamStats. Flow results can be seen in the image on the following page.

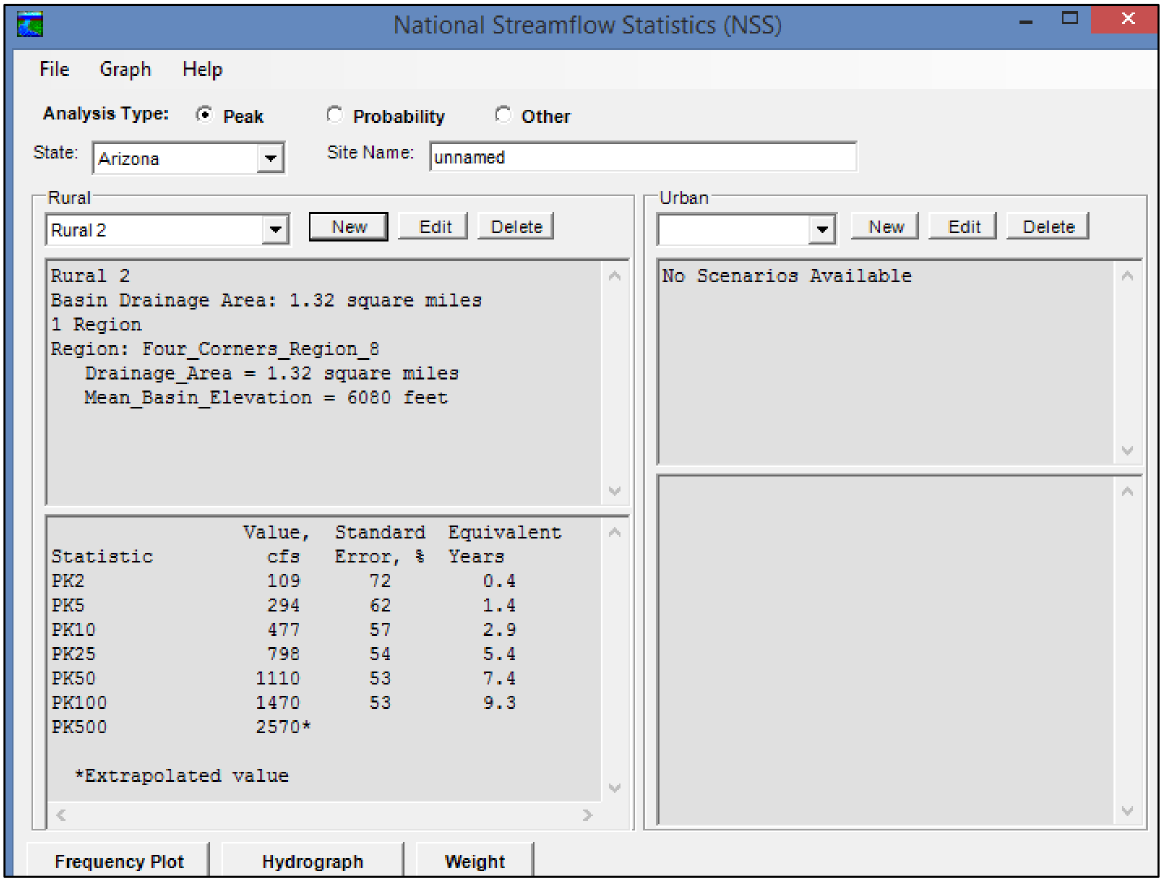

Figure 7. NSS Results (NSS)

As seen in Figure 7, the results for 10, 25, and 100-year flood flow were 477 cubic feet per second (cfs), 798 cfs, and 1470 cfs. Flow results were verified using regression equations for Arizona created by the USGS, as seen in Figure 8.

Regression equation	Average standard error of prediction, in percent	Equivalent years of record
Region 8 -108 stations		
$Q_2 = 598AREA^{0.501}(ELEV/1,000)^{-1.02}$	72	0.37
$Q_5 = 2,620AREA^{0.449}(ELEV/1,000)^{-1.28}$	62	1.35
$Q_{10} = 5,310AREA^{0.425}(ELEV/1,000)^{-1.40}$	57	2.88
$Q_{25} = 10,500AREA^{0.403}(ELEV/1,000)^{-1.49}$	54	5.45
$Q_{50} = 16,000AREA^{0.390}(ELEV/1,000)^{-1.54}$	53	7.45
$Q_{100} = 23,300AREA^{0.377}(ELEV/1,000)^{-1.59}$	53	9.28

Figure 8. USGS Arizona Regression Equations (USGS National Flood Frequency Program)

The standard error for the 10, 25 and 100-year flood flows is 57, 54 and 53 percent, respectively.

3.6 HEC-RAS

An analysis of the current conditions of the channel was run using the HEC-RAS program for a 10, 25, and 100- year flood flow. A reach was traced using the data from AutoCAD. The reach totaled in length 544 ft. Twenty-one cross sections were created along the reach beginning upstream with intervals of 50ft. As the cross sections neared the headcut intervals decreased to 25, 15, 10, and 5 feet both above and below the headcut to obtain a comprehensive analysis of energy change at the headcut. Below is an image taken from HEC-RAS of the complete reach and cross sections.

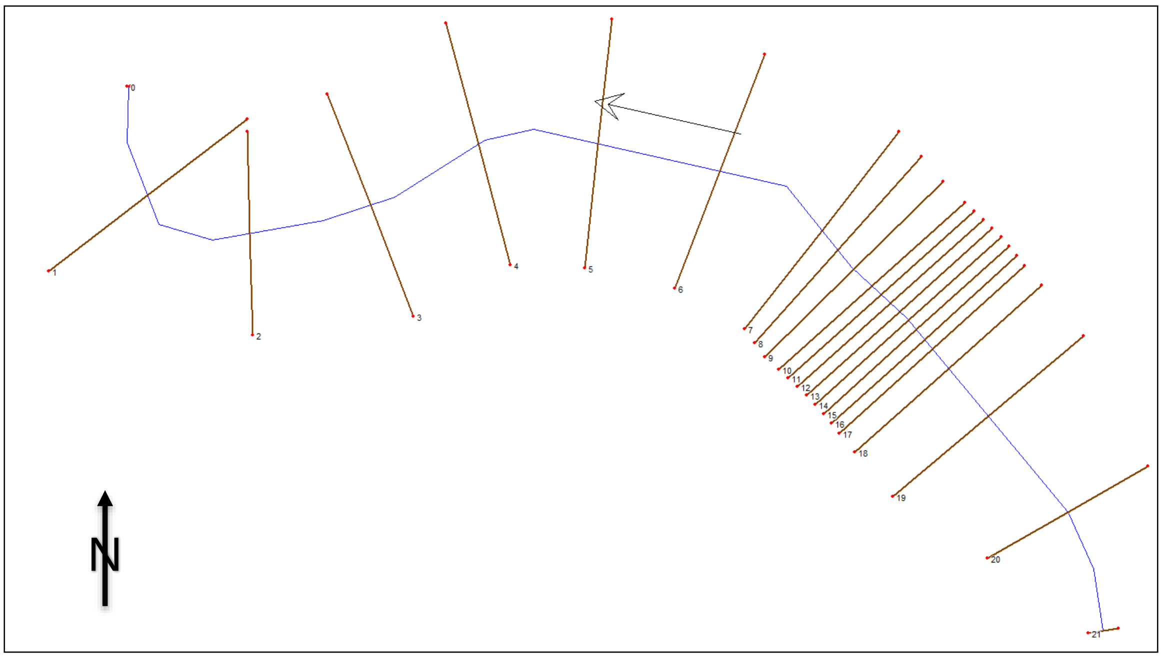

Figure 9. HEC-RAS Reach and Cross Sections (HEC-RAS)

As seen in Figure 9, all 21 cross sections have been created in HEC-RAS, using the dimensions created from the profile view in AutoCAD.

A Steady Flow Analysis was run in HEC-RAS using the original survey data under a mixed flow regime. Mixed flow is the combination of both supercritical and subcritical flows in a channel reach. Supercritical flow is shallow and fast while subcritical flow is deep and slow. After the program was ran additional cross sections were interpolated to obtain more accurate results of the stream velocity and flood conditions. Cross sections were interpolated at uniform distances between existing cross sections with an increase of interpolations above and below the headcut.

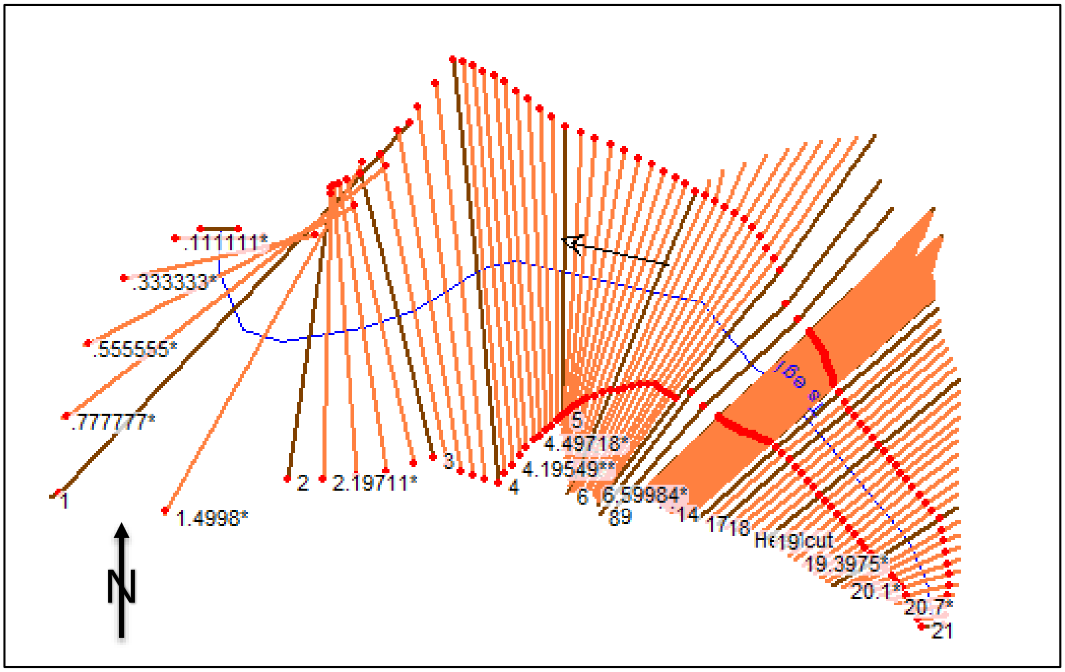

Figure 10. HEC-RAS Reach with Interpolated Cross Sections (HEC-RAS)

Figure 10 above displays the final HEC-RAS after interpolated cross sections had been created.

A Steady Flow Analysis was run once again with the additional cross sections. A profile view of the stream after analysis was performed can be seen in Figure 11.

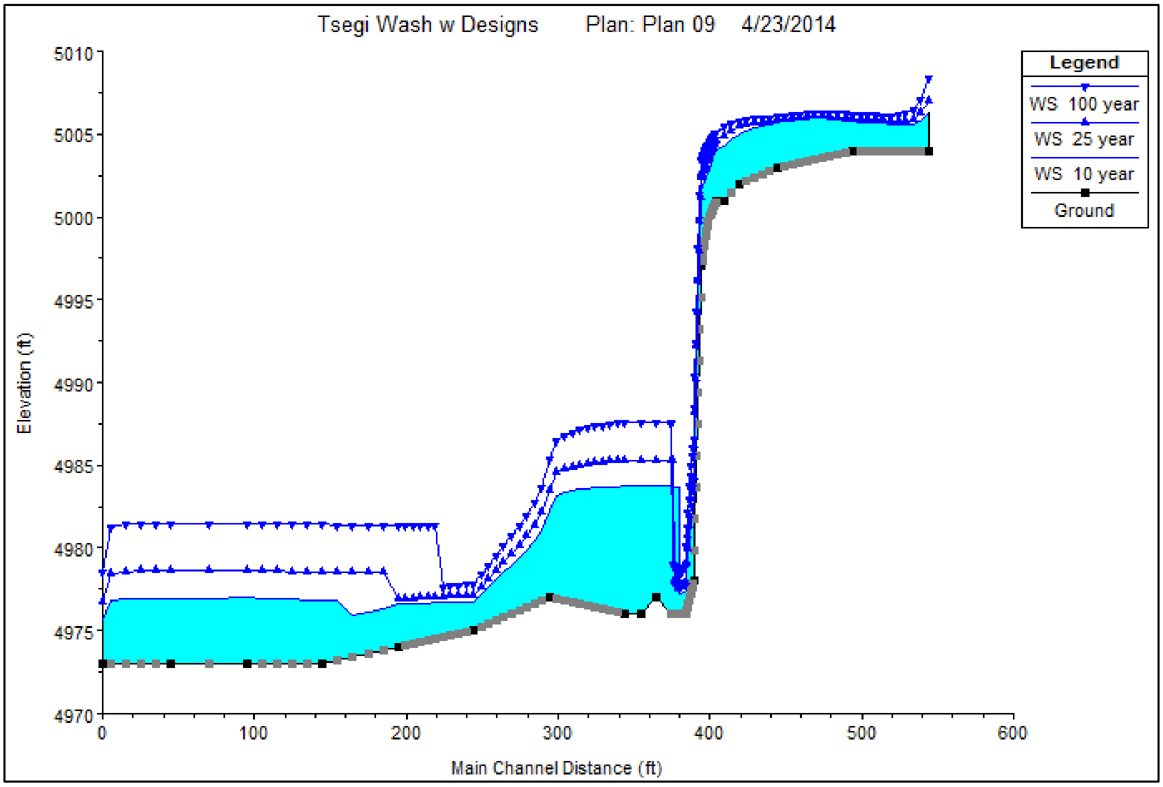

Figure 11. Profile View of Channel Reach (HEC-RAS)

The profile in the figure above shows the stream velocity beginning at a supercritical flow as it approaches the headcut. Directly below the drop off at the headcut the velocity changes to a subcritical flow as energy accumulates in a pool at the bottom, scouring the base of the headcut. The energy created at the bottom of the headcut causes the stream to exit the plunge pool at a supercritical flow, eventually returning to a natural subcritical flow.

The HEC-RAS software outputted flow characteristics at each cross section along the channel. Cross section 15 was a point of focus because that is where the headcut began. The output results for velocity and shear stress of a 10-yr, 25-yr, and 100-yr flow at station 15 are shown below.

Table 2. HEC-RAS Results (HEC-RAS)

Reach	River Sta	Profile	Vel Chnl	Shear Chan
			(ft/s)	(lb/sq ft)
Headcut	15	10 year	13.98	2.70
Headcut	15	25 year	14.41	2.65
Headcut	15	100 year	16.27	3.13

As seen in Table 2 above, the velocity during a 10 year flow is 13.98 ft/s, velocity during a 25 year flow is 14.41 ft/s, and velocity during a 100 year flow is 16.27 ft/s. At these velocities no existing vegetation can provide stability for the soil at the headcut, as can be supported by Table 3 below.

Table 3. Allowable Velocities (Natural Resources Conservation Service, Part 654 – Stream Restoration Design)

Table 8–6 Allowable velocities for channels lined with grass

Cover	Slope range percent	Allowable velocity (ft/s)	
		Erosion-resistant soils	Easily eroded soils
Bermudagrass	0–5 5–10 >10	8 7 6	6 5 4
Buffalograss, Kentucky bluegrass, smooth brome, blue grama	0–5 5–10 >10	7 6 5	5 4 3
Grass mixture	0–5 5–10	5 4	4 3
	Not recommended on slopes greater than 10%		
Lespedeza sericea, weeping lovegrass, ischaemum (yellow bluestem), kudzu, alfalfa, crabgrass	0–5	3.5	2.5
	Not recommended on slopes greater than 5%, except for side slopes in a compound channel		
Annuals—used on mild slopes or as temporary protection until permanent covers are established, common lespedeza, Sudangrass	0–5	3.5	2.5
	Not recommended for slopes greater than 5%		

In order to reduce velocity at the headcut and prevent further erosion, three design alternatives were created and tested using HEC-RAS software.

3.6.1 Live Vegetation

The live vegetation alternative was designed by leveling out 5 ft. of earthwork beginning at the headcut and continuing out at a 10:1 slope until the bottom of the channel was reached. A total of 3067 yd^3 of dirt was used to complete the earthwork. Cross section elevations were edited in HEC-RAS to modify the channel to the proposed earthwork design of a 10% slope downstream of the headcut.

Willow stakes and a grass seeding mixture were used as the methods of stabilization along the stream bank. Willow stakes range from 1-3 in. in diameter and 2-3 ft. in length. Stakes are placed 1-3 ft. apart at a 90 degree angle along the banks, protruding 2-3 in. above the surface. The willow roots spread and create soil stability. Figure 12 displays an example of willow staking.

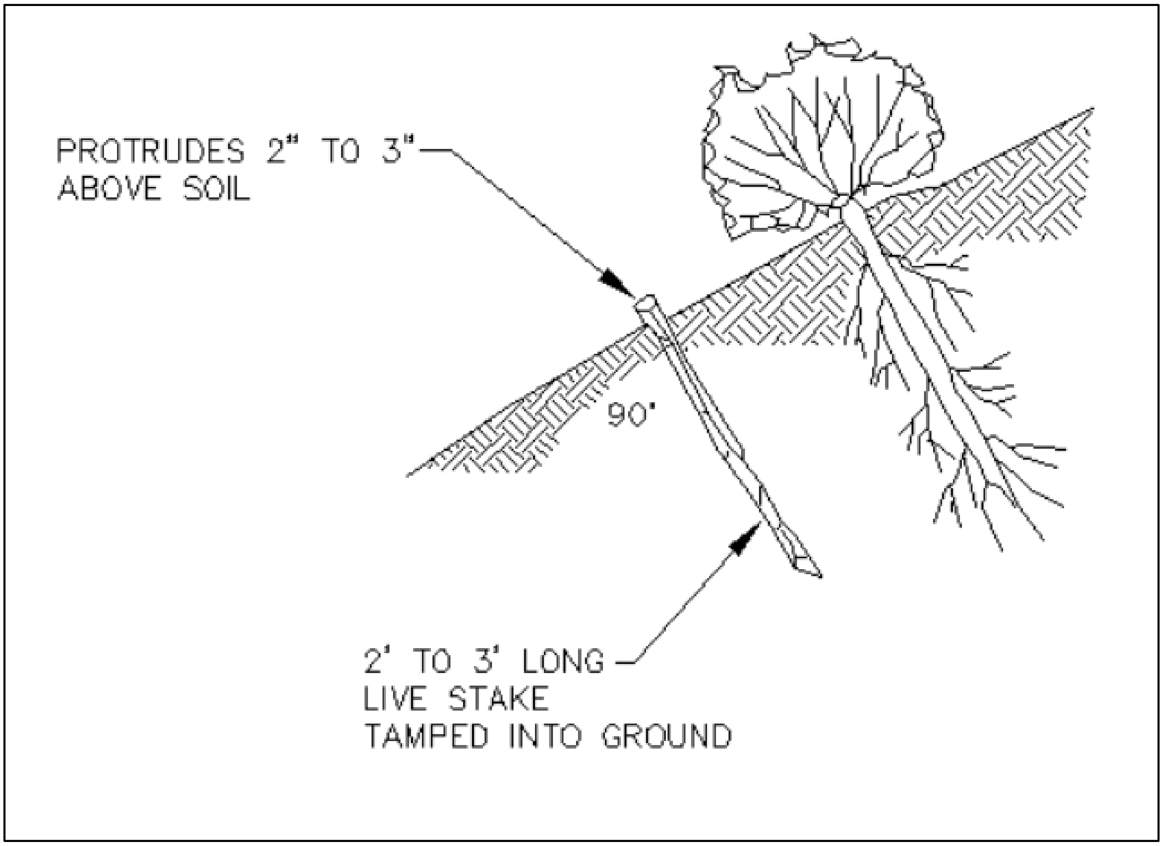

Figure 12. Willow Staking (Bank Stabilization)

The Manning's Coefficients at varying cross sections along the channel were adjusted until velocities were within the allowable range. Table 4 below lists the velocity and shear stress live willow stakes can withstand.

Table 4. Allowable Shear and Velocity (Natural Resources Conservation Service)

Type of Treatment	Velocity ft/sec	Allowable Shear lb/sq ft
Soil Bioengineering[4]		
Live willow stakes	3-10	2.10-3.10

After running several analyses, final Manning's values were chosen to create a design that would stabilize the stream using the least amount of costly materials. Upstream of the headcut vegetation was added using only willows. Beginning at cross section 15 where earthwork began a combination of 50% willows and 50% grass was planted using a composite Manning's value of 0.09. Starting at the downward slope of the channel the combination changed to 40% willows and 60% grass, a Manning's value of 0.078. A table of the exact Manning's coefficients used to run the HEC-RAS model is shown below.

Table 5. Manning's Coefficients Live Vegetation (HEC-RAS)

	River Station	Frctn (n/K)	n #1	n #2	n #3
1	21	n	0.15	0.15	0.15
2	20	n	0.15	0.15	0.15
3	19	n	0.15	0.15	0.15
4	18	n	0.15	0.15	0.15
5	17	n	0.15	0.15	0.15
6	16	n	0.15	0.15	0.15
7	15	n	0.09	0.078	0.09
8	14	n	0.09	0.078	0.09
9	13	n	0.15	0.15	0.15
10	12	n	0.078	0.078	0.078
11	11	n	0.078	0.078	0.078
12	10	n	0.078	0.078	0.078
13	9	n	0.078	0.078	0.078
14	8	n	0.078	0.078	0.078
15	7	n	0.078	0.078	0.078
16	6	n	0.078	0.078	0.078
17	5	n	0.078	0.078	0.078
18	4	n	0.078	0.078	0.078
19	3	n	0.078	0.078	0.078
20	2	n	0.078	0.078	0.078
21	1	n	0.078	0.078	0.078
22	0	n	0.078	0.078	0.078

In the table above the left overbank of the channel is represented in column 3 as *n #1*, the main channel is *n #2*, and the right overbank is represented in the final column as *n #3*. The Manning's coefficients used to form the composite values seen above were 0.15 for willows and 0.03 for grass (Chow, 1959).

A profile view of the completed live vegetation design is seen in Figure 13.

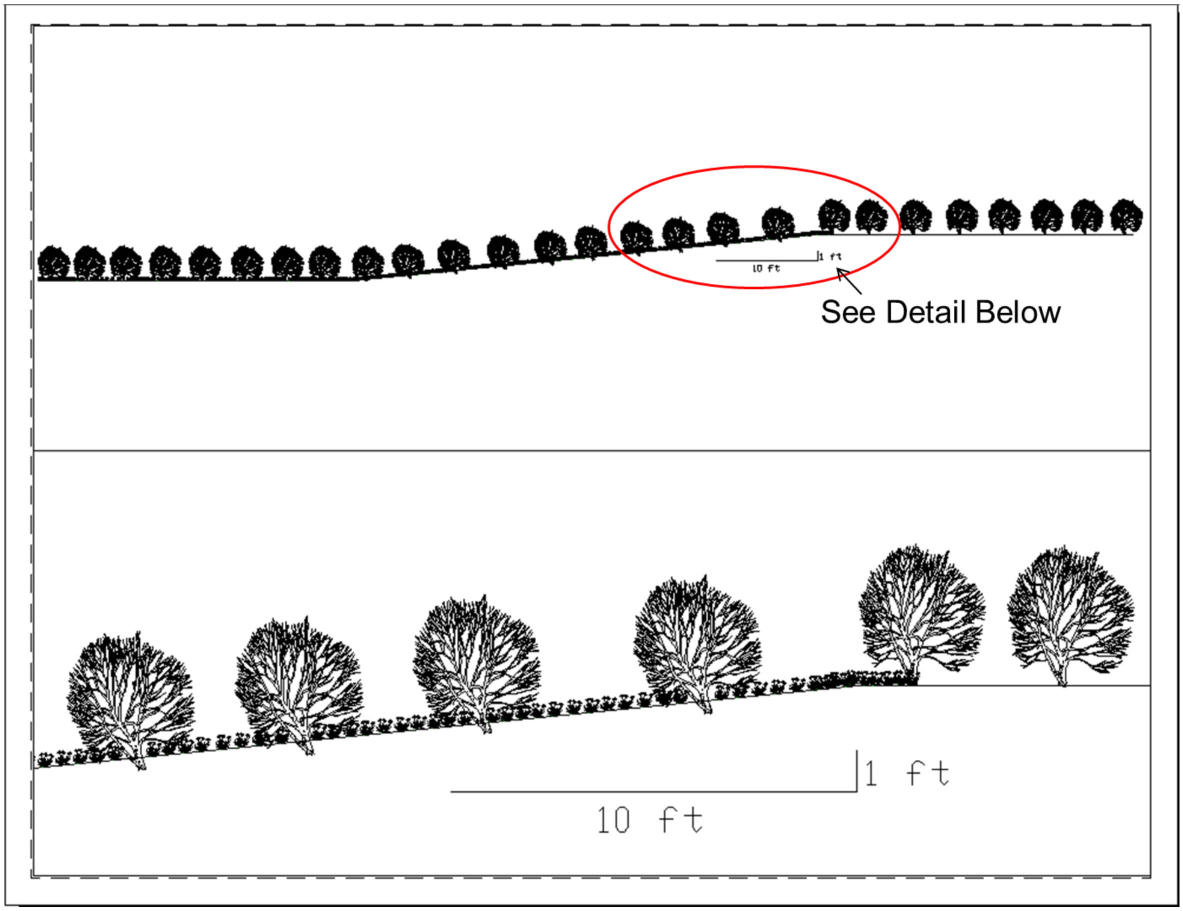

Figure 13. Live Vegetation Profile View (AutoCAD)

The drawing above displays two views of the headcut stabilization using live vegetation. The top view presents the entire length of the reach. The bottom drawing exhibits a magnified view of the reach. The detailed view focuses on the area of the reach where the headcut is located and where earthwork and the use of grass seeding began.

The channel reach profile after a steady flow analysis was run using the HEC-RAS software with the final vegetation design is seen in Figure 14 on the following page.

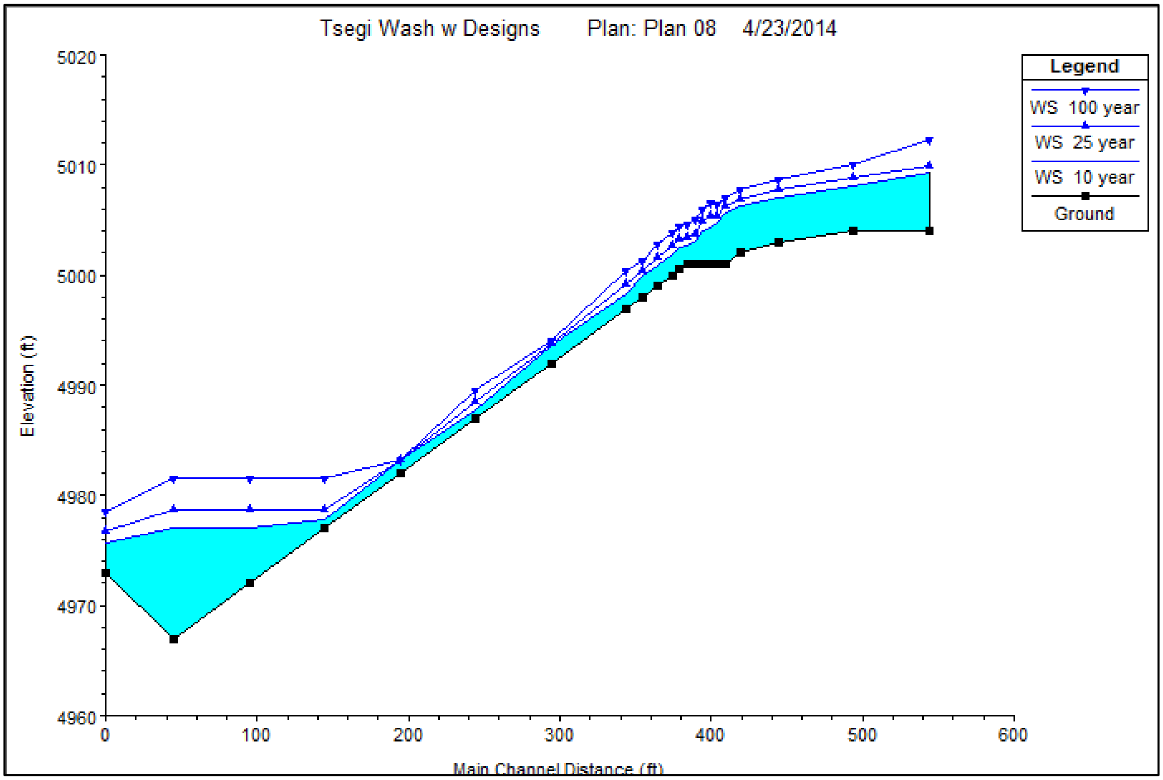

Figure 14. Live Vegetation Profile (HEC-RAS)

The profile shows the new flow levels for a 10, 25, and 100 year flow with the adjusted cross sectional elevations and manning's coefficients for the vegetation design.

Below are the velocity and shear stress results after running the steady flow analysis using the final live vegetation design. The results are inside the design parameters for allowable velocity of willow stakes at all stations of the reach, which is at or below 10 ft/s. However, the allowable shear stress for 76% of the channel reach exceeds the permissible shear of 2.10-3.10 lb/sqft as previously stated in Table 4. Table 6 shows the results for stations 10-15 of the reach for 10, 25, and 100 year flows.

Table 6. Velocity and Shear Stress Outputs for Live Vegetation (HEC-RAS)

Reach	River Sta	Profile	Vel Chnl	Shear Chan
			(ft/s)	(lb/sq ft)
Headcut	15	10 year	1.46	0.25
Headcut	15	25 year	1.85	0.37
Headcut	15	100 year	2.49	0.60
Headcut	14	10 year	5.27	3.66
Headcut	14	25 year	6.42	5.05
Headcut	14	100 year	8.82	8.93
Headcut	13	10 year	7.32	29.16
Headcut	13	25 year	8.38	34.97
Headcut	13	100 year	8.57	32.51
Headcut	12	10 year	7.00	8.10
Headcut	12	25 year	9.56	14.29
Headcut	12	100 year	12.87	23.83
Headcut	11	10 year	4.55	3.11
Headcut	11	25 year	4.81	3.06
Headcut	11	100 year	5.34	3.26
Headcut	10	10 year	6.59	6.85
Headcut	10	25 year	7.72	8.44
Headcut	10	100 year	9.34	10.95

The values in the above table begin at station 15 where the headcut originally began until it was leveled off until station 12, and then sloped off at a 10:1 ratio for the remainder of the channel reach. As can be seen in the final column of the table the shear stress values at stations 14, 13, and 10 are all in excess of the allowable shear for willow stakes.

3.6.2 Bioengineering

The bioengineering alternative was designed by leveling out 5 ft. of earthwork beginning at the headcut and continuing out at a 5:1 slope until the bottom of the channel was reached. A total of 1597 yd^3 of dirt was used to complete the earthwork. Cross sections were edited in HEC-RAS to modify the channel to the proposed earthwork design of a 20% slope downstream of the headcut.

Boulders, willow stakes, and a grass seeding mixture were used as the methods of stabilization along the stream bank. Boulder size was calculated using the Natural Recourses Conservation Service (NRCS) rock chute excel spreadsheet. Using the slope, channel width, Manning's coefficients, and channel flow a 6 ft. diameter rock was determined to be needed. Excel spreadsheet can be seen in Appendix G.

The allowable shear and velocity for a medium sized boulder can be seen in Table 7.

Table 7. Allowable Shear and Velocity for Medium Boulders (NRCS)

Type of Treatment	Velocity ft/sec	Allowable Shear lb/sq ft
Soil Bioengineering[4]		
Boulder		
Very large (>80-inch diameter)	25	37.4
Large (>40-in diameter)	19	18.7

As seen in Table 7 above an interpolation was performed to estimate the velocity and shear for a 6 ft. boulder. The allowable shear stress is 32 lb/sqft. The allowable velocity is 22 ft/sec for the determined boulder size used in the bioengineering design.

The turf reinforcement mat is a combination of vegetative growth and synthetic materials. The selected mat to be used is turf reinforcement mat 5c. The material composition can be seen in Table 8 below.

Table 8. Turf Reinforcement Mat Shear Stress Parameters (Erosion Control Technology Council)

Product	Material Composition	Permissible Shear Stress
5.C Turf Reinforcement Mat	**A non-degradable rolled erosion control product.**	**≤ 10 lb/sqft**

As seen in Table 8, the allowable shear for the selected design in less than 10lbs/sqft.

Several analyses were ran in HEC-RAS to evaluate the most efficient distribution of materials for cost effectiveness and stabilization capabilities. The corresponding Manning's values to go along with the analyses are as follows: upstream of the headcut only willows were used for a Manning's value of 0.15, along the 5:1 slope a 50% mixture of boulders and willows was used at a value of 0.11 and finally, the remaining reach was a 50% mixture of willows and grass with a corresponding value of 0.09. A table of the exact Manning's coefficients used to run the HEC-RAS model is shown on the following page.

Table 9. Manning's Coefficient Bioengineering (HEC-RAS)

	River Station	Frctn (n/K)	n #1	n #2	n #3
1	21	n	0.15	0.15	0.15
2	20	n	0.15	0.15	0.15
3	19	n	0.15	0.15	0.15
4	18	n	0.15	0.15	0.15
5	17	n	0.15	0.15	0.15
6	16	n	0.15	0.15	0.15
7	15	n	0.15	0.15	0.15
8	14	n	0.15	0.15	0.15
9	13	n	0.15	0.15	0.15
10	12	n	0.15	0.15	0.15
11	11	n	0.11	0.11	0.11
12	10	n	0.11	0.11	0.11
13	9	n	0.11	0.11	0.11
14	8	n	0.11	0.11	0.11
15	7	n	0.11	0.11	0.11
16	6	n	0.11	0.11	0.11
17	5	n	0.11	0.11	0.11
18	4	n	0.09	0.09	0.09
19	3	n	0.09	0.09	0.09
20	2	n	0.09	0.09	0.09
21	1	n	0.09	0.09	0.09
22	0	n	0.09	0.09	0.09

As seen in the table above, the channel, left overbank and right overbank were all given the same Manning's coefficient to remain consistent. Starting at the top of the reach (Station 21) until the edge of the start of the 5:1 slope (Station 12) a coefficient of 0.15 was used to represent willows planted in that area. Throughout the 5:1 slope a Manning's coefficient of 0.11 was used to represent the 50% use of boulders and willows. After the 5:1 slope (Stations 4-0) a Manning's coefficient of 0.09 was used to represent a 50% mixture of grass and willows (Chow, 1959).

A profile view of the completed live vegetation design is seen in Figure 15.

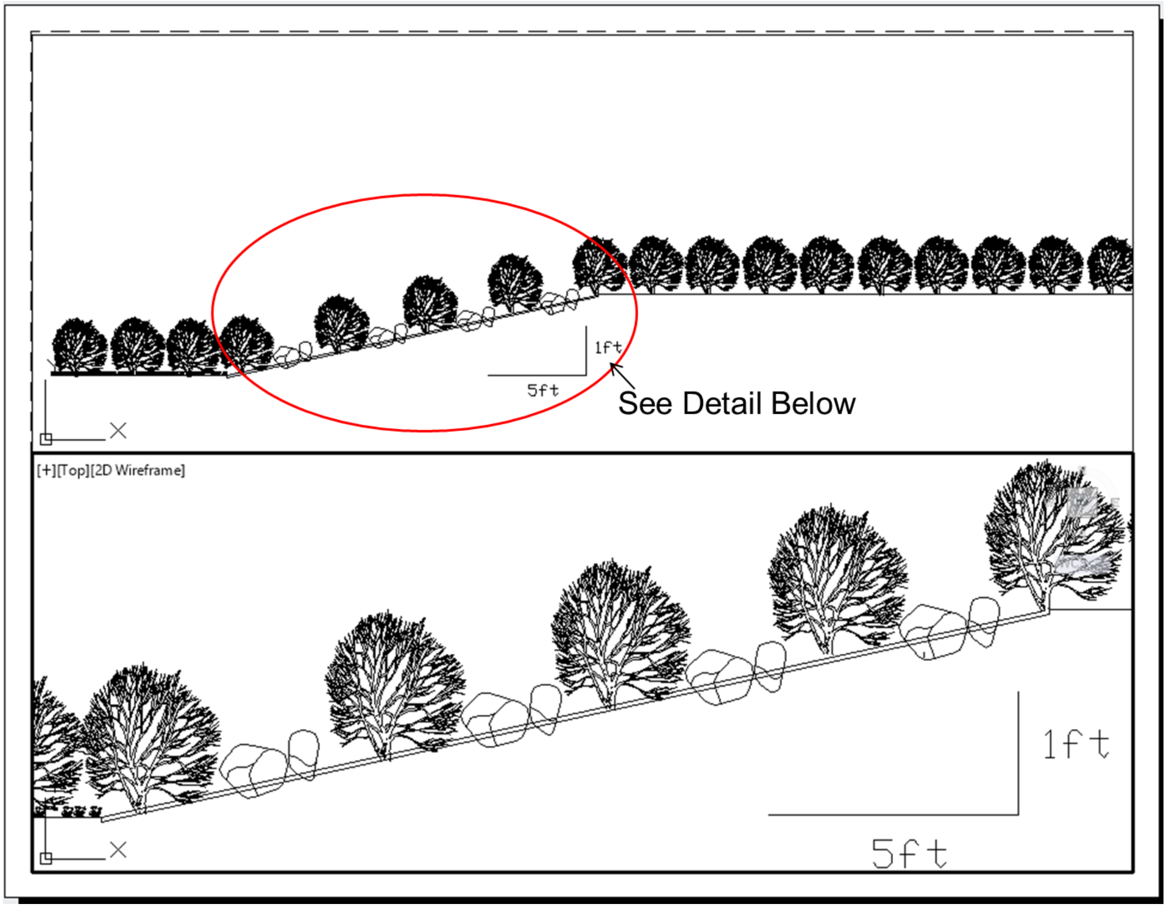

Figure 15. Bioengineering Profile View (AutoCAD)

The AutoCAD drawing above shows two views of the headcut stabilization method of using bioengineering. The top view displays the complete length of the reach, which shows willows being used at the top, then a mixture of willows and boulders, followed by a combination of grass and willows used at the end. The bottom view is an enlarged view of the reach with the focus of the reach area during the 5:1 slope area that required earthwork.

The HEC-RAS channel reach profile after a steady flow analysis was run using the bioengineering design is seen in Figure 16.

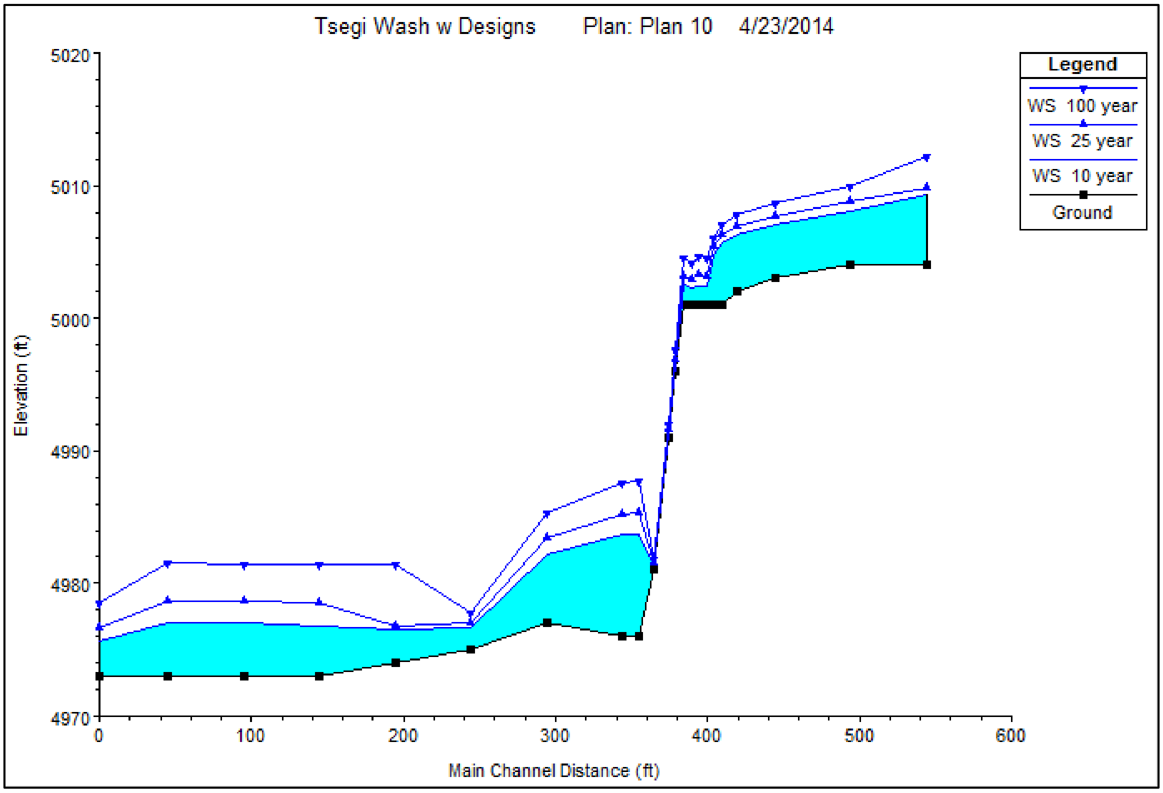

Figure 16. Bioengineering (HEC-RAS)

The above figure shows the flow approach to the adjusted 5:1 slope and how a 10, 25, and 100 year flow will perform during those events.

Below are the velocity and shear stress results after running the steady flow analysis using the final live vegetation design. The results are inside the design parameters for allowable velocity of willow stakes at all stations of the reach, which is at or below 10 ft/s. However, the allowable shear stress for 76% of the channel reach exceeds the permissible shear of 2.10-3.10 lb/sqft as previously stated in Table 4.

Table 10 shows the results for stations 10-15 of the reach for 10, 25, and 100 year flows.

Table 10. Velocity and Shear Stress Outputs for Bioengineering (HEC-RAS)

Reach	River Sta	Profile	Vel Chnl	Shear Chan
			(ft/s)	(lb/sq ft)
Headcut	15	10 year	3.66	6.16
Headcut	15	25 year	3.98	6.87
Headcut	15	100 year	4.38	7.69
Headcut	14	10 year	4.11	7.92
Headcut	14	25 year	4.44	8.68
Headcut	14	100 year	4.68	8.88
Headcut	13	10 year	4.04	7.79
Headcut	13	25 year	4.54	9.16
Headcut	13	100 year	4.78	9.39
Headcut	12	10 year	7.36	29.39
Headcut	12	25 year	8.22	33.27
Headcut	12	100 year	8.54	32.21
Headcut	11	10 year	7.99	20.09
Headcut	11	25 year	9.88	28.29
Headcut	11	100 year	11.82	36.14
Headcut	10	10 year	7.59	18.86
Headcut	10	25 year	9.30	25.72
Headcut	10	100 year	12.07	38.97

As seen in the table above the velocities for the 10 and 25 year flood are within allowable velocities for willows and boulders. The shear is in excess for the turf reinforced mat and the willows. The mat can only withstand a shear of 10 lb/sqft, stations 12-6 all exceed the allowable shear for the mat. Also, the shear at those stations exceeds the allowable shear for willows which is a maximum 3.1 lb/sqft.

3.6.3 Rock Armor

The third alternative is rock armoring which was also designed by leveling out 5 ft. of soil beginning at the headcut and then earthwork would continue at a 3:1 slope until the bottom of the channel is reached. The amount of soil required to fill the 3:1 slope and the 5 ft. at the headcut is 1009 yd^3. The original HEC-RAS model was adjusted to match the design slope below the headcut of 33%.

The materials used to stabilize the channel with the armoring design consist of boulders, willow stakes, and the grass seeding mixture. The mean boulder diameter was also sized using the NRCS rock chute spreadsheet in Appendix G. The mean boulder diameter for rock armoring was calculated to be 6 ft, using a slope of 0.33 and the 25 year flow of 798 cfs. A boulder of 6 ft in diameter can withstand a velocity of 22 ft/s and a shear stress of 32 lb/sqft using the same interpolation that was performed for bioengineering.

In order to determine the best combination of materials to stabilize the headcut and reduce cost, different scenarios were analyzed in HEC-RAS. The corresponding Manning's values to go along with the analyses are as follows: up stream of the headcut only willows were used for a Manning's value of 0.15, along the 3:1 slope and the 5 ft of fill only boulders were used with a Manning's value of 0.07 and finally, for the remaining reach only grass was used with a corresponding value of 0.03. A table of the exact Manning's coefficients used to run the HEC-RAS model is shown below.

Table 11. Manning's Coefficient for Rock Armoring (HEC-RAS)

River Station	Frctn (n/K)	n #1	n #2	n #3
21	n	0.15	0.15	0.15
20	n	0.15	0.15	0.15
19	n	0.15	0.15	0.15
18	n	0.15	0.15	0.15
17	n	0.15	0.15	0.15
16	n	0.15	0.15	0.15
15	n	0.07	0.07	0.07
14	n	0.07	0.07	0.07
13	n	0.07	0.07	0.07
12	n	0.07	0.07	0.07
11	n	0.07	0.07	0.07
10	n	0.07	0.07	0.07
9	n	0.07	0.07	0.07
8	n	0.07	0.07	0.07
7	n	0.07	0.07	0.07
6	n	0.07	0.07	0.07
5	n	0.03	0.03	0.03
4	n	0.03	0.03	0.03
3	n	0.03	0.03	0.03
2	n	0.03	0.03	0.03
1	n	0.03	0.03	0.03
0	n	0.03	0.03	0.03

As seen in Table 11 above the channel, left overbank and right overbank were all given the same Manning's coefficient to remain consistent. Starting at the top of the reach (Station 21) until the headcut (Station 15) a coefficient of 0.15 was used to represent willows planted in that area. Throughout the 3:1 slope a Manning's coefficient of 0.07 was used to represent the use of boulders. After the 3:1 slope (Stations 4-0) a Manning's coefficient of 0.03 was used to represent 100% grass seeding (Chow, 1959).

Two side profile views of the completed rock armoring design can be seen in Figure 17.

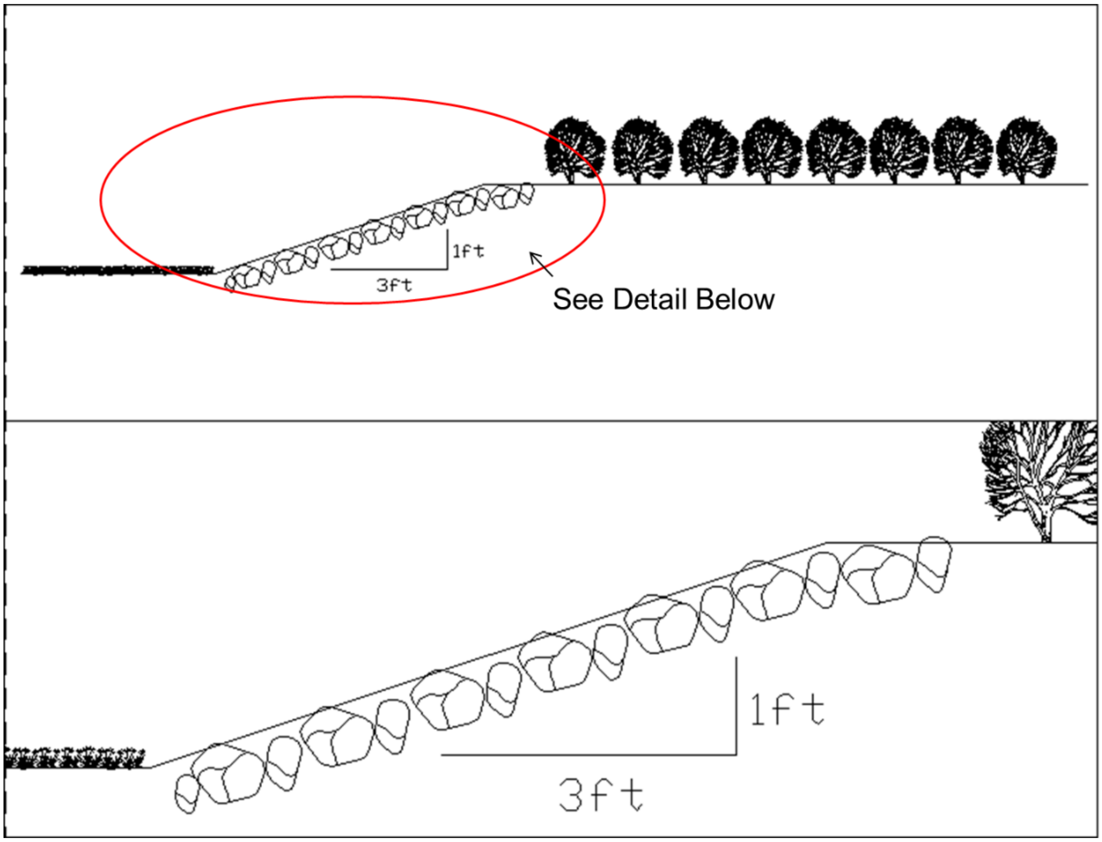

Figure 17. Rock Armoring Profile View (AutoCAD)

The profile views of the armoring design were created using AutoCAD. The visual representations of the design were created to show how the willows will line the channel above the headcut, followed by rock embedded beneath the soil in the 5 ft of fill and continue through the length of the 3:1 slope, followed by the grass seeding covering the remaining reach. The top profile view demonstrates the entire channel, and the bottom side profile view shows a close up of the slope, with the rock beneath the soil.

An overall channel profile from HEC-RAS can be seen in Figure 18 after a steady flow analysis was run using the rock armoring design.

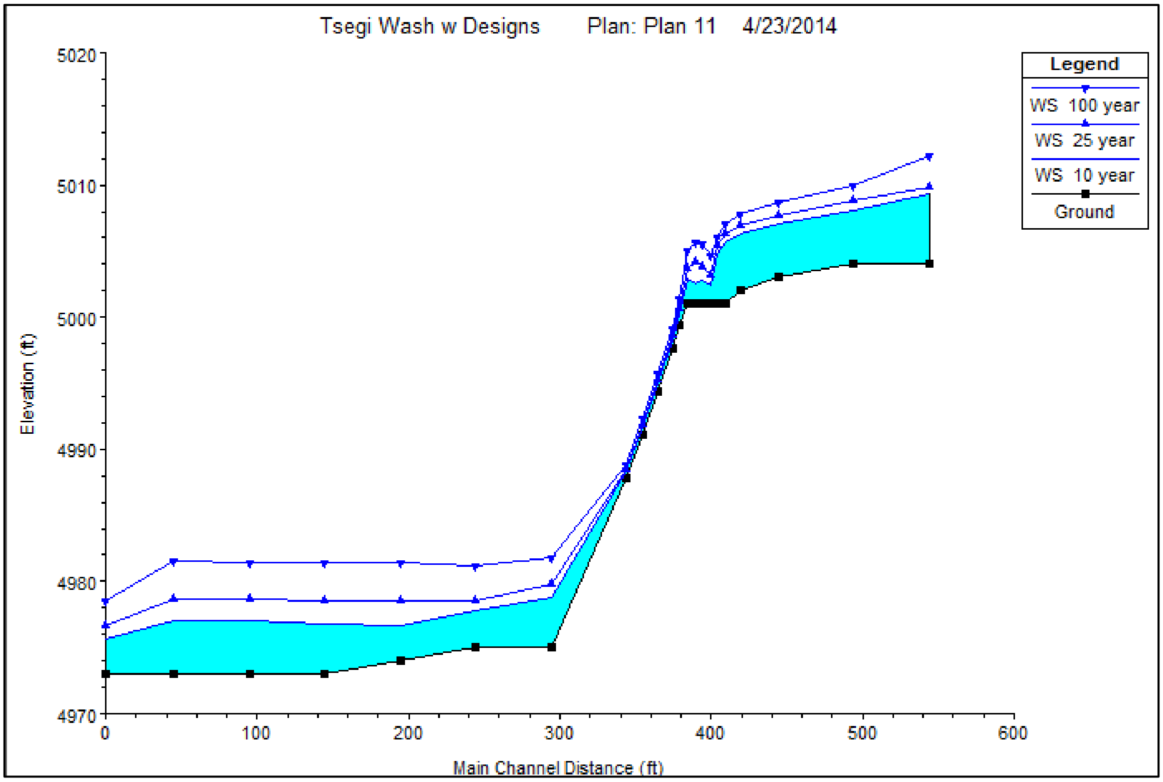

Figure 18. Hard Armoring (HEC-RAS*)*

In the figure above, the channel profile shows the 10, 25, and 100 year flow throughout the channel after rock armoring has been implemented and the channel has been taken out at a 3:1 slope.

Table 12 shows the resulting velocities and shear stresses for 10, 25 and 100 year flows for the channel after the rock armoring design has been implemented and ran in HEC-RAS. The river stations of interest begin at station 16, where the rock armoring begins right before the 3:1 slope, and continue to station 6 where the slope meets the bottom of the channel. The allowable velocity for the boulder size used is 22 ft/sec and the allowable shear is 32 lbs/sqft, using Table 7.

Table 12. Rock Armoring Design Velocities and Shear of the Channel

Reach	River Sta	Profile	Vel Chnl	Shear Chan
			(ft/s)	(lb/sq ft)
Headcut	16	10 Year	6.73	23.03
Headcut	16	25 Year	7.23	25.45
Headcut	16	100 Year	8.23	31.33
Headcut	15	10 Year	11.99	6.10
Headcut	15	25 Year	11.97	5.36
Headcut	15	100 Year	11.16	4.07
Headcut	14	10 Year	9.53	3.65
Headcut	14	25 Year	9.06	2.89
Headcut	14	100 Year	7.19	1.59
Headcut	13	10 Year	9.51	3.74
Headcut	13	25 Year	6.46	1.40
Headcut	13	100 Year	6.25	1.19
Headcut	12	10 Year	7.35	2.08
Headcut	12	25 Year	8.23	2.37
Headcut	12	100 Year	8.55	2.30
Headcut	11	10 Year	14.20	9.92
Headcut	11	25 Year	15.40	10.24
Headcut	11	100 Year	16.45	10.02
Headcut	10	10 Year	15.33	12.68
Headcut	10	25 Year	17.29	14.22
Headcut	10	100 Year	19.15	14.87
Headcut	9	10 Year	15.13	12.29
Headcut	9	25 Year	18.12	15.82
Headcut	9	100 Year	21.23	18.82
Headcut	8	10 Year	15.08	12.32
Headcut	8	25 Year	18.36	16.47
Headcut	8	100 Year	22.31	21.29
Headcut	7	10 Year	14.51	11.92
Headcut	7	25 Year	17.95	16.51
Headcut	7	100 Year	22.61	23.19
Headcut	6	10 Year	1.28	0.05
Headcut	6	25 Year	1.69	0.08
Headcut	6	100 Year	2.14	0.11

From the table above, the velocities for 10 and 25 year flow range between 6 ft/sec and 18 ft/sec and are all below the allowable velocity for boulders. The shear values for 10 and 25 year flow range from 1 – 25 lbs/sqft and are all below the allowable shear value of 32 lbs/ sqft.

4.0 Identification of Selected Design

The results of the HEC-RAS models in conjuction with the cost of the project were used to determine the most efficient design alternative to stabilize the headcut and reduce erosion. Table 13 below shows the overall cost for each design alternative proposed.

Table 13. Cost of Alternatives

	Live Vegetation	Bioengineering	Hard Armor
Materials	$20,219	$61,478	$45,982
Equipment	$15,830	$16,017	$27,197
Labor	$6,400	$6,400	$6,400
Design	$29,813	$29,813	$29,813
Total	**$72,262**	**$129,538**	**$109,392**

Totals were based on the cost of materials, equipment, and labor required to complete the project. Materials included willow stakes, grass seeds, solar pump, boulders, and a turf reinforcement mat. The solar pump is needed to provide water to the vegetation and includes the pump as well as installation cost. Required materials vary for each alternative. Equipment includes bulldozer, backhoe, and a helicopter. Due to the difficulty of the site location a helicopter is necessary to get materials and supplies to the location of the headcut. A bulldozer and backhoe are used to perform earthwork. A detailed cost estimate for all three alternatives is attached in the appendices section.

The aesthetic appeal, cultural, and environmental impacts were also taken into consideration when deciding the best method. Cultural impacts include the potential removal of archeological artifacts during the earthwork process and possible displacement of ancient remains. Environmental impacts include further drawdown of the water table in the area due to the solar pump. The overall decision was based on the withstanding of the design during a 25 year flood flow.

4.1. Live Vegetation

The live vegetation alternative consisted of only willow stakes and grass seeding making it the cheapest alternative as well the most aesthetically pleasing, maintaining the natural look of the site. The use of only grass seeding does no provide enough stabilization to stop the erosion process with the velocities of the stream. Due to this willow staking had to be incorporated. After the testing process the least amount of willows that could be used to withstand the velocities were staked along the entire reach minimizing the amount of stakes used after the headcut, as previously described. However, no combination of willow stakes and grass seeding along the reach was able to endure the amount of shear stress during a flow event, therefore eliminating the alternative as an option.

4.2 Bioengineering

The bioengineering alternative was composed entirely of willow stakes upstream of the headcut. On the sloped grade there was a 50% mixture of large boulders and willow staking. Below the mixture was a turf reinforced mat to help stabilize the soil and reduce erosion. After the slope a 50% mixture of grass and willows was used. After analysis the willows and turf reinforced mat would experience too severe a shear stress to prevent failure of those materials. After the failure of these materials the entire design will be compromised. This design also costs the most of the three alternatives. The high cost as well as the potential for failure of the design eliminated this alternative as a final design option.

4.3 Hard Armoring

The hard armoring alternative entailed planting willows above the headcut until 5 feet before the proposed 3:1 slope. At the 5 foot mark and continuing throughout the slope large boulders of an average 6 foot diameter were placed. After the slope grass will be planted over the remaining reach. This design was within the allowable velocity and shear stress parameters for all parts of the design: upstream, slope and downstream. Hard armoring has the second highest cost overall. Given the remote location of the site the implementation of the design is difficult.

4.4 Do Nothing

The do nothing alternative leaves the headcut in its current conditions. Upstream of the headcut the channel is exhibiting signs of bypassing the headcut. As seen in Figure 19 the channel is moving around the rock outcropping and may go around the headcut after a severe storm.

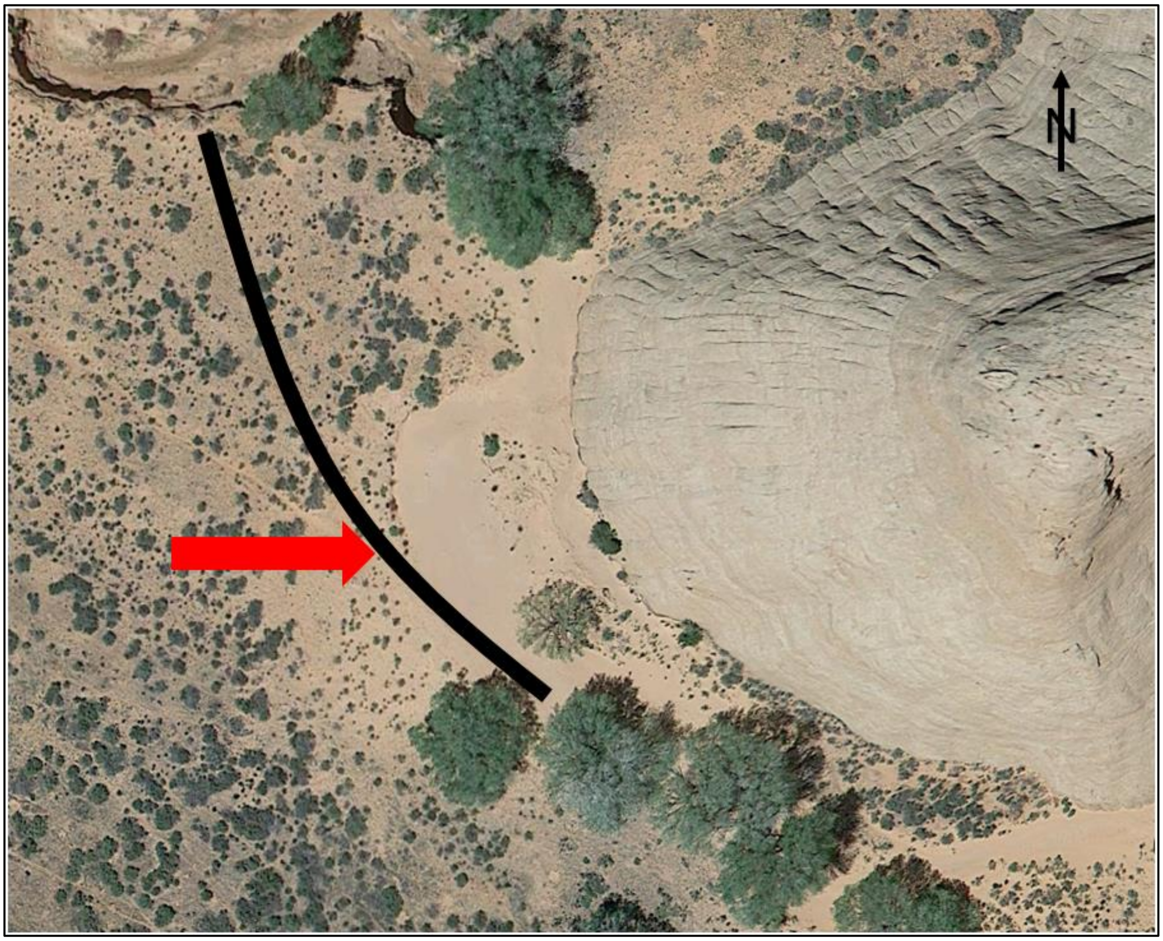

Figure 19. Possible Oxbow above Headcut

The above figure shows the slow erosion of the channel edge above the headcut. This erosion could eventually expand enough to completely circumvent the headcut altogether. The channel will most likely follow a path similar to one represented by the black line in the figure above, rendering any stabilization design useless.

The figure on the following page shows a channel that exhibits this finalized behavior in a neighboring canyon.

Figure 20. Completed Oxbow

The above figure shows a stream that at one time was flowing in the curved area indicated by the arrow. The stream eventually cut a new path which is what is predicted of current site streambed.

5.0 Final Design

Two options can be implemented for this project. The hard armoring design can be chosen or a do nothing approach can be selected. The hard armoring design has a high cost of $109,392 and will require soil to be displaced. The hard armoring design will require a detailed archeological survey for the area where soil is to be removed to be used in the creation of the 3:1 slope. In addition, hard armoring will be difficult to implement given the remote location of the site.

The do nothing alternative has no cost associated with that selection. The site will be left in its current condition with no further impacts due to construction. Due to the varying geomorphology of the stream bed and the possibility of any stabilization design being rendered useless by a change in the channel's route, the design alternative of do nothing is recommended. This option prevents spending that may or may not provide long term stabilization.

6.0 Cost of Implementing Final Design

6.1 Hard Armoring

The table below provides a breakdown of costs to implement the rock chute.

Table 14. Cost of Rock Chute

Materials	Willows	$450
	Rocks	$26,400
	Seeds	$132
	Solar Pump	$19,000
Equipment	Backhoe	$2,800
	Bulldozer	$11,480
	Helicopter	$12,917
Labor	4 People	$6,400

The table above shows a detailed breakdown of the costs associated with implementing the rock chute. Willows were priced at $20 a bundle with a total of 22 bundles required to cover the area above the headcut (Foggy Mountain Nursery, 2014). The amount of rocks required to cover the slope and the 5 feet of fill came out to 44 at $600 a rock (BLT Companies, 2014). The price of the seeds was $60 for a 20 pound bag, 44 pounds of seeds would be needed to cover the remaining area of the reach after the 3:1 slope (LOWE'S, 2014). The cost of the solar pump consists of the solar pump and the installation at $1,000 for the solar pump and $18,000 for the installation (Northern Arizona Wind & Sun, 2014). The cost of the backhoe and the bulldozer was for a 2 week rental period (Backhoe Loaders, 2014). The cost of renting the helicopter was $1,550 (Paradigm Helicopters, 2014). An 8 hour rental period would be required for the helicopter if it transported 1 rock every 10 minutes plus an hour to transport the willow bundles. Labor was calculated assuming the installation of the rock chute took 2 weeks and required 4 people at a pay rate of $20 an hour.

6.2 Do Nothing

The Do Nothing alternative has no cost associated with it.

7.0 Summary of Project Costs

The project was carried out in the following order of tasks required to perform analysis and develop a stabilization method: site assessment, hydrology, hydraulics, armoring design, and impacts evaluation. Certain sub-tasks were rearranged in the hydrology and hydraulics tasks, as can be seen in the original and final Gantt charts attached in the appendices section. Gage data was changed to the NOAA '14 Atlas data. Hydraulic radius and cross-sections were removed entirely from the hydrology section because they were to later be performed in the hydraulics section using a modeling software. Stream flow was moved from the hydrology section to hydraulics. Stream classification was removed from the site assessment task and stone-sizing criteria was eliminated from armoring design as neither were required for the project needs. Construction permitting was also taken off the original Gantt chart as the project is not to be implemented into the construction phase and permitting would be unnecessary. The reorganization of subtasks also resulted in a change of hours required to complete the tasks. The project remained on schedule except for a minor setback during the hydrology phase.

The table below shows the original estimated hours required to complete the tasks for each member working on the project.

Table 15. Original Project Personnel Cost Estimate

Task	Senior Engineer	Engineer	EIT	Tech	Admin. Asst.	Total Hours	Total Cost of Task
Fieldwork			14	10		24	$1,399
Hydrology		30	40	30		100	$7,735
Hydraulics		20	20			40	$4,048
Armoring Design	35	25	10	10		80	$9,418
Impacts Evaluation	20	4				24	$3,496
Document	20		30	20	70	140	$9,617
Total	**75**	**79**	**114**	**70**	**70**	**408**	**$35,715**

The estimated amount of hours required to complete all tasks was 408 hours at a total project cost of $35,715.

Table 16 shows the actual amount of hours spent on the project.

Table 16. Actual Project Personnel Cost

Task	Senior Engineer	Engineer	EIT	Tech	Admin. Asst.	Total Hours	Total Cost of Task
Fieldwork	24	24	24			72	$1,901
Hydrology		20	20			40	$4,048
Hydraulics	15	20	20	20		75	$4,048
Armoring Design	40	30	20	20		110	$11,867
Impacts Evaluation	8	8				16	$2,187
Document	20	20	15		30	85	$5,759
Total	**107**	**122**	**99**	**40**	**30**	**398**	**$29,813**

The actual amount of hours required to complete the project was 398 hours with a total project cost of $29,813. The difference in projected hours and actual hours spent working on the project was 10 hours. The hours reflect the changes in the Gantt chart with certain tasks being eliminated or rearranged. For example, hydrology required less hours than were originally projected due to switching tasks from hydrology to hydraulics. Hours spent working on the document were significantly reduced from the proposed to the actual hours due to an overestimation in the proposed hours. The actual hours required for fieldwork were also much higher than the proposed since two site visits were conducted with 3 personnel each spending 12 hours per site visit. In the proposed hours the bulk of the hours were allotted to hydrology, which did not involve as many hours as were initially anticipated. The majority of the hours were spent working on armoring design since that involved creating models for 3 different design alternatives.

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Appendices

Appendix A - Gantt Chart
Appendix B - CSV Point File
Appendix C - AutoCAD Topographic map
Appendix D - AutoCAD Profile View
Appendix E - Cross Section Data
Appendix F – Detailed Cost Estimate
Appendix G – Rock Chute Excel Sheet
Appendix H – Log Hours