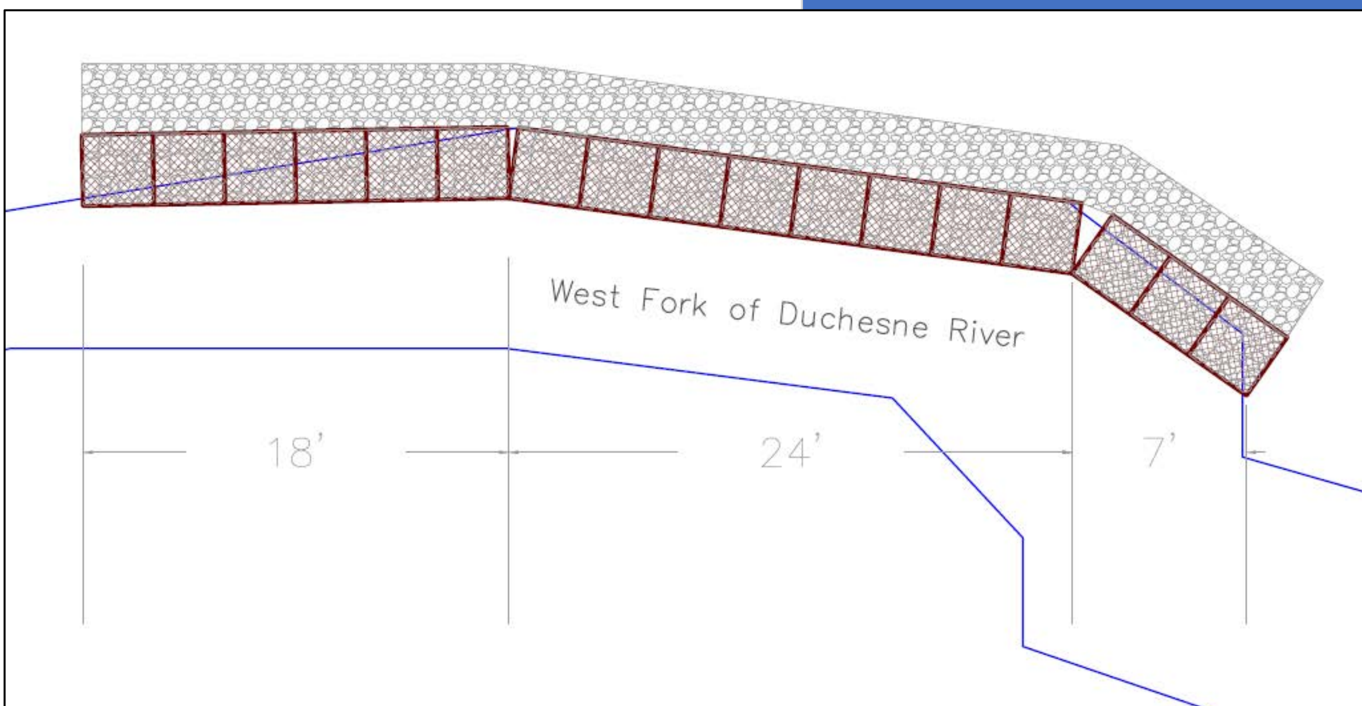
Scour Analysis on the West Fork of the Duchesne River



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1.0 Introduction

The West Fork of the Duchesne River is a perennial river that runs in the Uinta Mountains just east of Heber City, Utah. This area is a popular recreational destination for locals. The dirt road that traverses to the West Fork is FR050, which runs parallel to the river for several miles. There is a short length of roadway referred to as “the Dugway” and is the location of the project site. Its location can be seen in Figure 1 & 2.

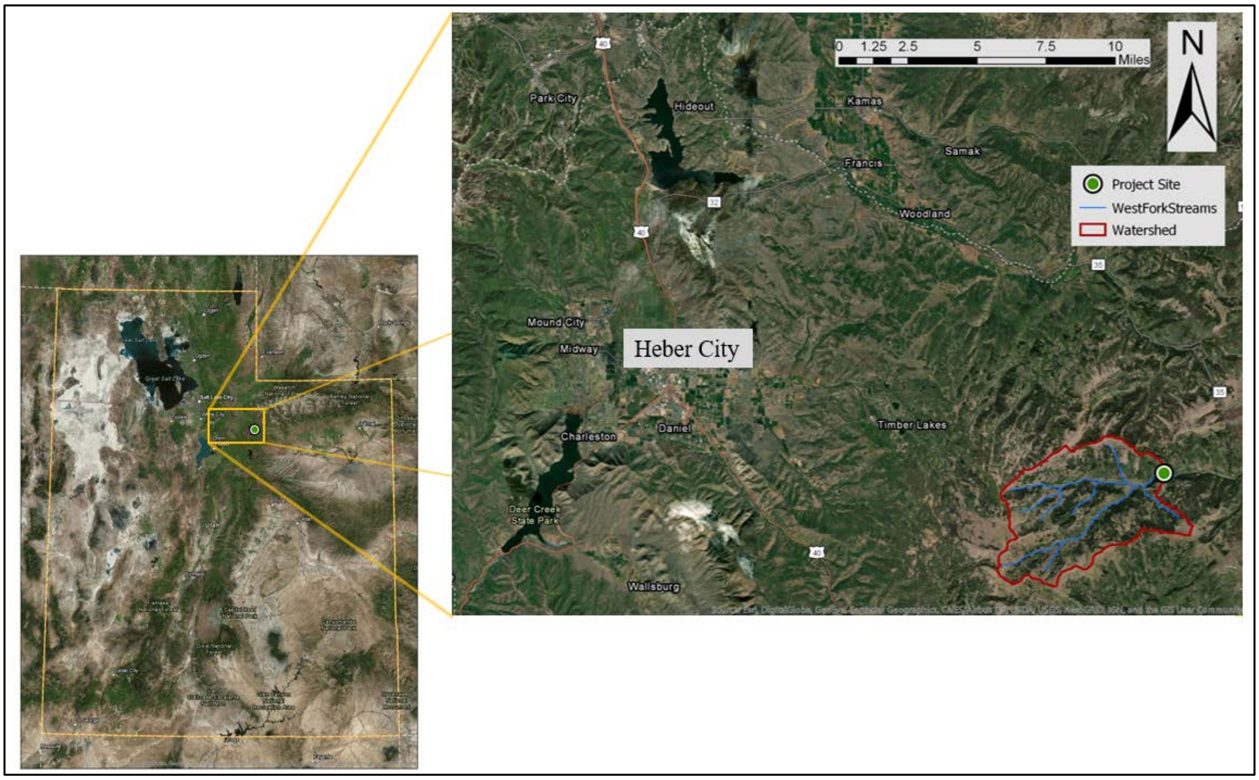

Figure 1: Locator map of project site.

The Dugway received its name because of the conditions of the road. This stretch of road is very narrow due to the terrain constraints, and there is a cliff on the south side of the road, which drops straight into the West Fork of the Duchesne as seen in Figure 2. When first constructed, the mountain on the north side was excavated to provide more space for the road.

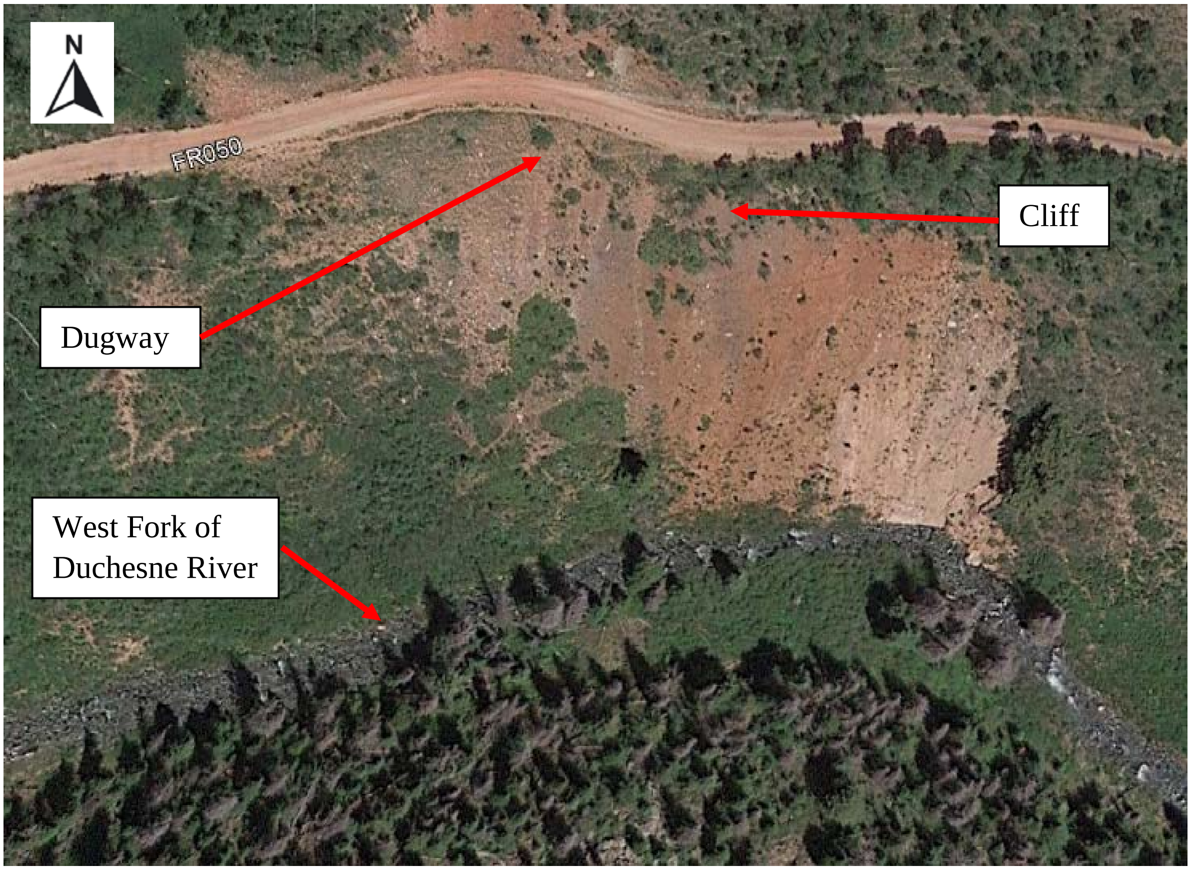

Figure 2: A stretch of road next to the West Fork of the Duchesne River called the Dugway.

1.1 Need for Action

This area of the road has been very problematic in the past, especially during storms. There have been times where the river has eroded the north bank just below the Dugway, which has caused more erosion on the steep slope. The area has had at least one occurrence where during a storm, a truck and horse trailer slipped off the cliff killing horses in the trailer. Due to the high elevation and resulting snowpack, the river sees large ranges in flow throughout the year. At the times of high flow there is threat to cause even more scouring in this location.

1.2 Proposed Solution

Riprap and gabions are proposed to prevent further scour of the riverbank at this point. In order to properly design these scour prevention structures, a hydrologic analysis was performed to approximate the existing conditions of the project site, and calculate the necessary parameters to design the riprap and gabions.

2.0 Hydrologic Analysis

A hydrologic analysis was performed to better understand the conditions upstream of the project site. Two applications were used to investigate the hydrologic conditions of the site:

- StreamStats
- ArcGIS Pro

These tools helped gather data and process the existing conditions, which gave a better perspective on how to proceed with the river bank improvement design. The results of these analyses are discussed in the following sections.

2.1 River Catchment Description from Stream Stats

StreamStats, a Geographic Information Systems (GIS) application, is provided by the United States Geological Survey (USGS). StreamStats can provide users several hydrologic tools and statistics for rivers in the United States. This application has been used to collect information on the project site including the river catchment area; stream data from a USGS stream gage 3.6 miles downstream; and the catchment area for the USGS stream gage site. The project site catchment and USGS stream gage site catchment can be seen in Figures 3 and 4, respectively.

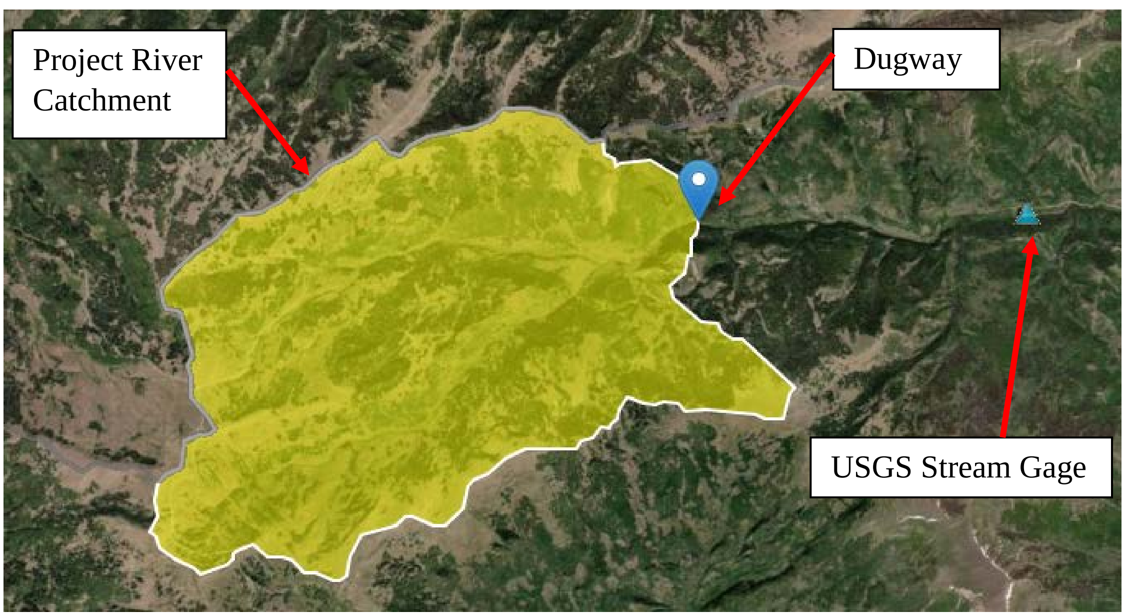

Figure 3: Catchment for project site (StreamStats 2018).

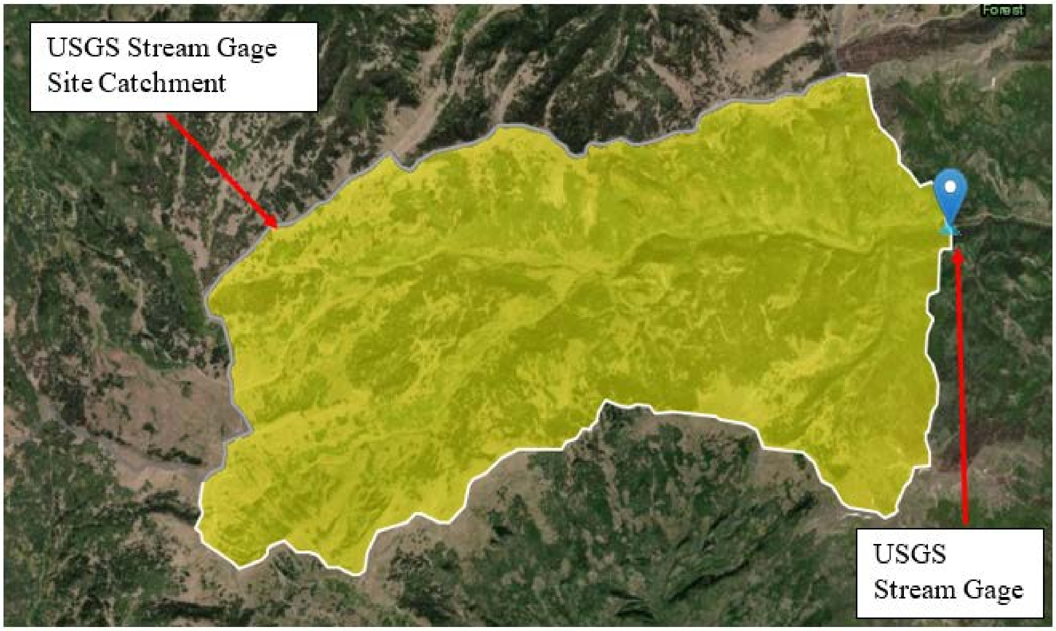

Figure 4: Catchment for USGS stream gage site (StreamStats 2018).

There was no data readily available for the river at the project site. The closest site with river data is approximately 3.6 miles downstream of the project site at the USGS stream gage. For this reason, it was necessary to obtain the area of both project site catchment and the USGS stream gage site catchment to ensure that the data collected at the stream gage site would be accurate for the project site location. These two catchment areas with the flow data obtained from the stream gage can be used to calculate the flow at the project site. Equation 1 is used to calculate the flow at the project site.

$$Q_P = Q_{SG} * \frac{A_P}{A_{SG}} \quad (1)$$

where Q_P is the flow at the project site; Q_{SG} is the flow at the stream gage; A_P is the catchment area for the project site; and A_{SG} is the catchment area for the stream gage.

Daily flow measurements were obtained at the stream gage site from October 1989 to September 1994. These flows were used to calculate minimum, average, and maximum annual flows that were measured at the stream gage. The maximum flow measured at the site was 270 cfs. This flow data for the stream gage can be seen in Table 1 (StreamStats 2018).

Table 1: Flow statistics at USGS stream gage site (StreamStats 2018)

ANNUAL			**DAILY**
Minimum Flow (cfs)	Average Flow (cfs)	Maximum Flow (cfs)	Peak Flow (cfs)
9.57	13.26	17.5	270

The area of the USGS stream gage catchment is 37 mi^2, and the area of project site catchment is 22.7 mi^2. Using this information, Equation 1 was used to calculate the minimum, average, maximum and peak-daily flow for the project site and is summarized in Table 2. The Peak Flow will be used in the design of the gabions and riprap as it is the worst case that the river has seen on record.

Table 2: Flow statistics at project site (StreamStats 2018)

ANNUAL			DAILY
Minimum Flow (cfs)	Average Flow (cfs)	Maximum Flow (cfs)	Peak Flow (cfs)
5.87	8.14	10.74	165.65

The data found in Table 3 is information on the type of landcover found on the project and the average slopes of the terrain. As seen, the majority of the catchment is mountainous terrain with steep slopes and mainly forest landcover (StreamStats 2018).

Table 3: Landcover and slope data for project site (StreamStats 2018).

Landcover Type	**% of Basin**	**Slope Data**	**Value (%)**
Forest	72.2	Mean Basin Slope	20.5
Developed	0.35	% Area with Slope greater than 30%	20.2
Herbaceous Upland	6.63		

2.2 Terrain Analysis from ArcGIS Pro

ArcGIS Pro is a GIS software that has several applications for analyzing watersheds and their properties. A Digital Elevation Model (DEM), that has elevation data accurate to 10 meter squares, was acquired from the Utah AGRC website and is seen in Figure 5 (Utah AGRC 2018). Stream location data was downloaded from the National Hydrography Dataset (NHD). The DEM and NHD Streams were used in a hydrologic analysis known as the Height Above Nearest Drainage (HAND) Method to calculate the desired variables for use in the design of the riprap and gabions.

The HAND Method uses the elevation data to delineate the surface area of the water for any desired river depth. The results from this method can be used in the development of a flow vs stage rating curve. The following is the basic steps for the HAND Method procedure:

- Use DEM to establish flow direction of each data point
- Use flow direction data to establish where flow will accumulate
- Set the local elevation of the flow accumulation in riverbeds to 0
- Measure the vertical change in elevation between riverbed and all points uphill of riverbed
- Show surface water areas for desired river depth

The water surface area from the HAND Method for river depths of 5, 10, and 20 ft can be seen in Figure 6.

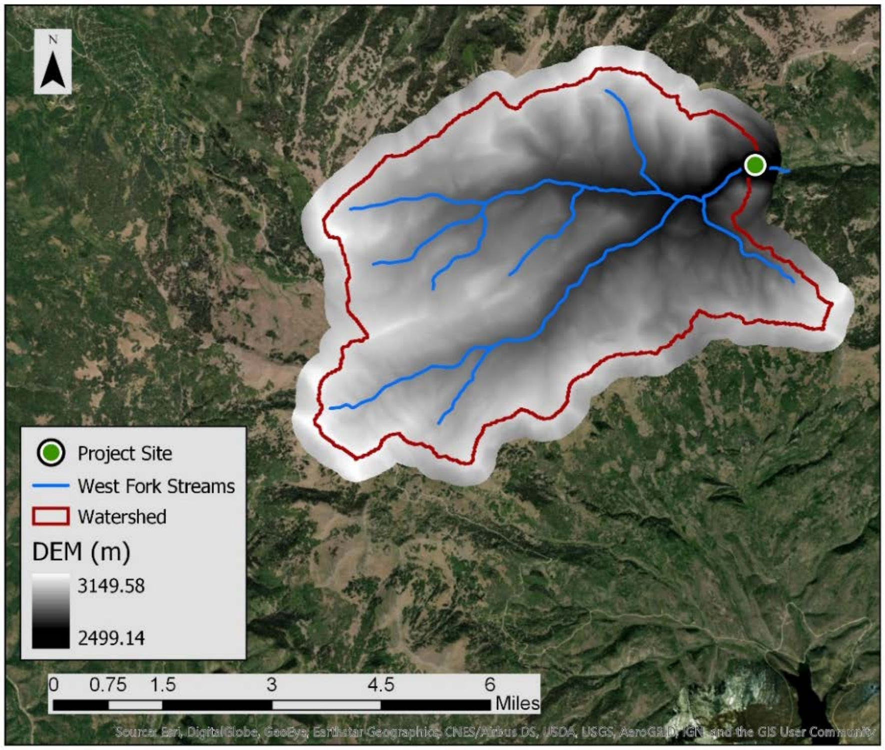

Figure 5: Digital Elevation Model (DEM) for project watershed.

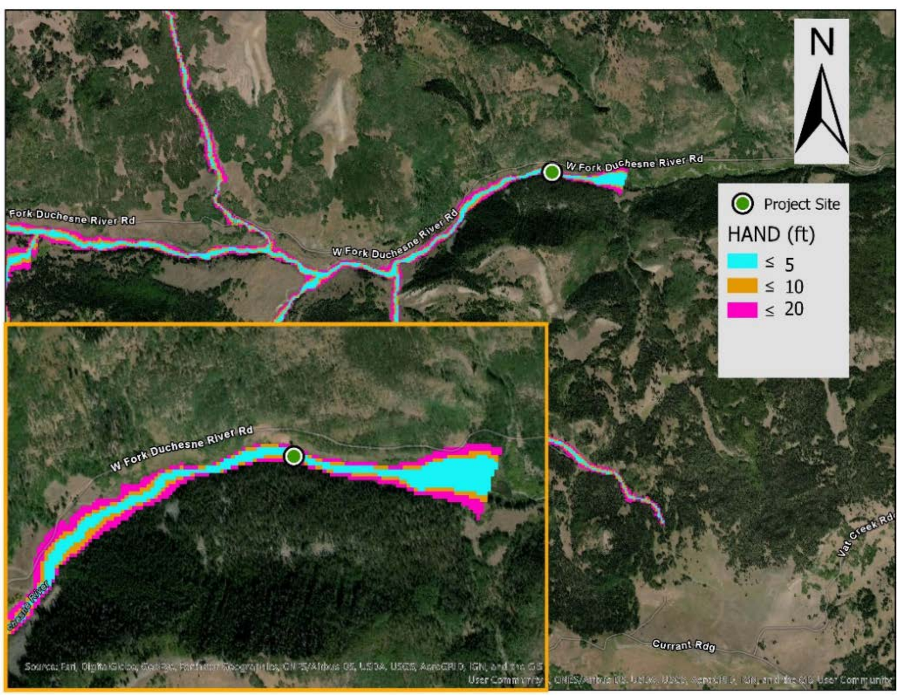

Figure 6: HAND Method for 5, 10, and 20 ft

The results from the HAND analysis were used in the development of a rating curve for the portion of the river where the project site is located. This was useful as this method produces estimates for characteristics needed in the design of riprap and gabions such as river depth and average velocity. The calculations for several HAND depths were computed and analyzed in a spreadsheet (see Appendix A: Hydrologic Calculations for more details). The results were the rating curve for the stream reach. The rating curve can be used with linear interpolation to produce the river depth for the design flow of 165.65 cfs. Table 4 shows the results from the design flow.

Table 4: Results from rating curve.

Design Flow	Q =	165.65	cfs
Stage Height	y =	1.45	ft
Avg Cross Sectional Area	A =	48.0	ft^2
Avg Velocity	V =	3.45	ft/s

The river depth (stage height) and average velocity are used in the design of the gabions and riprap.

3.0 Hydraulic Analysis and Project Design

After concluding the hydrologic analysis, a hydraulic analysis of the river was performed. This analysis consists of the following:

- Riprap design analysis
- Gabion design analysis

The hydraulic analysis of the project site helps determine how the flow of the river will interact with the sediment. The velocity and depth of the river have a significant impact on how much erosion occurs on the river bank. Higher velocities and depths produce more sediment transport. The velocity and depth of the river were used in determining the design of the riprap and gabions for prevention of this erosion.

3.2 Riprap Design Analysis

There are several methods developed in the design of riprap stone size. Seven methods were analyzed, and the results from the HEC-11 Method were chosen to be used in the design of the riprap stones. The HEC-11 Method was used because it produced the most reasonable results. UDOT also requires it, and the UDOT design guidelines are used in the final sizing of the stone (UDOT 2004).

Table 5: Riprap stone size from HEC-11 Method

HEC-11 Method		
D_{50} =	0.691	ft
D_{50} =	8.3	inches

The stone size results were closest to the "Facing" riprap class as seen in UDOT's table of riprap classifications (Appendix B), so this gradation class was used to in the design of the riprap on the project site. Three main stone sizes are used with this class and can be seen in Table 6 (UDOT 2004).

Table 6: Riprap Design Sizes

UDOT Classification	
Riprap Class	**Rock Size (ft)**
Facing	1.30
	0.95
	0.40

3.3 Gabion Design Analysis

Wire-enclosed rock or gabions consist of wire-mesh baskets filled with rock (UDOT 2004). Gabions were used in the bank protection design. A line of gabions wired together will run along the north river bank. The riprap will be placed behind/above the gabions and will extend up the slope to better protect the site from erosion as seen in the Technical Drawings in Appendix C.

The wire baskets used in gabion design are typically prefabricated, square shaped, and range in size. Based on guidelines in the UDOT Design Manual, 3 ft square wire baskets will be used with a maximum wire opening of 3 inches (UDOT 2004). The project site shows significant erosion for about 30 ft. To include a factor of safety, it is proposed to line the north bank for a length of 50 ft (10 ft beyond erosion upstream and downstream). This will ensure that the problematic area will be completely protected.

Table 7: Gabion Design Size

UDOT Design Guidelines				
Wire Basket Size		Wire Mesh Opening Size	Stone Size	
Height	3 ft	3 in x 3 in	Small	0.3 ft
Width	3 ft		Medium	0.7 ft
Depth	3 ft		Large	1 ft

Conclusion

Bank erosion on the West Fork of the Duchesne River has been evaluated. A hydrologic and hydraulic analysis of the project site was conducted to better determine the most efficient and effective way to improve the system. Fifty-one - 3 ft x 3 ft gabion blocks were designed to protect the side of the bank. Riprap was designed to be placed above the gabions and run up the slope for an additional 3 vertical feet. By installing these improvements, the erosion on the north bank of the river will be eliminated protecting the river and access road above.

References

Freeman, Gary E. and Fischenich, J. Craig. 2000. “Gabions for Streambank Erosion Control”.

Froehlich, D. C., and Benson, C. A. (1996). “Sizing Dumped Rock Riprap.” *Journal Of Hydraulic Engineering*.

Maynord, S. T., Ruff, J. F., and ABt, S. R. (n.d.). “Riprap Design .”

StreamStats, United States Geological Survey, streamstats.usgs.gov/ss/. Accessed 10 October 2018.

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UDOT. (2004). *Utah Department of Transportation Manual of Instruction – Roadway Drainage.*

Appendix A: Hydrologic Calculations

Rating Curve

The following is the detailed process in the development of the rating curve using ArcGIS Pro.

1. Pick Stage height, y

2. Determine Area of each data point cell, A_c

3. Using HAND map, determine number of data point cells flooded for stage height, N_{cell}

4. Using HAND map, calculate average side slopes of the river bed, S_b

5. Calculate Area of Water Surface, A_s

$$A_s = A_c * N_{cell}$$

6. Calculate Average Bed Slope of the stream reach

$$A_b = A_c * N_{cell} * S_b$$

7. Using HAND Map, determine average inundation depth, d

8. Determine Volume of water in stream reach, Vol

$$Vol = A_s * d$$

9. Determine stream reach Length, L

10. Using DEM, determine elevation at start and end of stream reach, Z_1 and Z_2

11. Calculate the average cross sectional area of stream, A

$$A = \frac{Vol}{L}$$

12. Calculate average wetted perimeter, P

$$P = \frac{Ab}{L}$$

13. Calculate Hydraulic Radius, R

$$R = \frac{A}{P}$$

14. Calculate channel slope, S

$$S = \frac{Z1 - Z2}{L}$$

15. Determine approximate Manning's coefficient of roughness, n

16. Using Manning's equation, calculate flow

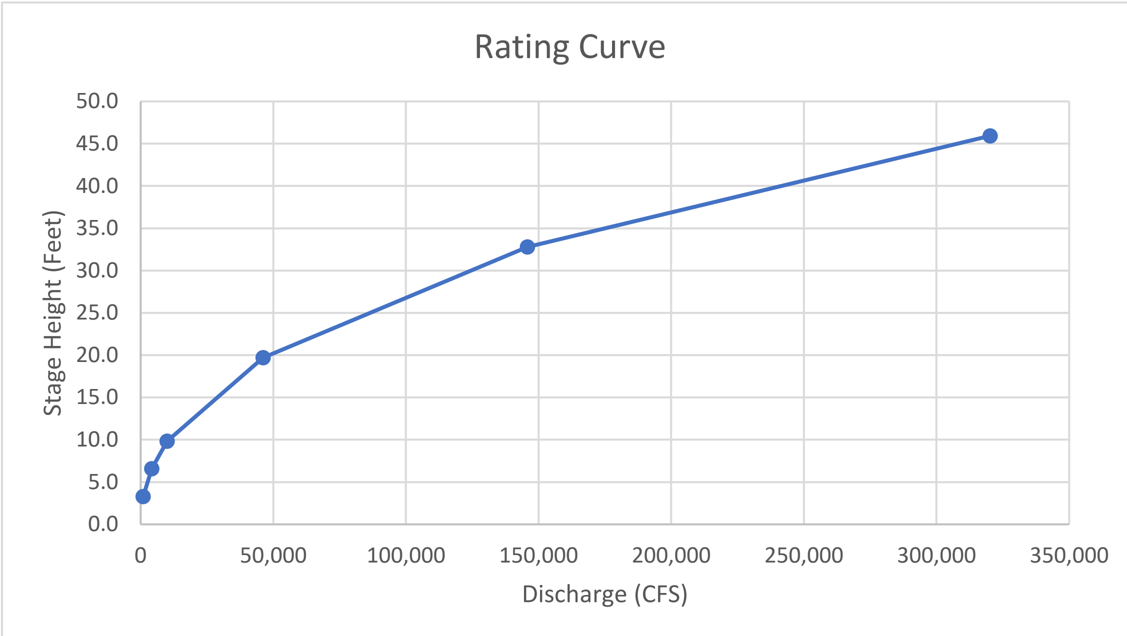
$$Q = \frac{1.4861}{n} A R^{2/3} S_o^{1/2}$$

17. Repeat Steps 1 -16 for each desired stage height

18. Plot Stage vs Flow Rating Curve

The following is the results of this calculation for the stream reach leading to the project site.

Stage Height (m)	y =	0.5	1	2	3	6	10	14
Stage Height (ft)	y =	1.6	3.3	6.6	9.8	19.7	32.8	45.9
Cell Size (m^2)	A_{cell} =	100	100	100	100	100	100	100
Flooding Cell Num	N_{cell} =	303	455	667	843	1327	1977	2,638
Average Bed Slope	S_b =	1.000380	1.0010	1.00325	1.00620	1.0144	1.0223	1.026971
Area of Water Surface (m^2)	A_s =	30,300	45,500	66,700	84,300	132700	197700	263,800
Average Bed Area (m^2)	A_b =	30,311.5	45,545	66,917	84,823	134607.5	202116.6	270,915.0
Avg Inundation Depth (m)	d =	0.385	0.674	1.3112	1.9265	3.683	5.799	7.834
Water Volume (m^3)	Vol =	11,672	30,648	87,460	162,402	488794	1146485	2,066,652
Reach Length (m)	L =	2,227	2,227	2,227	2,227	2227	2227	2,227
Reach Start Elev (m)	z_1 =	2,547.8	2,547.8	2,547.8	2,547.8	2547.8	2547.8	2,547.8
Reach End Elev (m)	z_2 =	2,512.4	2,512.4	2,512.4	2,512.4	2512.4	2512.4	2,512.4
Cross Sectional Area (m^2)	A =	5.2	13.8	39.3	72.9	219.5	514.8	928.0
Wetted Perimeter (m)	P =	13.6	20.5	30.0	38.1	60.4	90.8	121.7
Hydraulic Radius (m)	R =	0.39	0.67	1.31	1.91	3.63	5.67	7.63
Channel Slope (m/m)	S =	0.0159	0.0159	0.0159	0.0159	0.0159	0.0159	0.0159
Mannings "n"	n =	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Flow (m^3/s)	Q =	7.0	26.6	118.4	283.5	1308	4129	9,067.9
Flow (cfs)	Q =	247.02	941.07	4,180.5	10,012.7	46175	145810	320,231.27


Rating Curve
Stage Height (Feet)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
Discharge (CFS)

Appendix B: UDOT References

This is the riprap gradation classes according to UDOT (UDOT 2004).

TABLE 17-5 — Riprap Gradation Classes

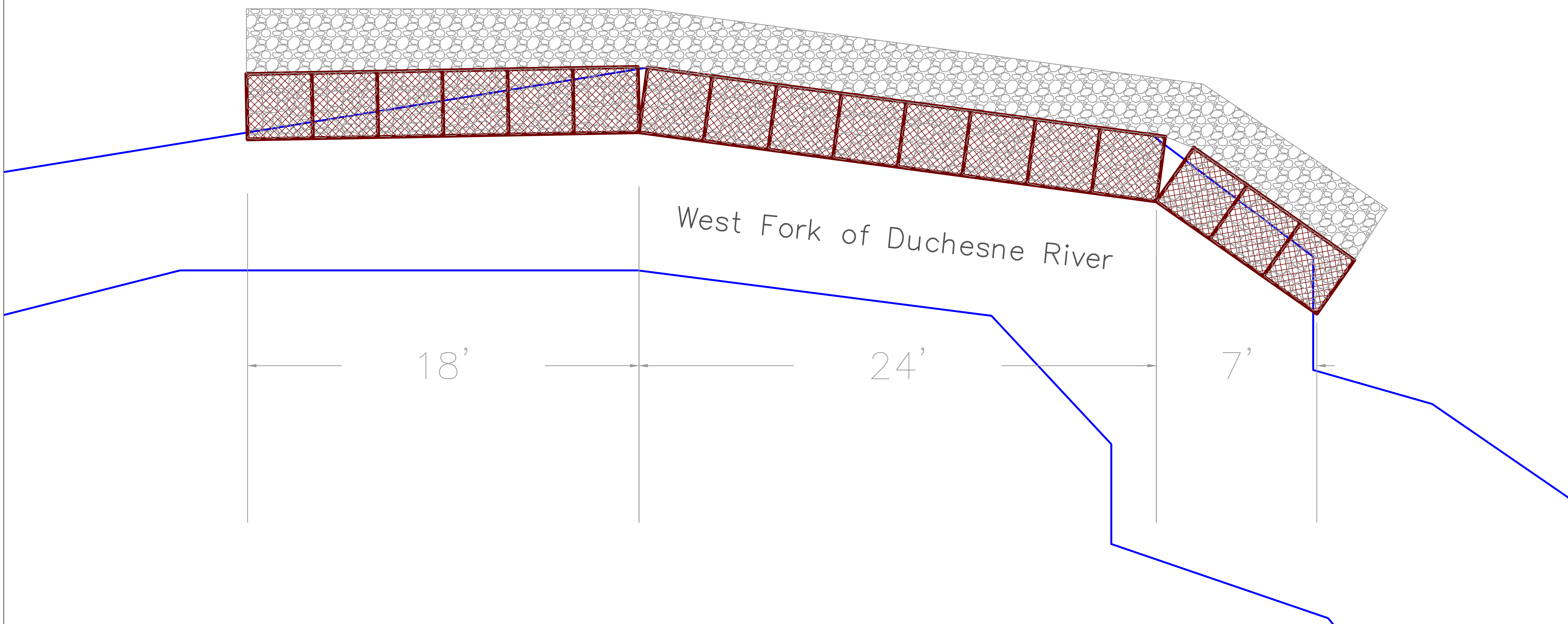
Riprap Class	Rock Size[1] (ft)	Rock Weight[2] (lb)	Percent of Riprap Smaller Than
Facing	1.30 0.95 0.40	200 75 5	100 50 10
Light	1.80 1.30 0.40	500 200 5	100 50 10
1/4 ton	2.25 1.80 0.95	1000 500 75	100 50 10
1/2 ton	2.85 2.25 1.80	2000 1000 500	100 50 5
1 ton	3.60 2.85 2.25	4000 2000 1000	100 50 5
2 ton	4.50 3.60 2.85	8000 4000 2000	100 50 5

[1] *Assuming a specific gravity of 2.65.*

[2] *Based on AASHTO gradations.*

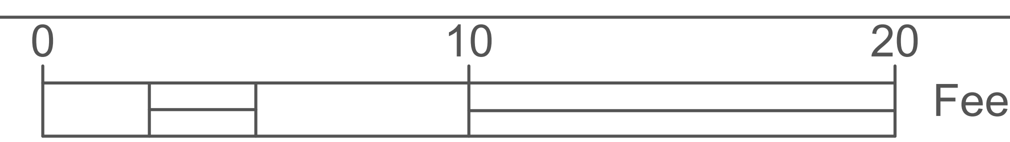
Appendix C: Technical Drawings

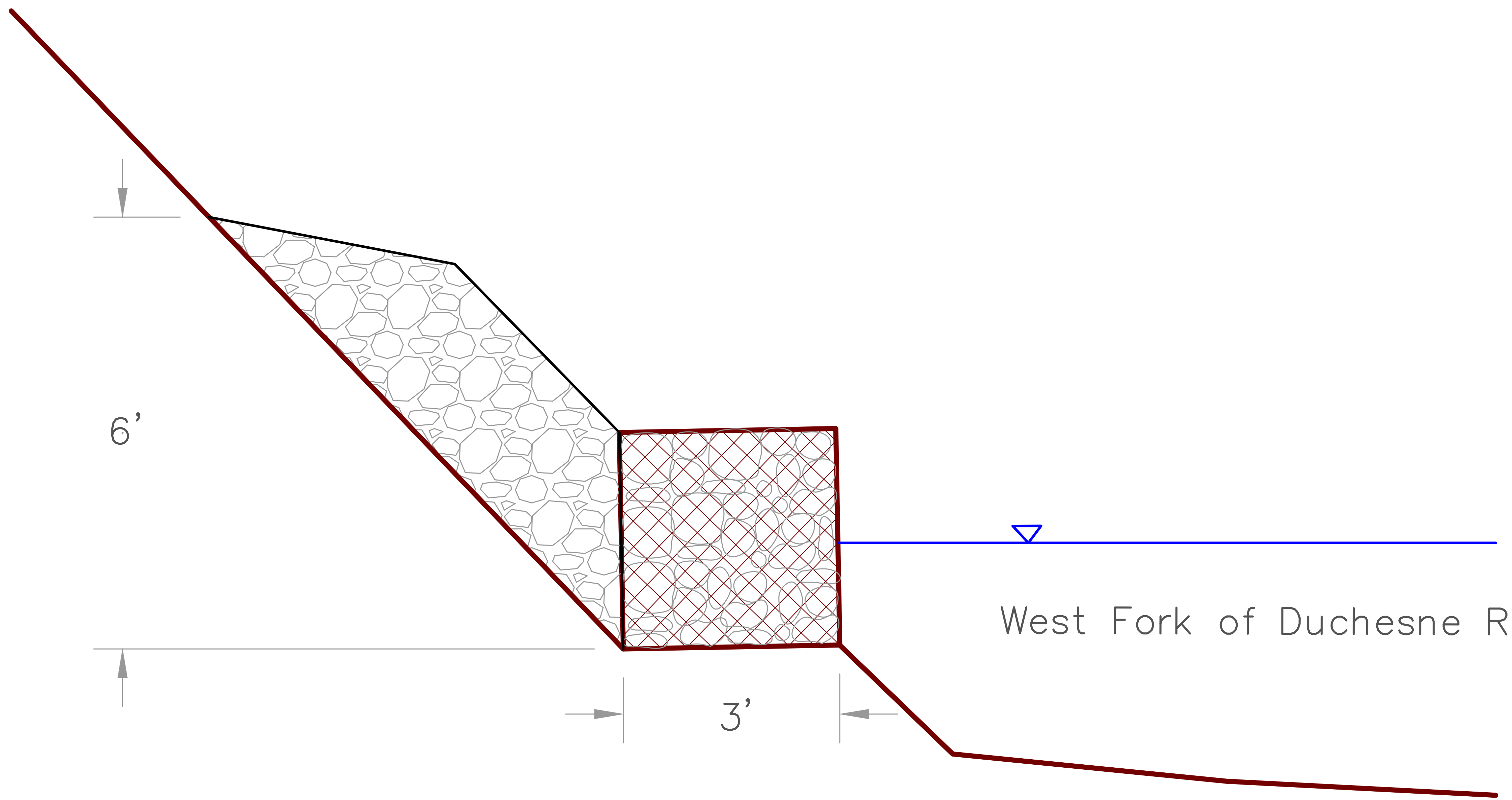
This section includes the technical drawings for the proposed project design.



Plan View

Designer		
Tanner Sweat		





Plan View

Designer		
Tanner Sweat		