APPENDIX F.2

Design of Hydraulic Stabilization for Meyer Draw and East Tributary Arroyo

BACKGROUND

The Meyer Draw is the main branch of the Arroyo Del Valle and runs through the Site between several mine waste rock piles. These facilities are illustrated on the aerial image shown in Figure 1. This image was collected as part of a topographic survey of the site conducted by Cooper Aerial Surveys in 2011 and is used in this analysis to represent existing site conditions.

The site design proposes to excavate all piles located Southwest of the Meyer Draw arroyo and backfill the excavated mine material into the two pits (Pit 1 and Pit 2). The largest pile on Site (Pile 4) will be regraded to stable slopes and left in place between the Meyer Draw and the East Tributary branches of the arroyo. Since the arroyo runs directly adjacent to the pile, Stantec designed channel stabilization measures to prevent arroyo erosion from destabilizing portions of the regraded Pile 4.

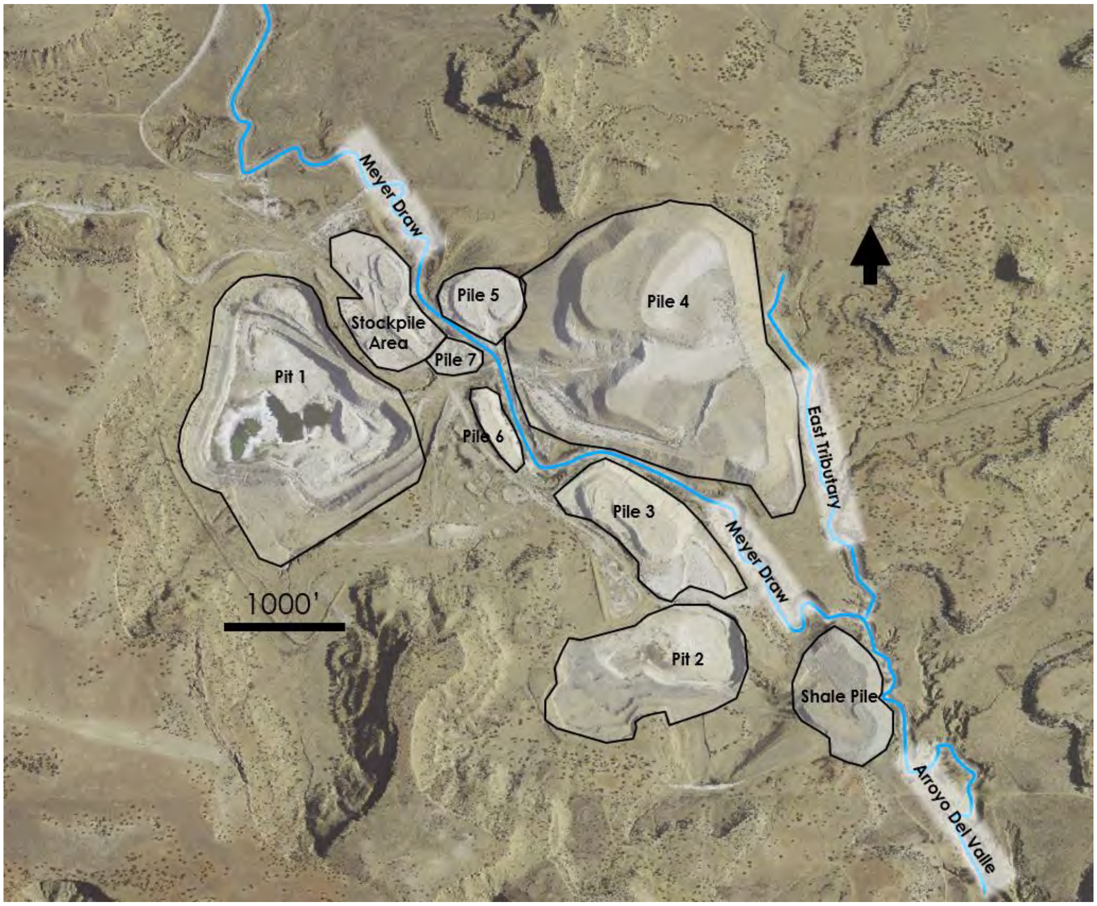


Figure 1: Project Site Existing Conditions (Photo Data: 05/31/2011)

Arroyo Geomorphic Assessment

The arroyo through the Site has been heavily influenced by mining activity. Figure 2 shows an aerial image of the project site prior to mining activities (in the year 1935) with an overlay of the outline of current (as of the 2011 site survey) major mine facilities.

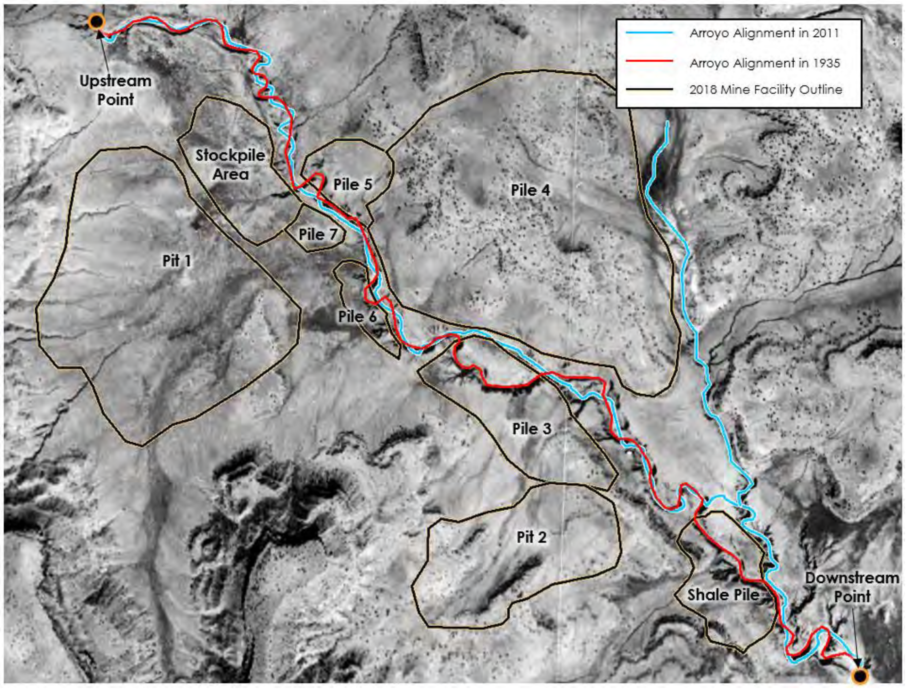


Figure 2: Project Site Prior to Mining Activities

Figure 2 shows that the piles adjacent to the arroyo have altered the pre-mine arroyo alignment between the upstream and downstream extents of the project reach. The pre-mine alignment passes through the current location of Pile 3 and the Shale Pile, and other alignment shifts were made, apparently to accommodate Pile 4, Pile 5, Pile 6, Pile 7 and the Stockpile Area.

Another aerial photograph was taken in 1977, during mining operations (see Figure 3).

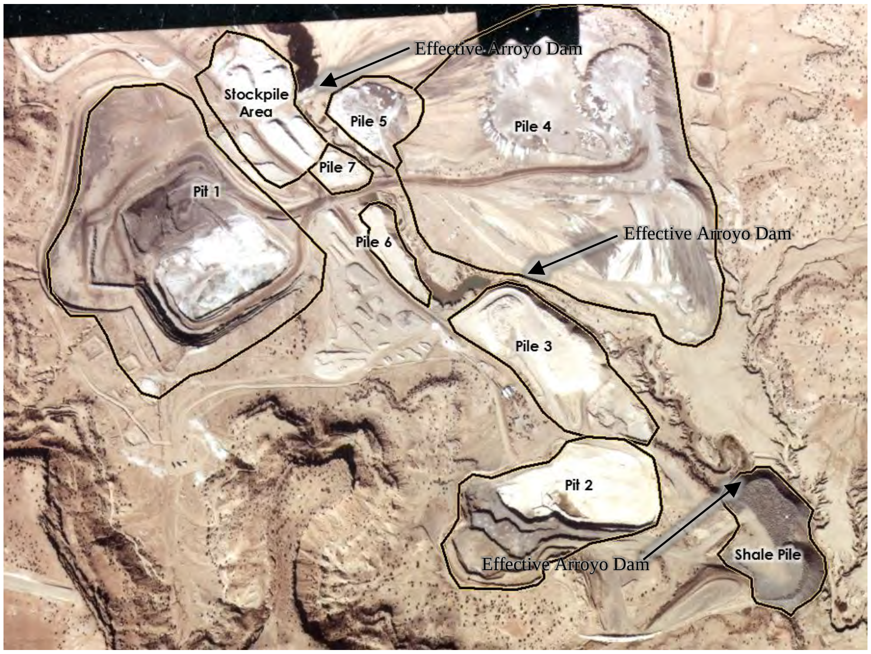


Figure 3: Project Site During Mine Operation

Figure 3 shows that during mine operations Pile 3, the Shale Pile, and a mine road located just east of the Stockpile dammed the arroyo and caused flows to pond behind the facilities. Later, arroyo flow eroded new reaches of channel around (Pile 3 and the Shale Pile) or through (road crossing East of the Stockpile Area) the impeding facilities.

From the 2011 survey, the gradients along the arroyo profile appear to be in a state of non-equilibrium as they continue to adjust to impacts of these mining activities, particularly at the narrow “pinch point” between Pile 3 and Pile 4 (profile station 67+00 in Figure 4). The profile shows two sections with abnormally steep slopes (nearly 3 percent) in the reach directly below the pinch point.

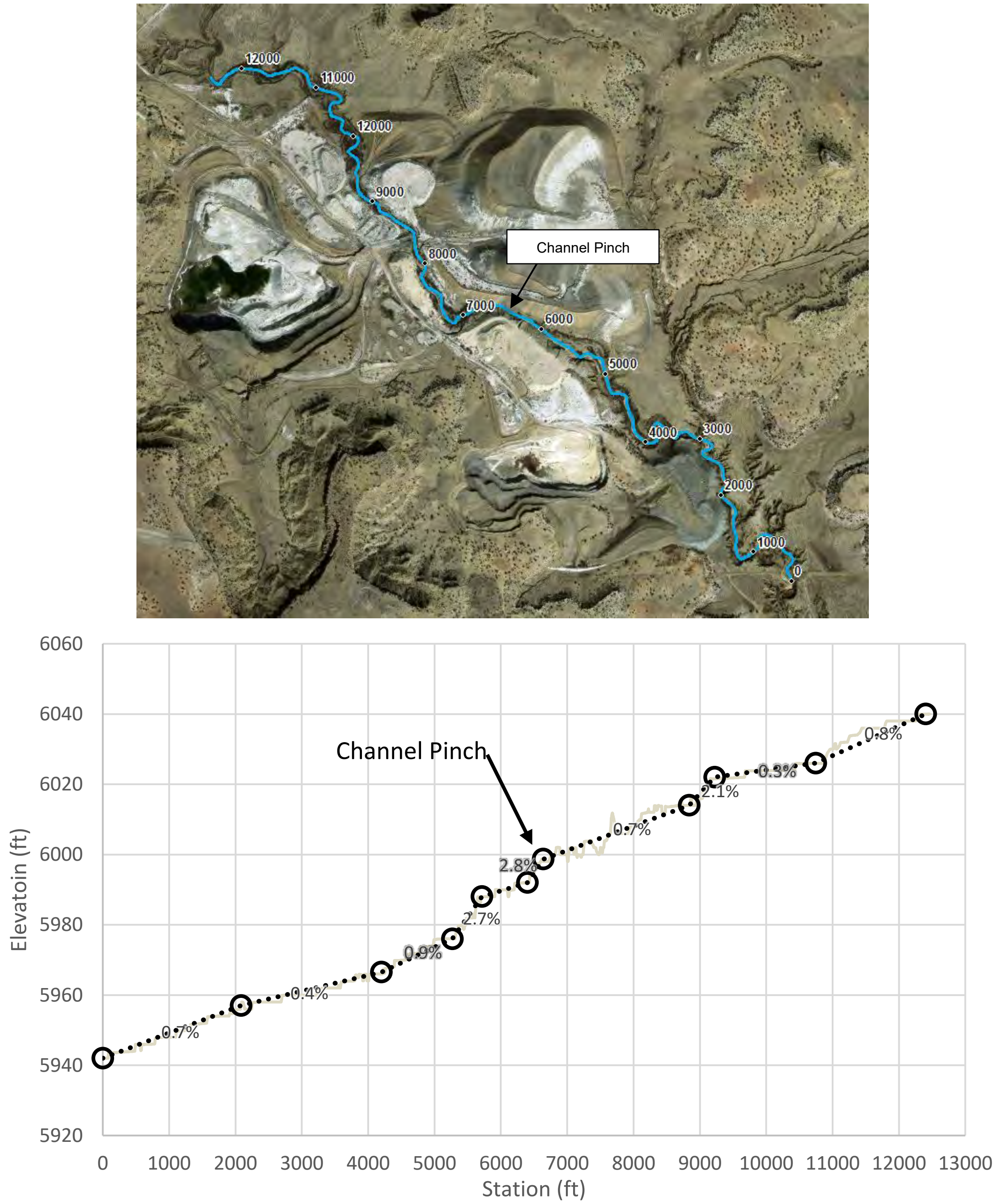


Figure 4: Plan and Profile of the Existing (2011) Arroyo

While visiting the Site, Stantec observed that these steep sloped sections correspond to locations where large slope failures on Pile 3 and Pile 4 at approximate stations 65+00 and 58+00 caused quantities of material from the piles to fall into the channel, depositing large cobbles and boulders (see Figures 5 through 7).

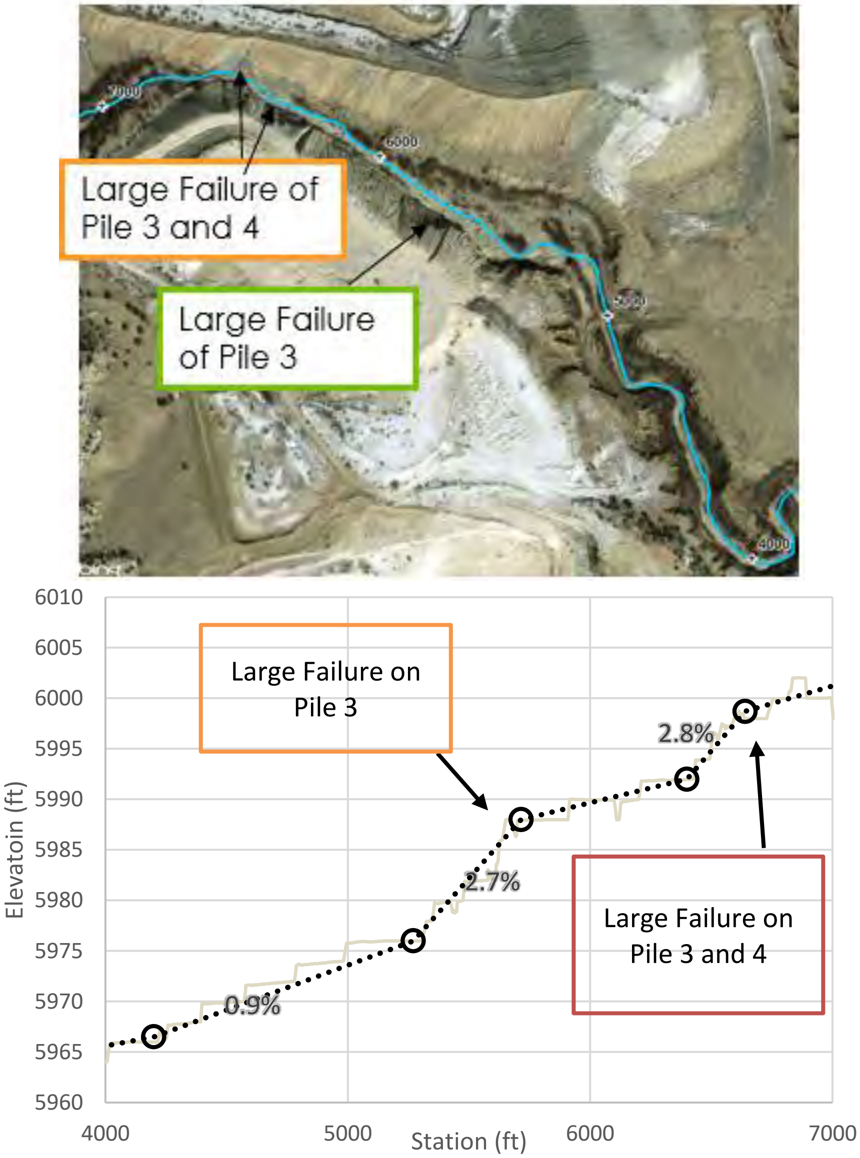


Figure 5: Plan and Profile between Stations 4000 and 7000

Figure 6: Large Failures of Pile 3 (Near Left) and Pile 4 (Far Center) at Approximate Station 65+00

Figure 7: Large Failure Pile 3 at Approximate Station 68+00

Stantec believes the channel through this reach is vertically unstable as the channel is trying to down cut to the gradients present prior to mining actives. This vertical down cutting is slowed when bank failures cause quantities of large boulder and cobble materials stored in Stockpiles 3 and 4 to fall into the channel. It is Stantec's opinion that if the channel were left in its current condition after removal of Stockpile 3 and stabilization of Stockpile 4, the arroyo down cutting would accelerate. Overtime, arroyo down cutting would lead to slope failures along the regraded toe of Stockpile 4 located immediately adjacent to the arroyo.

Stantec proposes installing grade control structures along the Meyer Draw channel to prevent vertical down cutting. The proposed structures will be constructed using roller compacted concrete. Design of the grade control structures is shown on Sheet 18 of the St. Anthony Mine Closeout Plan Design Drawings (design drawings). The structures will lower the channel invert a nominal height. Between structures, the channel will slope at 0.75 percent. Justification for slope is provided below.

To protect against horizonal channel movement a layer of riprap with median stone diameters of 12 inches and 9 inches is proposed along the base of stockpile 4 for both the Meyer Draw and East Tributary branches of the arroyo, respectively (see details 3 and 4 on Sheet 16 of the design drawings). Methods used to evaluate the suitability of this riprap lining is presented below.

Methods

Vertical Grade Control Design Methods

Improvements for vertical grade stability along the Meyer Draw requires establishment of a stable channel cross section and equilibrium slope. Stantec conducted evaluation of the stable channel cross section and equilibrium slope following guidance provided by the Sediment and Erosion Design Guide published by the Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA, 2008). This manual was used due to its completeness in addressing regional arroyo hydraulics and the proximity of its originating county (Sandoval County) to the project site.

Stantec determined the equilibrium slope by evaluating sediment continuity through the engineered project reach with the relatively undisturbed channel reach located immediately upstream during the dominant discharge flow event.

Observations and measurements used to evaluate the upstream reach were taken from the 2011 site survey (Cooper Aerial, 2011) as well as a site visit by Stantec personnel in spring 2018. The cross section selected to represent the upstream reach is illustrated at the end of this report in Attachment A. This section was selected because it is upstream of the obviously mine impacted region of the Site but is still inside the available site survey extents. The cross section selected to represent this reach is located where the cross-sectional dimensions are not overly widened by bend scour.

The dominant discharge flow is the flowrate primarily responsible for creating the form of the existing arroyo dimensions. For this evaluation, Stantec assumed the dominant discharge to be equal to 820 cubic feet per second (cfs). This value was assumed because, when applied to the computational methods below, it produced an equilibrium slope that mirrored the observed average slope estimates made of undisturbed arroyo alignment (measured from the 1935 aerial photograph – Figure 2).

The assumed dominant discharge corresponds to a discharge between the 2-year (412 cfs) and 5-year (1205 cfs) flow events according to Stantec's hydrologic investigation. It also equals 20 percent of the 100-year discharge (4100 cfs).

Evaluation of Channel Hydraulics

To facilitate the evaluation of sediment continuity, the channel hydraulics during the dominant discharge event were determined for the upstream and design channel reaches assuming normal depth flow conditions using the Manning's equation (Equation 2).

$$Q_d = \frac{1.49}{n} * A * \left(\frac{A}{P}\right)^{\frac{2}{3}} * S^{\frac{1}{2}} \qquad \text{Equation 2}$$

Where:

n = channel roughness, 0.03

A = channel flow area, feet squared

P = channel wetted perimeter, feet

S = channel slope, feet per feet

Stantec determined the channel roughness (n) in this evaluation based on guidance provided by the U.S. Geological Survey for coarse sand bedded channels (USGS, 1989).

The channel flow area (A) and wetted perimeter (P) were determined as a function of the channel cross sectional geometry and the flow depth (Y).

The channel velocity (V_d) at dominant discharge was determined by fluid continuity (Equation 3).

$$V_d = \frac{Q_d}{A} \qquad \text{Equation 3}$$

Channel geometry measurements of the upstream reach were taken from the Cooper Aerial (2011) survey. An illustration showing the location and topography of the upstream reach sampling location is provided in Attachment A. Stantec estimated channel sediment particle sizes based on a channel bed sample collected by Stantec at the location indicated in Attachment A. Daniel B. Stephens and Associates (2018) analyzed the sample.

The design reach cross sectional geometry was determined considering guidance provided by the SSCAFCA as well as limitations for practical construction. The SSCAFCA (2008) provides Equation 4 as a reasonable estimate of observed stable arroyo bottom widths in the region. Stantec used this relationship to compute the designed reach bottom width (B).

$$B = 0.5 * F_d^{0.6} * F_r^{-0.4} * Q_d^{0.4} \qquad \text{Equation 4}$$

Where:

B = design arroyo bottom width, feet

F_d = width-depth ratio of flowing water at dominant discharge, (40)

F_r = channel flow Froude number at dominant discharge, (0.7)

Q_d = arroyo dominant discharge (820 cubic feet per second – see Equation 1)

The SSCAFCA (2008) suggests the following for the values assumed in Equation 4:

- Width-depth ratios (F_d) equal to 40 is typically observed in regional arroyos
- Average Froude Number (F_r) in stable sand-bed streams rarely exceed 0.7 to 1.0

For constructability, Stantec assumed a design reach, cross section side slope angles of 3 feet horizontal for every 1 foot vertical.

Equilibrium Slope

To evaluate sediment continuity, the unit sediment load computed during the design discharge flow event was calculated for the upstream and the downstream reaches. The Zeller-Fullerton Relationship with Colby Correction Factor applied to account for the likely presence of high concentrations of fine suspended sediment as described in SSCAFCA (2008) (Equation 5).

$$q_s = 0.0064 * \frac{n^{1.77} * V^{4.32} * G^{0.45}}{Y^{0.3} * D_{50}^{0.61}} * C \qquad \text{Equation 5}$$

Where:

q_s= unit sediment load, cubic feet per second per foot

V = velocity in the channel, feet per second

G = bed sediment gradation coefficient; given as $G = \frac{1}{2}\left(\frac{D_{85}}{D_{50}} + \frac{D_{50}}{D_{15}}\right)$

Y = channel flow depth, feet

D_{50} = median arroyo bed particle size, millimeters

C = Colby Correction Factor, given as $C = 1 + (K_1 * K_2 - 1)$

K_1 = 0.9 from SSCAFCA, 2008 Figure C.1 = f (Y, 60 degrees temperature assumed)

K_2 = 2 from SSCAFCA, 2008 Figure C.1 = f (Y, 45000 ppm fine sediment concentration assumed)

The design reach channel slope (S) was evaluated iteratively by Equation 5 to establish a design reach flow depth (Y_d) and velocity (V_d) that produced a unit sediment load for the design reach (qs_d) equal to the unit sediment load in the upstream reach (qs_u).

Pile 4 Side Slope Riprap

As stated above, for lateral stability of the arroyo channel, riprap will be installed on the toe of Pile 4 that intersects the bank of the Meyer Draw and East Tributary channels. The design flow event considered to size arroyo channel riprap and to determine arroyo scour potential is the 100-year discharge taken from Appendix E.1 (4100 cfs and 409 cfs for the Meyer Draw and East Tributary channels, respectively). The design median stone diameter for the riprap gradation was determined by Maynord's equation as described in NEH-TS14c (2007) (Equation 6).

$$D_{50r} = C_s * C_v * C_t * Y * \left[\left(\frac{\gamma_w}{SG_{rr} * \gamma_w - \gamma_w}\right)^{0.5} * \frac{V}{\sqrt{K_1 * g * Y}}\right]^{2.5} * K_a * K_b \qquad \text{Equation 6}$$

Where:

D_{50r} = minimum stable median stone diameter, inches

C_s = side slope stability coefficient, 0.3 for angular rock on 3:1 side slope

C_v= velocity distribution coefficient, 1.0 for straight channel

C_t= riprap thickness coefficient, 1.0 for 2*D_{50} thickness

Y = channel flow depth, feet (100-year event)

γ_w = specific weight of water, 62.4 pounds per foot cubed

SG_{rr}= riprap specific gravity, 2.65 assumed

V = channel velocity, feet per second (100-year event)

K_1 = side slope correction factor, given as $K_1 = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\varphi}}$

θ = bank side slope angle with horizontal, 3H:1Z = 18.4 (deg)

φ = riprap angle of repose, 40 degrees assumed

g = gravitational acceleration constant, 32.2 feet per second squared

K_a= unit conversion constant, feet to inches (12)

K_b = gradation conversion constant, 1.15

Channel hydraulic parameters (Y and V) were determined by the Manning's equation (Equation 2).

The channel roughness (n) used for hydraulic evaluation of the Meyer Draw and East Tributary arroyos considered that only one bank of the arroyo would be lined with riprap. The other bank and channel bottom will remain unlined and the channel roughness was computed by Equation 7.

$$n = \frac{P_u n_u + P_l n_l}{P_t} \qquad \text{Equation 7}$$

Where:

P_u = wetted perimeter of the unlined portion of the channel cross section, feet

n_u = unlined channel roughness, 0.03 (USGS, 1989)

P_l = wetted perimeter of the lined portion of the channel cross section, feet

n_l = lined channel roughness, as computed by Strickler's Equation from USACE (1994)

$$n_l = 0.036 * D_{90} *^{\frac{1}{6}}$$

D_{90} = diameter which is larger than 90 percent of stones in riprap gradation, 16 inches assumed

P_t = total channel wetted perimeter, feet

A riprap stability factor (SF) that compares the design median riprap size (D_{50rr} = 12 and 9 inches) against the minimum stable median riprap size (D_{50r}) for the Meyer Draw and East Tributary branches of the arroyo was determined by Equation 8. The National Resources Conservation Services National Engineering Handbook – Technical Supplement 14B (NRCS, 2007) states, SF values should usually range between 1.1 and 1.5. For this evaluation a minimum SF value of 1.4 was assumed.

$$SF = \frac{D50_{rr}}{D50_r} \qquad \text{Equation 8}$$

General scour was considered to aid in design of riprap toe protection. The Lacey regime method (Lacey, 1931) as presented in Pemberton and Lara (1984) (Equation 9) as well as the relationship developed by Zeller (1981) (Equation 10) we each considered to evaluate the potential depth of scour that could occur during the design (100-year) discharge event (Q = 4100 cfs). These equations were selected for their specific relevance to silt/sand bottomed channels like the Arroyo del Valle through the Site. For design purposes, the larger predicted scour between the two methods is assumed.

$$Y_s = Z_l * 0.47 * \left(\frac{Q}{f}\right)^{\frac{1}{3}} \qquad \text{Equation 9}$$

Where:

Y_s = predicted scour depth, feet

Z_l = Lacey's multiplying factor

f = Lacey's silt factor computed as $f = 1.76 * D_{50n}^{\frac{1}{2}}$

D_{50n}= native sediment median particle diameter, millimeters

Pemberton and Lara (1984) recommends a multiplying factor (Z) equal to 0.25. The native sediment median particle diameter (D_{50n}) was assumed to be equal to 0.045 mm. This value equals the median particle diameter measured at upper end of the Meyer Draw (see Attached Figure 1).

$$Y_s = Y * \left(\frac{0.0685 * V^{0.8}}{Y_h^{0.4} * S^{0.3}} - 1\right) \qquad \text{Equation 10}$$

Where:

Y = flow depth, feet

V = flow velocity, feet per second

Y_h = hydraulic depth of flow where $Y_h = \frac{A}{B + Y * Z}$

A = flow area, feet squared

B = channel bottom width, feet

Z = bank angle, horizontal to vertical

Arroyo Design Evaluation Results

Arroyo Equilibrium Slope Results

Table 1 shows the results of evaluations used to determine the arroyo equilibrium slope.

Table 1: Equilibrium Slope Results

Design Parameter	Units	Upstream Reach	Design Reach
Design Discharge, Qd	Cubic Feet per Second	820	820
Median Bed Particle Diameter, D_{50}	millimeters	0.045	0.045
Channel Roughness, n	-	0.031	0.031
Flow Area, A	Square Feet	143	144
Wetted Perimeter, P	Feet	99	91
Flow Depth, Y	Feet	1.5	1.7
Flow Velocity, V	Feet per Second	5.7	5.7
Design Arroyo Bottom Width, B	Feet	-	80
Design Arroyo Slope, S	Feet per Feet	-	0.0075
Unit Sediment Load, qs	Cubic Feet per Second per Foot	0.45	0.49

From Table 1, the design channel bottom width computed using the suggested rule of thumb method presented in Equation 4 yields a design channel bottom width of 80 feet. This design arroyo bottom width is approximately equal to the bottom width of the upstream arroyo cross section (see Attachment A). Continuity of the channel cross section between the upstream and design reach is desirable to create a hydraulically smooth transition. The computed unit sediment load for the upstream reach is 0.45 cfs per foot of channel width. The design channel slope computed to mirror this unit sediment load is 0.0075 feet per feet (0.75 percent). This compares well to slope estimates made by observation of the undisturbed arroyo alignment (measured from the 1935 aerial photograph – see Figure 2). From the 1935 aerial photograph, Stantec estimates the undisturbed channel length through the reach was 12,850 feet. Assuming the bed elevations at the upstream point (6040 feet) and downstream point (5943 feet) indicated in Figure 2 were the same in 1935 as when the site was surveyed in 2011, the average channel slope through the reach would also be 0.75 percent.

It should be noted that the predicted equilibrium slope is fairly sensitive to the arroyo dominant discharge value assumed which is based on observation and rule of thumb metrics and is not known with much certainty. It will be necessary to design robust grade control structures that are capable of remaining stable under a range of slopes between structures.

Pile 4 Slide Slope Riprap Results

Table 2 lists the channel roughness computed by Equation 7 and the channel hydraulic parameters computed for the design (100-year) discharge by Equation 2. Table 2 also shows the minimum stable median stone diameters computed by Equation 6 and the stability factor for the design riprap with a median stone diameter of 12 inches on the Meyer Draw branch and 9 inches on the East Tributary branch.

Table 2: Riprap Sizing Results

	Meyer Draw Channel	East Tributary Channel
Composite Channel Roughness, n	0.031	0.033
Channel Flow Depth, Y	4.4 feet	2.6 feet
Channel Flow Velocity, V	10.0 feet per second	8.2 feet per second
Minimum Stable Median Stone Diameter, $D50_f$	7.5 inches	5.2 inches
Stability Factor, SF	1.6	1.7

From Table 2, Stantec predicts the design riprap will protect the channel during the 100-year flood event with minimum predicted stability factors equal to 1.6. Table 3 shows the design scour depths evaluated by Equation 8 and 9.

Table 3: Channel Scour Results

	Meyer Draw Channel	East Tributary Channel
Scour Depth – Lacey	2.6 feet	1.2 feet
Scour Depth - Zeller	0.4 feet	0.0 feet
Design Scour Depth	2.6 feet	1.2 feet

The scour depths predicted during the 100-year event by the Lacey and Zeller methods range between 2.6 feet and 0.4 feet in the Meyer Draw channel. The scours depths in the East Tributary channel range between 1.2 feet and 0.0 feet. Pile 4 riprap revetments shall be installed to minimum depth of 2.6 feet and 1.2 feet below the invert of the Meyer Draw and East Tributary branches.

Future Evaluations

The roller compacted concrete grade control structure design presented on Sheet 18 of the design drawings represents a conceptual level design only. Future design iterations will take the stable channel slope and cross-sectional geometry presented here and optimize structure drop height to minimize the excavation and material volumes necessary to provide adequate protection along the Meyer Draw Arroyo.

Future design iterations will also address the soil filter systems beneath the riprap revetments. Properly designed soil filters will particularly important at this Site due to the highly erosive soils present. The channel filter system may utilize granular filters (as depicted in the design drawings) or manufactured geotextiles specifically designed for surface water drainage applications.

References

Cooper Aerial, 2011. Project site aerial survey taken in 2011.

Daniel B. Stephens and Associates, 2018. Laboratory Report for Stantec – St. Anthony Geotech Investigation. PO#233001076-DBS. June 20.

Lacey, G. 1931. Regime diagrams for the design of canals and distributaries. Tech. paper no. 1. United Provinces: Public Work Dept., Irrigation Branch.

Natural Resources Conservation Service, 2007. National Engineering Handbook Part 654 – Technical Supplement 14c – Stone Sizing Criteria. NEH-TS14c. August.

Pemberton, E.L., and J.M. Lara. 1984. Computing degradation and local scour: technical guideline for Bureau of Reclamation. U.S. Dept. of Interior, Bureau of Reclamation Engineering and Research Center. Denver, CO.

SSCAFCA, 2008. Sediment and Erosion Design Guide. Prepared by Mussetter Engineering Inc. for Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA). November.

U.S. Geologic Survey, 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. United States Geological Survey Water-Supply Paper 2339

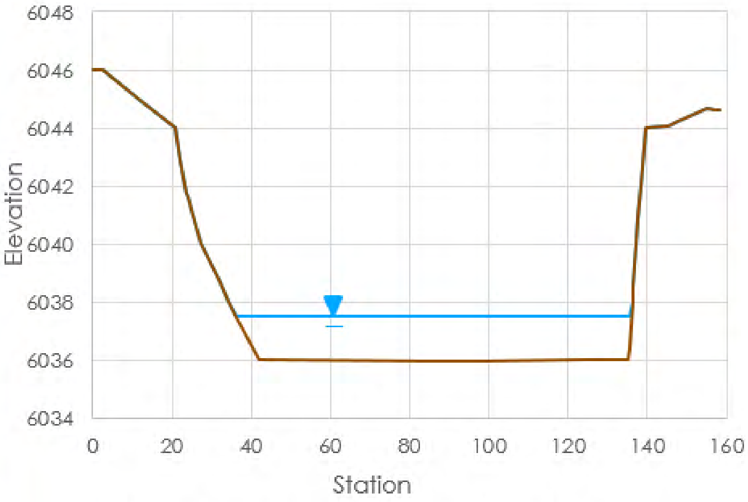
U.S. Army Corps of Engineers. 1994. Hydraulic design of flood control channels. EM 1110-2-1601.

Zeller, M.E. 1981. Scour depth formula for estimation of toe protection against general scour. Pima County Department of Transportation and Flood Control District, Tucson, Arizona.

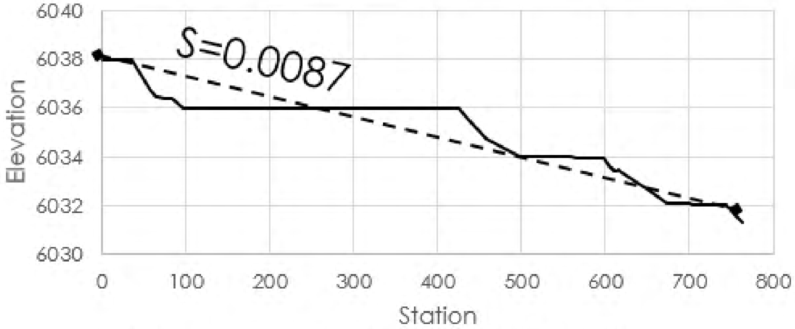
ATTACHMENT A

Upstream Cross Section Figure

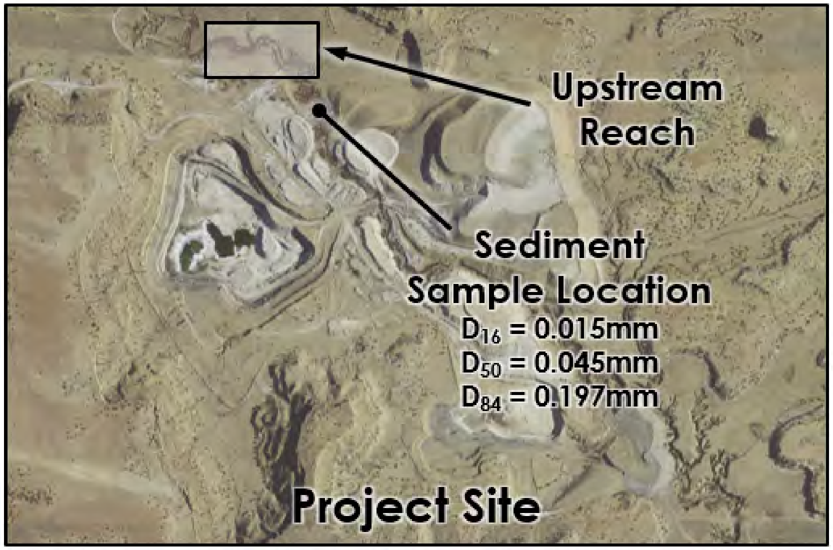
Upstream Reach



Upstream Cross Section



Upstream Reach Profile



Upstream Reach

Sediment Sample Location

D_{16} = 0.015mm

D_{50} = 0.045mm

D_{84} = 0.197mm

Project Site

ATTACHMENT B

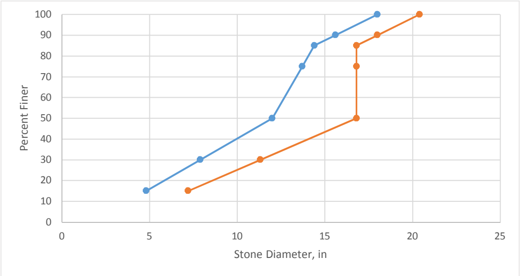
Calculation Worksheets

Arroyo Riprap Armoing along Pit 4 Calculations

Input Variables	**Main**		**Trib**		**Notes**
Hydrologic Element :	Ex-Outlet		EX-SB3		
Discharge, Q (cfs) :	4102		409		Appendix E.1
Slope, S (ft/ft) :	0.0075		0.014		Design Drawings
Bottom Width, B (ft) :	80		15		Design Drawings
Side Slope, Z1:1 :	3		3		Design Drawings
Side Slope, Z2:1 :	3		0.5		
RR Specific Gravity, SGs :	2.65		2.65		Assumed Riprap Parameter
RR Anlge of Repose, (deg) :	40.00		40.00		Assumed Riprap Parameter
Median Riprap, D50 (in) :	12		9		Design Median Riprap Diameter
Natural bed Roughness, nb :	0.030		0.03		Table 1 (USGS, 1989), Assumed Coarse Sand Bed
RR Roughness, nr :	0.041		0.041		Eq. 3.2 (USACE, 1994) Strickler's Equation for RR Line Bank
Composite Roughness, n :	0.031		0.033		
Flow Depth, Y (ft) :	4.393	4.39425	2.56	2.56336	Manning's Equation
Iterate to Zero --->	2.918		0.020		
Flow Area, A (ft2) :	409.34		49.94		A = (B+Z*Y)*Y
Wetted Per., P (ft) :	107.8		26.0		P = B+2*Y*(Z^2+1)^0.5
Channel Top Width, TW (ft) :	106.4		24.0		T = B+2*Y*Z
Channel Velocity, V (fps) :	10.02		8.19		V = Q/A
Unit Discharge, q (cfs/ft) :	44.03		20.99		q = V*Y
Channel Shear, T (lbs/ft2) :	1.8		1.7		T = 62.4*(A/P)*S

RR Gradation Criteria		
Percent Finer	**Min**	**Max**
100	D50 x 1.5	D50 x 1.7
85	D50 x 1.2	D50 x 1.4
50	D50 x 1.0	D50 x 1.4
15	D50 x 0.4	D50 x 0.6

Design RR Gradation		
Percent Finer	**Min (in)**	**Max (in)**
100	18	20.4
90	*15.6*	*18.0*
85	14.4	16.8
75	*13.7*	*16.8*
50	12	16.8
30	*7.9*	*11.3*
15	4.8	7.2



Method Base	**Method**	**RR at Failure**	**Stability Factor**	**RR at Failure**	**Stability Factor**
Velocity*	Maynord Equation	7.54	1.6	5.21	1.7
Shear	HEC-15 Critical Shear	3.58	3.35	4.39	2.05
Shear	NCH Research Program Report 108	5.33	2.25	5.04	1.79
Shear*	Far West States (FWS)	7.00	1.71	7.63	1.18
Velocity	FHWA - HEC-11	5.77	2.08	4.28	2.10
Velocity	Isbash Method	7.88	1.52	5.26	1.71
Velocity	Cal-Trans RSP	6.85	1.75	4.58	1.97

References

USGS, 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. United States Geological Survey Water-Supply Paper 2339
HEC-11, 1989. Design of Riprap Revetment. Federal Highway Administration - Hydrauilc Engineering Circular No. 11
USACE, 1994. Hydraulic Design of Flood Control Channels. U.S. Army Corps of Engineers. Engineering Manual 1110-2-1601.
NEH-TS14c, 2007. Stone Sizing Criteria. U.S. Bureau of Reclamation. National Engineering Handbook Part 654. Technical Supplement 14C.

Maynord Equation	**Main**	**Trib**	**Notes**
Stability Coeff, Cs :	0.30	0.30	0.3 for "Angular Rock" and 0.375 for "Rounded Stone"
Vert Vel Coeff, Cv :	1.00	1.00	Use 1.0 for "Straight Channel"
Thickness Coeff, Ct :	1.00	1.00	Use 1.0 if RR thickness is greater then 1.5D50
Side Slope Correction, K1 :	0.87	0.87	Eq. 3-4 (USACE, 1994)
Min Stable RR, D30 (in) :	6.55	4.53	Eq. TS14c-5 (NEH-TS14c, 2007)
Min Stable RR, D50 (in) :	7.54	5.21	D50 = 1.15*D30 Per NEH-TS14C, 2007
RR Stability Factor :	**1.59**	**1.73**	

HEC-15 Critical Shear	**Main**	**Trib**	**Notes**
Shear Velocity, u* (fps) :	1.030	1.075	Eq. 6.10 (HEC-15, 2005)
Kinematic Viscosity, v (ft2/s) :	1.21E-05	1.21E-05	Fluid Property of Water (assumed)
Particle Reynolds Number, Re :	8.51E+04	6.66E+04	Eq. 6-9 (HEC-15, 2005)
Computed F* :	0.0760	0.0641	See Table 6.1 (HEC-15, 2005)
SF :	1.14	1.08	See Table 6.1 (HEC-15, 2005)
Channel Bottom - D50 (in) :	3.60	4.41	Eq. 6-8 (HEC-15, 2005)
Side Slope Correction for RR, K1 :	0.868	0.868	Eq. 6-16 (HEC-15, 2005)
Side Slope Correction for Shear, K2 :	0.871	0.871	Eq. 3.4 (HEC-15, 2005)
SS - Minimum Stable D50 (in) :	3.58	4.39	Eq. 6-15 (HEC-15, 2005)
RR Stability Factor :	3.35	2.05	

NCH Research Program Report 108	**Main**	**Trib**	**Notes**
Channel Shear, T (lbs/ft2) :	1.8	1.7	Eq. TS14C-2 (NEH-TS14c, 2007)
Critical Shera, Tc (lbs/ft2) :	4.0	3.0	Eq. TS14C-3 (NEH-TS14c, 2007)
Minimum Stable D50, (in) :	5.33	5.04	Eq. TS14C-4 (NEH-TS14c, 2007)
RR Stability Factor :	2.25	1.79	

Far West States (FWS)	**Main**	**Trib**	**Notes**
Channel Curve Correction, C :	1.0	1.0	"Straight Channel" See Figure TS14C-8 (NEH-TS14c, 2007)
Side Slope Correction, K :	0.87	0.87	Eq. 3-4 (USACE, 1994)
Minimum Stable D75, (in) :	8.27	9.00	Eq. TS14C-19 (NEH-TS14c, 2007)
Minimum Stable D50, (in) :	7.00	7.63	Assumed D75 = 1.18*D50 (See Manual Example Problems)
RR Stability Factor :	1.71	1.18	

FHWA - HEC-11	**Main**	**Trib**	**Notes**
Side Slope Correction, K1 :	0.87	0.87	Eq. 7 (HEC-11, 1989)
RR SG Factor Correction, Csg :	1.00	1.00	Eq. 8 (HEC-11, 1989)
Stabilty Factor SF:	1.00	1.00	Assumed
Stablity Factor Correction, Csf :	0.76	0.76	Eq. 9 (HEC-11, 1989)
Minimum Stable D50, (in) :	5.77	4.28	Eq. 6 (HEC-11, 1989)
RR Stability Factor :	2.08	2.10	

Isbash Method	**Main**	**Trib**	**Notes**
Turbulence Coeff. C :	1.20	1.20	For "Low Turbidity" C = 1.2. For "High Turbidity" C = 0.86
Min Stable D50 :	7.88	5.26	Eq. TS14C-1 (NEH-TS14c, 2007)
RR Stability Factor :	1.52	1.71	

Cal-Trans RSP	**Main**	**Trib**	**Notes**
Flow Type Coeff, :	0.67	0.67	For "Parallel flow" VM = 0.67, "impinging flow" VM = 1.33
Minimum Stone Weight, W (lbs) :	30.80	9.17	Eq. TS14c-18 (NEH-TS14c, 2007)
Miminum Stable D50 (in) :	6.85	4.58	Cubic shaped RR assumed
RR Stability Factor :	1.75	1.97	

Arroyo Scour Depth Calculation

Design Riprap Diameter, D50d (in) :	12	9	
	Main	**Trib**	**Notes**
	Design Parameters		
Hydrologic Element :	Ex-Outlet	EX-SB3	
Design Discharge, Qd (cfs/ft) :	4102.40	409.00	100-Year Discharge (REF: HYDROLOGY REPORT)
Flow Depth, Y (ft) :	4.39	2.56	
Flow Velocity, V (fps) :	10.02	8.19	
Flow Area, A (ft) :	409.34	49.94	
Unit Discharge, q (cfs/ft) :	44.03	20.99	
Channel Top Width, Wf (ft) :	106.4	24.0	See Arroyo Riprap spreadsheet Cell C18 and E18
Hydrauilc Depth, Yh (ft) :	3.8	2.1	
Channel Slope , S :	0.0075	0.014	
Median Bed Particle Size, D50b (mm) :	0.045	0.045	Measured at SA GM 1T
	Predicted Scour Depth - Pemberton and Lara and Zeller		
Blench Zero Bed Factor, fbo :	0.0271	0.0271	Pemberton and Lara, 1984
Blench Multiplying Factor, Z :	0.6	0.6	Pemberton and Lara, 1984
Blench Scour Depth, Zb (ft) :	24.9	15.2	Pemberton and Lara, 1984
Lacey's Silt Factor, f :	0.37	0.37	Pemberton and Lara, 1984
Lacey Multiplying Factor, Z :	0.25	0.25	Pemberton and Lara, 1984
Lacey Scour Depth, Zl (ft) :	2.6	1.2	Pemberton and Lara, 1984
Zeller Scour Depth, Zz (ft) :	0.42	-0.03	Zeller, M.E. 1981.
	Launching Riprap Toe		
Design Scour Protection Depth, Dp (ft) :	2.6	1.2	Design Parameter
Stone Launch Angle, (Z:1) :	2	2	(USACE, 1994)
Stone Volume Increase Factor (%) :	25%	25%	Table 3-2 (USACE, 1994)
Riprap Layer Thickness, Trr (ft) :	2	1.5	Trr = 2*D50
Riprap Buried Depth, Drr (ft) :	3	3	Design Parameter
Required RR Toe Volume, Vrr (ft3/ft) :	-2.2	-7.5	

Arroyo Equilibrium Slope Calculation

Design Criteria:
Iterate the Design Channel Slope until the Corrected Unit Sediment Discharge in the Design Reach matches the Correctied Unit Sediment Discharge in the Upstream Reach

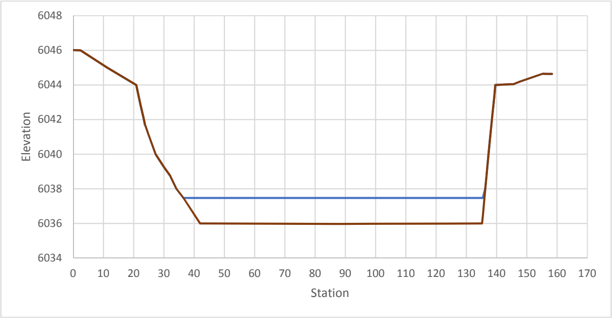
Upstream Cross Section

Design Discharge, Qd (cfs) :	820	
Channel Roughness, n :	0.031	
Bed Slope, S (ft/ft) :	0.0087	
Channel Invert Ele. (ft) :	6035.9702	
Flow Depth, Y (ft) :	1.5	Iterate - Try : 1.5002
Iterate to Zero :	0.1	
Area, A (ft2) :	143.30	
Wetted Perimeter, P (ft) :	99.40	
Average Channel Velocity, V (fps) :	5.7	
Median Particle Diameter, D50 (mm) :	0.045	Measured at GM 1T
Bed Gradation, D84 (mm) :	0.197	Measured at GM 1T
Bed Gradation, D16 (mm) :	0.015	Measured at GM 1T
Bed Gradation Coeff. G :	3.69	Eq. 3.14 From SSCAFCA, 2008
Unit Sediment Discharge, qs (cfs/ft)	0.271	Eq. C.1 From SSCAFCA, 2008
Colby's Correction Factor (K1) :	0.9	See Figure C.1 From SSCAFCA, 2008
Colby's Correction Factor (K2) :	2	See Figure C.1 From SSCAFCA, 2008
Colby's Correction Factor (K3) :	-	See Figure C.1 From SSCAFCA, 2008
Colby Correction Factor :	1.8	Eq. C.2 From SSCAFCA, 2008
Corrected Unit Sediment Discharge, qs (cfs/ft) :	0.49	

Design Cross Section

Design Discharge, Qd (cfs) :	820	
Channel Roughness, n :	0.031	
Bed Slope, S (ft/ft) :	0.0075	
Channel Bottom Width, B (ft) :	80	Eq. 3.35 From SSCAFCA, 2008
Design Width Depth Ratio, Fd :	40	40 from SSCAFCA, 2008
Design Froude Number, Fr :	0.7	Between 0.7 to 1.0 from SSCAFCA, 2008
Channel Side Slope, (Z:1) :	3	
Flow Depth, Y (ft) :	1.7	Iterate - Try : 1.6978
Iterate to Zero :	0.1	
Area, A (ft2) :	144	
Wetted Perimeter, P (ft) :	91	
Average Channel Velocity, V (fps) :	5.7	
Median Particle Diameter, D50 (mm) :	0.045	Measured at GM 1T
Bed Gradation, D84 (mm) :	0.197	Measured at GM 1T
Bed Gradation, D16 (mm) :	0.015	Measured at GM 1T
Bed Gradation Coeff. G :	3.69	Eq. 3.14 From SSCAFCA, 2008
Unit Sediment Discharge, qs (cfs/ft)	0.252	Eq. C.1 From SSCAFCA, 2008
Colby's Correction Factor (K1) :	0.9	See Figure C.1 From SSCAFCA, 2008
Colby's Correction Factor (K2) :	2	See Figure C.1 From SSCAFCA, 2008
Colby's Correction Factor (K3) :	-	See Figure C.1 From SSCAFCA, 2008
Colby Correction Factor :	1.8	Eq. C.2 From SSCAFCA, 2008
Corrected Unit Sediment Discharge, qs (cfs/ft) :	0.45	

Upstream Cross Section



Station	Elevation	WSE	Flow Depth	Flow Area	Wetted Perimeter
0	6046	6046.02	0.00	0.00	0.00
2	6046	6046.00	0.00	0.00	0.00
11	6045	6045.00	0.00	0.00	0.00
21	6044	6044.00	0.00	0.00	0.00
22	6043	6042.87	0.00	0.00	0.00
23	6042	6042.00	0.00	0.00	0.00
24	6042	6041.72	0.00	0.00	0.00
24	6042	6041.60	0.00	0.00	0.00
25	6041	6041.16	0.00	0.00	0.00
27	6040	6040.00	0.00	0.00	0.00
30	6039	6039.26	0.00	0.00	0.00
32	6039	6038.77	0.00	0.00	0.00
34	6038	6038.00	0.00	0.00	0.00
36	6037	6037.47	0.00	0.00	0.00
42	6036	6037.47	1.47	4.03	5.68
42	6036	6037.47	1.47	0.51	0.35
42	6036	6037.47	1.47	0.14	0.09
44	6036	6037.47	1.47	1.82	1.24
87	6036	6037.47	1.50	64.17	43.19
88	6036	6037.47	1.50	1.63	1.09
89	6036	6037.47	1.50	1.34	0.89
98	6036	6037.47	1.49	13.64	9.11
123	6036	6037.47	1.48	37.61	25.30
135	6036	6037.47	1.47	17.62	11.95
135	6036	6037.47	1.06	0.38	0.51
136	6038	6038.00	0.00	0.41	0.00
137	6039	6038.58	0.00	0.00	0.00
137	6040	6040.00	0.00	0.00	0.00
138	6041	6040.89	0.00	0.00	0.00
138	6042	6042.00	0.00	0.00	0.00
139	6043	6043.34	0.00	0.00	0.00
140	6044	6044.00	0.00	0.00	0.00
145	6044	6044.04	0.00	0.00	0.00
146	6044	6044.04	0.00	0.00	0.00
148	6044	6044.20	0.00	0.00	0.00
155	6045	6044.65	0.00	0.00	0.00
157	6045	6044.63	0.00	0.00	0.00
158	6045	6044.64	0.00	0.00	0.00