APPENDIX F.3

Design of Bench and Downdrain Channels for Pile 4

BACKGROUND

The proposed closure plan for Pile 4 is to push the pile material to the borders of the Meyer Draw and East Tributary branches of the Arroyo del Valle that flanks the southwest and eastern pile edges. From the arroyo edges, the pile will be sloped at a design grade of 20 percent. The pile slopes will be broken by benches that capture and convey rainfall runoff from the Pile interbench slopes. The maximum length of the interbench slopes will be 400 feet (see Appendix G). Stormwater conveyance channels constructed on the stockpile benches will extend from the north face of the pile at an approximate 2 percent grade toward an armored downdrain channel at the southern end of the stockpile (see Figure 1, see also Sheet 9 of the St. Anthony Mine Closeout Plan design drawings). The bench channel cross sections will be triangular with riprap armoring near the channel invert and vegetation lining on the outer portions (see Detail 1 on Sheet 16 of the design drawings). The downdrain channel will convey flow at a slope which decreases from approximately 11 percent at the upstream portion to approximately 5 percent at the downstream portion. The downdrain channel will be riprap lined with a trapezoidal cross section (see Detail 2 on Sheet 16 of the design drawings). The downdrain will convey flow off the stockpile and will discharge near the confluence of the Arroyo de Valle's Meyer Draw and East Tributary branches. This document describes Stantec's evaluations of hydraulic conditions in the Stockpile 4 bench and downdrain channels during a runoff event with a 1 in 100-year probability of occurring.

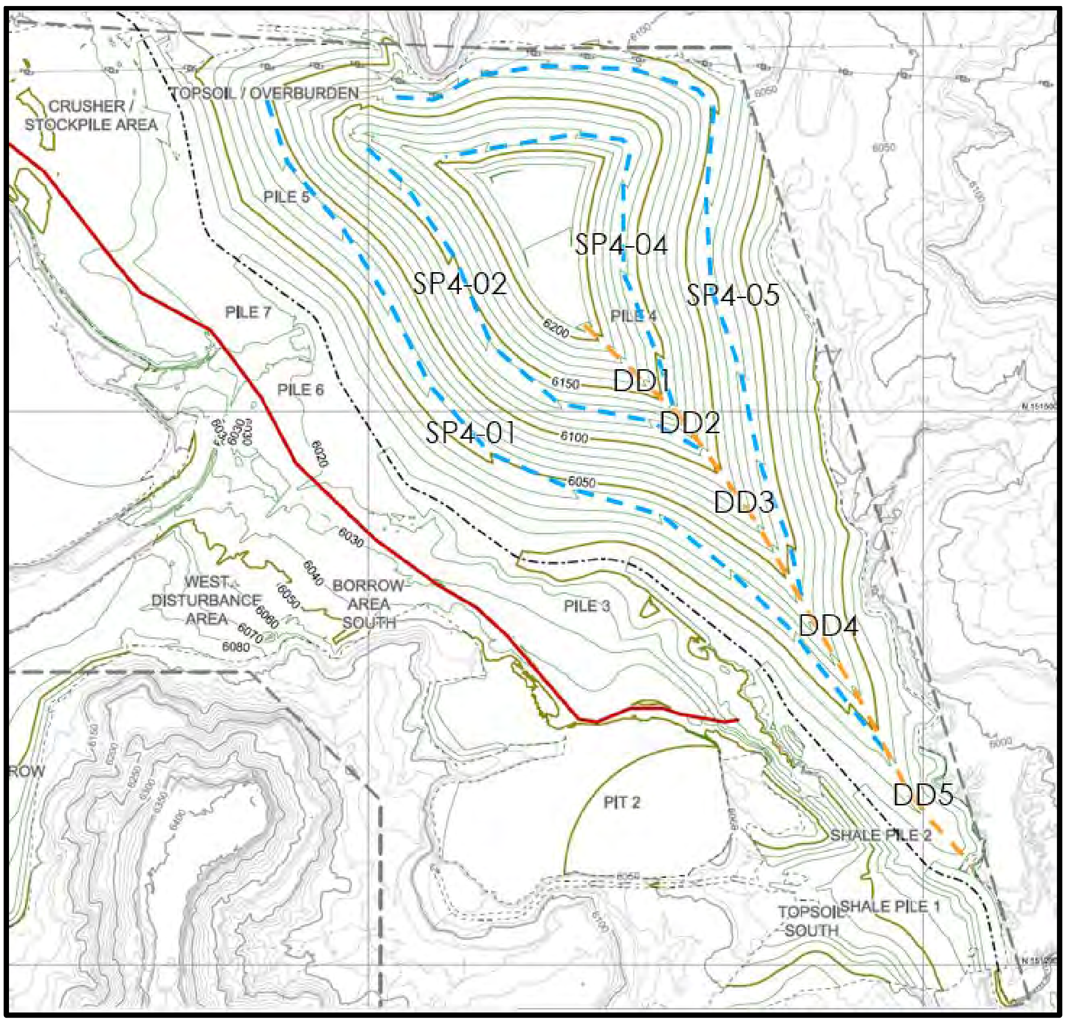

Figure 1: Plan View of the Proposed Stockpile 4

Design Data

The bench channels and downdrain are designed to protect against hydraulic scour during the rainfall event with a 1 in 100-year probability of occurrence.

The design discharge values for the bench channels and downdrains were taken from the site hydrologic study (see Appendix E.1). Detail 1 on Sheet 16 of the design drawings shows channel geometric parameters for the bench channels. Detail 2 on Sheet 16 of the design drawings show downdrain geometric parameters. Tables 1 and 2 present these design values for the bench channels and downdrain, respectively.

Table 1: Bench Channel Design Parameters

	Units	SP4-01	SP4-02	SP4-04	SP4-05
Design Discharge, Q	cfs	40	31	19	35
Channel Slope, S	ft/ft	0.02	0.02	0.02	0.02
Minimum Riprap Armoring Depth, d_{rr}	ft	1.15	1.15	1.15	1.15
Bench Side Slope, Z_1:1	-	20	20	20	20
Bench Side Riprap Armoring Width, W_{dd}	ft	23	23	23	23
Hill Side Slope, Z_2:1	-	5	5	5	5
Channel Depth, H_b	-	2	2	2	2
cfs = cubic feet per second; ft/ft = feet per feet					

Table 2: Downdrain Design Parameters

	Units	DD1	DD2	DD3	DD4	DD5
Design Discharge, Q	cfs	13	31	61	88	123
Channel Slope, S	ft/ft	0.11	0.10	0.08	0.05	0.05
Channel Side Slopes, Z:1	-	3	3	3	3	3
Channel Depth, H_{dd}	ft	2.5	2.5	2.5	2.5	2.5
cfs = cubic feet per second; ft/ft = feet per feet; ft = feet						

Methods

Bench Channel Design Methods

The bench channels will be stabilized using riprap at the channel thalweg where the flow depth, and shear stress (see Equation 1), is highest. The bench cross slope is gradual (5 percent or 20 feet horizontal to 1 foot vertical). A significant bench width that will convey flow during the design storm event will flow shallow enough that vegetation lining alone will be sufficient for scour protection.

Bench channel riprap was evaluated using the methods described in the Federal Highway Administrations Design of Roadside Channels with Flexible Linings (FHA, 2005). Stantec evaluated the vegetative lining using Stability Design of Grass-Lined Open Channels (Temple et. al, 1987).

Table 2 provides parameters used to characterize the channel lining riprap and vegetation. Vegetative parameters used in this analysis were chosen to be consistent with those used for the Pile 4 vegetated cover analysis (see Appendix F).

Table 3: Channel Lining Parameter Characterization

Parameter	Value	Units	Reference
Bench Channel Riprap			
Median Diameter, D_{50}	6	inches	Design Parameter
Specific Gravity, SG	2.6	-	Assumed
Vegetation			
Soil Plasticity Index, PI	10	-	Approximated from cover borrow soil characterizations
Soil Void Ratio, e	0.605	-	Approximated from cover borrow soil characterizations
Soil Roughness, n_s	0.0156	-	Table 3.3 (Temple et.al., 1987) – For cohesive soils
Vegetation Stem Height, h	0.5	feet	Assumed
Vegetation Stem Density, m	67	Stems per foot	Table 3.1 (Temple et.al., 1987) – Grass Mixture with Poor Cover
Vegetation Cover Factor, C_f	0.38	-	Table 3.1 (Temple et.al., 1987) – Grass Mixture with Poor Cover

Channel Hydraulics

Stantec evaluated channel hydraulics assuming normal flow depth, using the Manning's equation (Equation 1).

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

Where:

n_c = composite channel roughness (see Equation 3)

A = channel flow area, square feet

$$A = \frac{Y * (Z_1 * Y + Z_2 * Y)}{2}$$

P = channel wetted perimeter, feet

$$P = Y * \left(\sqrt{1 + Z_1} + \sqrt{1 + Z_2}\right)$$

Y = channel flow depth, feet

Stantec developed a composite channel roughness (n_c) where the weighted average roughness for the riprap and vegetation lined portions of the channel were considered by Equation 2.

$$n_c = \frac{P_{rr} * n_{rr} + P_v * n_v}{P_t} \qquad \text{Equation 2}$$

Where:

n_c = composite roughness

n_{rr} = riprap lining roughness

n_v = vegetation lining roughness

P_{rr} = wetted perimeter of the riprap lining, feet

P_v = wetted perimeter of the vegetation lining, feet

P_t = wetted perimeter of the channel

Stantec used the riprap lining roughness computation method recommended in HEC-15 (FHA, 2005)in this analysis (Equation 3).

$$n_{rr} = \frac{1.49 * d_a^{\frac{1}{6}}}{\sqrt{g} * f(Fr) * f(REG) * f(CG)} \qquad \text{Equation 3}$$

$$f(Fr) = \left(\frac{0.28 * Fr}{b}\right)^{\log\left(\frac{0.755}{b}\right)}$$

$$f(REG) = 13.434 * \left(\frac{T}{D_{50}}\right)^{0.492} * b^{1.025 * \left(\frac{T}{D_{50}}\right)^{0.118}}$$

$$f(CG) = \left(\frac{T}{d_a}\right)^{-b}$$

Where:

d_a = average channel flow depth, feet

$$d_a = \frac{T}{A}$$

T = channel top width, feet

$$T = Y * (Z_1 + Z_2)$$

A = channel flow area, square feet

g = gravitational acceleration constant, 32.2 feet per second squared

Fr = channel Froude number

$$Fr = \frac{V}{\sqrt{g * \frac{A}{T}}}$$

b = parameter describing the effective roughness concentration

$$b = 1.14 * \left(\frac{d_{50}}{T}\right)^{0.453} * \left(\frac{d_a}{D_{50}}\right)^{0.814}$$

D_{50} = median riprap particle diameter, feet

The vegetation lining roughness was evaluated by Equation 4 (Temple et.al., 1987).

$$n_v = e^{C_i * \left(0.0133 * [\ln(q_v)]^2 - 0.0954 * \ln(q_v) + 0.297\right) - 4.16} \qquad \text{Equation 4}$$

Where:

C_i = vegetation retardance curve index value

$$C_i = 2.5 * \left(h * \sqrt{M}\right)^{\frac{1}{3}}$$

qv = maximum unit discharge over the vegetation, cubic feet per second per foot

$$q_v = Y_v * V$$

Y_v = maximum flow depth over the vegetation lining, feet

$$Y_v = Y - d_{rr}$$

V = average channel flow velocity, feet per second

$$V = \frac{Q}{A}$$

Riprap Stability

Stantec evaluated the bench channel stability using shear stress methods. The applied channel shear stress was calculated by Equation 5.

$$\tau = \gamma * Y * S \qquad \text{Equation 5}$$

Where:

τ = applied channel shear stress, pounds per foot squared

γ = unit weight of water, 62.4 pounds per foot cubed (assumed)

Y = channel flow depth, feet

S = channel slope, feet per feet

The maximum permissible shear stress for the riprap was evaluated by Equation 6 (FHA, 2005).

$$\tau_{p-rr} = \frac{F_* * \gamma_W * (SG-1) * D_{50}}{SF} \qquad \text{Equation 6}$$

Where:

τ_{p-rr} = maximum permissible shear stress on the riprap, pounds per foot squared

F_* = Shield's parameter, dimensionless

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

SF = manual recommended safety factor, dimensionless

The values prescribed in the manual for the Shield's parameter (F_*) and the safety factor (SF) are determined as a function of the particle Reynolds number (Re) (Equation 7). If Re is less than $4x10^4$ then the manual recommends using an F_* equal to 0.047 and SF equal to 1. If Re is greater than $2x10^5$ the manual recommends using F_* equal to 0.15 and SF equal to 1.5. If Re lands between $4x10^4$ and $2x10^5$ then a linear interpolation with Re is to be used.

$$Re = \frac{\sqrt{g * Y * S} * D_{50}}{\nu} \qquad \text{Equation 7}$$

Where:

v = kinematic viscosity of water, $1.21*10^{-5}$ square feet per second

Vegetation Stability

The reference manual (Temple et.al., 1987) instructs that vegetation lining stability be evaluated with consideration for the capacity of the soil particles underlying the vegetation to resist washout and the capacity of the vegetation itself to resist washout during the design flow event.

Equation 8 computes the applied shear stress on the soil (τ_s) and is directly impacted by the vegetation covering as the full channel shear forces are resisted by the combined soil and vegetation system.

$$\tau_s = \gamma_w * Y_v * S * \left(1 - C_f\right) * \left(\frac{n_s}{n_v}\right)^2 \qquad \text{Equation 8}$$

The remainder of the total shear stress is applied to the vegetation. The applied vegetal stress (τ_v) is computed by Equation 9.

$$\tau_v = \gamma_w * Y_v * S - \tau_s \qquad \text{Equation 9}$$

Stantec evaluated the maximum permissible effective shear stress on the underlying soil particles (τ_a) using Equation 10. This equation is recommended in the manual (Temple et.al., 1987) for cohesive Unified Soil Classification System (USCS)[BK1] silty sand (SM) type soils with a plasticity index less than 20.

$$\tau_a = (1.07 * I^2 + 7.15 * I + 11.9) * 10^{-4} * C_e^2 \qquad \text{Equation 10}$$

Where:

τ_a = permissible effective shear stress on the soil, pounds per square foot

C_e = soil void ratio correction factor, unitless

$$C_e = 1.42 - 0.61 * e$$

Equation 11 computes the maximum permissible effective shear stress on the vegetation (τ_{va}) .

$$\tau_{va} = 0.75 * C_i \qquad \text{Equation 11}$$

Equation 12 computes a stability factor (SF) for the riprap and both the soil and vegetation lining .

$$SF = \frac{\tau_{p*}}{\tau_{a*}} \qquad \text{Equation 12}$$

Where:

SF = stability factor

τ_{p*} = maximum permissible stress

τ_a = applied stress

Downdrain Design Methods

Stantec evaluated the riprap armoring for stabilizing the downdrain channels using methods suggested by Robinson, et.al. (1998).

The downdrain was designed assuming riprap with a median stone diameter (D_{50}) as outlined in Table 4.

Table 4: Downdrain Design Median Stone Diameter

	DD1	DD2	DD3	DD4	DD5
Median Stone Diameter, D_{50}	6”	9”	9”	9”	12”

Channel Hydraulics

Similar to the bench channels, Stantec evaluated the downdrain hydraulics assuming normal depth using the Manning’s equation (Equation 1). The downdrain channel roughness (n_{dd}) was evaluated using Equation 13.

$$n_{dd} = 0.029 * (25.4 * D_{50} * S)^{0.147}$$ Equation 13

Riprap Stability

As recommended by Robinson et. al. (1998), If the downdrain slope (S) is less than 0.1 feet per feet then Stantec used Equation 14 to compute the downdrain riprap stability. If the downdrain slope (S) is greater than 0.1 feet per feet then Equation 15 is used.

$$D_{50f} = 1.413 * q^{0.529} * S^{0.794} * K$$ Equation 14

$$D_{50f} = 0.46 * q^{0.529} * S^{0.307} * K$$ Equation 15

Where:

D_{50f} = median stone diameter at the brink of failure, inches

q = design unit discharge of flow, cubic feet per second per foot

K = conversion factor, feet to inches (12)

A stability factor for the downdrain riprap was determined by Equation 16.

$$SF = \frac{D_{50}}{D_{50f}}$$ Equation 16

Results

Bench Channel Results

Table 5 summarizes the results of bench channel hydraulic computations.

Table 5: Bench Chanel Hydraulic Computation Results

	Units	SP4-01	SP4-02	SP4-04	SP4-05
Flow Depth, Y	ft	1.41	1.29	1.10	1.36
Flow Velocity, V	fps	1.61	1.49	1.25	1.52
Riprap Roughness, n_{rr}	-	0.110	0.114	0.126	0.113
Vegetation Roughness, n_v	-	0.074	0.106	N/A[1]	0.086
Composite Roughness, n_c	-	0.103	0.114	0.126	0.109

ft = feet; fps = feet per second

1. Flow is predicted to be contained entirely inside of the riprap lining

Table 6 provides the results of the bench channel riprap stability computations.

Table 6: Bench Channel Riprap Stability Results

	Units	SP4-01	SP4-02	SP4-04	SP4-05
Applied Shear, τ	lbs/ft^2	1.76	1.61	1.37	1.69
Maximum Permissible Shear, τ_{p-rr}	lbs/ft^2	2.42	2.42	2.42	2.42
Riprap Stability Factor, SF	-	1.4	1.5	1.8	1.4

lbs/ft^2 = pounds per square foot

The maximum permissible shear stream for the 6-inch bench channel riprap computed by Equation 5 is 2.42 pounds per square foot. This permissible shear stress is at least 1.4 times greater than maximum applied shear stress predicted by Equation 1. Therefore, all bench channel riprap is predicted to be protective during the 100-year flow event.

Table 7 provides the results of the bench channel vegetation lining stability computations.

Table 7: Bench Channel Vegetation and Soil Stability Results

	Units	SP4-01	SP4-02	SP4-04	SP4-05
Soil Applied Shear, τ_s	lbs/ft^2	0.009	0.002	N/A[1]	0.005
Vegetation Applied Shear, τ_v	lbs/ft^2	0.32	0.17	N/A[1]	0.25
Maximum Permissible Soil Shear, τ_a	lbs/ft^2	0.021	0.021	0.021	0.021
Maximum Permissible Vegetation Shear, τ_{va}	lbs/ft^2	3.00	3.00	3.00	3.00
Soil Stability Factor	-	2.3	8.9	N/A[1]	3.9
Vegetation Stability Factor	-	9.5	17.4	N/A[1]	11.9

lbs/ft^2 = pounds per square foot

1. Flow is predicted to be contained entirely inside of the riprap lining

From Table 7, the maximum permissible shear stress for bench channel vegetation and the underlying soil is 3.00 pounds per square foot and 0.021 pounds per square foot, respectively. Compared against the shear stress predicted to be applied during the 1 in 100-year event for each of the bench channels yields a soil stability factor of at least 2.0 and a vegetation stability factor of at least 8.2 for all bench channel. Therefore, the vegetative linings are predicted to be stable during the 1 in 100-year flow event.

Downdrain Channel Results

Table 8 presents the channel hydraulics and riprap stability results computed for the downdrain channels.

Table 8: Downdrain Channel Hydraulic and Channel Stability Computation Results

	Units	DD1	DD2	DD3	DD4	DD5
Flow Depth, Y	ft	0.39	0.48	0.74	1.00	1.22
Flow Velocity, V	fps	5.34	5.76	6.73	6.80	7.35
Roughness, n_{dd}	-	0.044	0.046	0.044	0.041	0.043
Unit Discharge, q	cfs/ft	2.10	2.75	5.01	6.80	9.01
Minimum Stable Riprap, D_{50f}	in	4.4	4.7	5.8	6.0	7.0
Riprap Stability Factor	-	1.4	1.9	1.5	1.5	1.7
Channel Freeboard	ft	2.1	2.0	1.8	1.5	1.3
ft = feet, fps = feet per second, cfs/ft = cubic feet per second per foot, in = inch						

From Table 8, the predicted minimum stable median riprap diameter on the downdrain increases from 4.4 inches at the top to 7.0 inches at the bottom. The design median riprap diameter also increases from 6 inches at the top to 12 inches at the bottom to maintain a minimum riprap stability factor of 1.4 through all sections of the downdrain. A minimum channel freeboard of 1.3 feet will be maintained through all downdrain segments.

Future Evaluations

The information presented here reflects a preliminary design. Future design iterations will address the soil filter systems beneath the riprap revetments. Properly design soil filter will be particularly important at this site due to the highly erosive soils. The channel filter system may utilize granular filters (as depicted in the preliminary St. Anthony Mine Closeout Plan design drawings) or manufactured geotextiles specifically designed for surface water drainage applications.

References

Federal Highways Administration (FHA), 2005. Design of Roadside Channels with Flexible Linings. Hydraulic Engineering Circular No. 15, Third Edition.. September.

Robinson, K.M., Rice, C.E., Kadavy, K.C., 1998. Design of Rock Chutes. American Society of Agricultural Engineers. Vol. 41(3):621-626.

Temple, D.M., Robinson, K.M., Ahring, R.M., Davis, A.G., 1987. Stability Design of Grass-Lined Open Channels. Agriculture Handbook Number 667. United States Department of Agriculture.

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ATTACHMENT A

Calculation Worksheets

Bench Channel Stability Calculations

Channel :	SP4-01	SP4-02	SP4-04	SP4-05	
Input Variables					**Notes**
Hydrologic Element :	SB_SP4-01	SB_SP4-02	SB_SP4-04	SB_SP4-05	
Discharge, Q (cfs) :	39	31	18	35	Appendix E.1
Slope, S (ft/ft) :	0.02	0.02	0.02	0.02	Design Drawings
Bottom Width, B (ft) :	0	0	0	0	Design Drawings
Hillside Side Slope, Zl:1 :	5	5	5	5	Design Drawings
Bench Side Slope, Zr:1 :	20	20	20	20	
RR Specific Gravity, SGs :	2.65	2.65	2.65	2.65	Assumed Riprap Parameter
Median Riprap, D50 (in) :	6	6	6	6	Design Median Riprap Diameter
Bench Depth, H :	2	2	2	2	
Grass Roughness, ng :	0.075	0.095	#NUM!	0.084	Temple
RR Roughness, nr :	0.111	0.119	0.135	0.115	Eq. 6.2 (HEC-15, 2005)
Reletive Roughness, da/D50 :	1.406	1.335	1.150	1.372	Check that da/D50<1.5 (HEC-15, 2005)
f(FR) :	0.631	0.596	0.555	0.614	Eq. 6.3 (HEC-15, 2005)
f(REG) :	8.331	7.992	7.109	8.167	Eq. 6.4 (HEC-15, 2005)
f(CG) :	0.424	0.431	0.451	0.428	Eq. 6.5 (HEC-15, 2005)
b :	0.219	0.215	0.204	0.217	Eq. 6.6 (HEC-15, 2005)
Composite Roughness, n :	0.104	0.116	0.135	0.110	
Flow Depth, Y (ft) :	1.41	1.33	1.15	1.37	Manning's Equation
Iteration Parameter :	0.04	0.00	0.32	0.02	0.38
Flow Area, A (ft2) :	24.7	22.3	16.5	23.5	A = (B+Z*Y)*Y
Wetted Per., P (ft) :	35.3	33.5	28.9	34.5	P = B+2*Y*(Z^2+1)^0.5
Top Width, T (ft) :	35.2	33.4	28.7	34.3	T = B+2*Y*Z
Channel Velocity, V (fps) :	1.58	1.38	1.11	1.48	V = Q/A
Average Flow Depth, da (ft) :	0.7	0.7	0.6	0.7	
Froude Number, Fr :	0.33	0.30	0.26	0.31	
RR Lining Depth, Yrr (ft) :	1.15	1.15	1.15	1.15	
RR Lining Width, Wrr (ft) :	28.8	28.8	28.8	28.8	
RR Lining Wetted Per, Prr (ft) :	28.9	28.9	28.9	28.9	
RR Lining Width (Bench), (ft) :	23.0	23.0	23.0	23.0	
Grass Depth, Yg (ft) :	0.26	0.18	0.00	0.22	
Grass Width, Wg (ft) :	6.4	4.6	0.0	5.5	
Grass Wetted Per, Pg (ft) :	6.4	4.6	0.0	5.6	
Riprap Stability					
RR Shear, Trr (lbs/ft2) :	1.75	1.67	1.44	1.71	T = 62.4*(A/P)*S
Shear Velocity, u* (fps) :	0.9	0.9	0.7	0.9	Eq. 6.10 (HEC-15, 2005)
Kinematic Viscosity, v (ft2/s) :	1.21E-05	1.21E-05	1.21E-05	1.21E-05	Assumed
Particle Reynolds Number, Re :	3.74E+04	3.55E+04	3.06E+04	3.65E+04	Eq. 6.9 (HEC-15, 2005)
Computed F* :	0.047	0.047	0.047	0.047	Table 6.1 (HEC-15, 2005)
SF :	1.00	1.00	1.00	1.00	Table 6.1 (HEC-15, 2005)
Maximum Permissible Shear, Tp (lbs/ft2) :	2.42	2.42	2.42	2.42	Eq. 6.8 (HEC-15, 2005)
RR Stability Factor :	1.4	1.5	1.7	1.4	
Grass Stability					
Veg Unit Discharge, qv (cfs/ft) :	0.41	0.25	0.00	0.33	q = V*Yv
Max Allowable Soil Shear, Ta (lbs/ft2) :	0.021	0.021	0.021	0.021	Ta = Tab*Ce^2, Eq. (Temple, 1987)
Max Allowable Veg Shear, Tva (lbs/ft2) :	3.00	3.00	3.00	3.00	Tva = 0.75*Ci, Eq. 1.17 (Temple, 1987)
Effective Soil Stress, Te (lbs/ft2) :	0.009	0.004	#NUM!	0.006	Eq. 1.13 (Temple, 1987)
Vegitation Stress, Tv (lbs/ft2) :	0.31	0.23	#NUM!	0.27	Tv = T - Te, Eq. 1.18 (Temple, 1987)
Soil Stability Factor, :	2.5	5.4	#NUM!	3.5	
Vegetation Stability Factor :	9.6	13.2	#NUM!	11.1	

Soil	
Soil Type :	SM
Soil Plasticity Index, PI :	10
Soil Void Ratio, e :	0.605
Void Ratio Correction Factor, Ce :	1.05095
Basi Allowable Shear, Tab (lbs/ft2) :	0.01904
Soil Roughness, ns :	0.0156

Vegitation		
Stem Height, h (ft) :	0.5	Assumed
Stem Density, m :	67	Table 3.1 (Temple, 1987) Grass Mixture, Poor Condition
Retardance Index, Ci :	4.00	Eq. 1.3 (Temple, 1987)
Cover Factor, Cf :	0.375	Table 3.1 (Temple, 1987) Grass Mixture, Poor Condition

Downdrain Channel Calculations

Channel Hydraulics

Input Variables	SP4-DD1	SP4-DD2	SP4-DD3	SP4-DD4	SP4-DD5	Notes
Hydrologic Element :	J-SP4_DD1	J-SP4_DD2	J-SP4_DD3	J-SP4_DD4	J-SP4_DD5	
Discharge, Q (cfs) :	12.90	30.90	60.70	87.40	121.70	REF Hydrology Report
Slope, S (ft/ft) :	0.11	0.10	0.08	0.05	0.05	REF Design Drawings
Bottom Width, B (ft) :	5	10	10	10	10	REF Design Drawings
Hillside Side Slope, Zl:1 :	3	3	3	3	3	REF Design Drawings
Bench Side Slope, Zr:1 :	3	3	3	3	3	REF Design Drawings
RR Specific Gravity, SGs :	2.65	2.65	2.65	2.65	2.65	Assumed Riprap Parameter
RR Anlge of Repose, (deg) :	40.0	40.0	40.0	40.0	40.0	Assumed Riprap Parameter
Median Riprap, D50 (in) :	6	9	9	9	12	Design Median Riprap Diameter
RR Roughness, nr :	0.044	0.046	0.044	0.041	0.043	Eq. 14 (Rice et al, 1998)
Flow Depth, Y (ft) :	0.39	0.48	0.74	1.00	1.22	Manning's Equation
Iteration Parameter :	0.01	0.25	0.36	1.00	2.25	3.87
Flow Area, A (ft2) :	2.4	5.5	9.1	13.0	16.8	A = (B+Z*Y)*Y
Wetted Per., P (ft) :	7.5	13.0	14.7	16.3	17.7	P = B+2*Y*(Z^2+1)^0.5
Channel Top Width, TW (ft) :	7.4	7.9	9.5	11.0	12.3	T = B+2*Y*Z
Channel Velocity, V (fps) :	5.30	5.67	6.67	6.72	7.27	V = Q/A
Flow Unit Discharge, q (cfs/ft) :	2.09	2.70	4.96	6.72	8.90	q = V*Y

Riprap Stability

HEC-15	SP4-DD1	SP4-DD2	SP4-DD3	SP4-DD4	SP4-DD5	Notes
RR Shear, Trr (lbs/ft2) :	2.7	3.0	3.5	3.0	3.7	T = 62.4*(A/P)*S
Shear Velocity, u* (fps) :	1.4	1.6	1.8	1.5	1.9	Eq. 6.10 (HEC-15, 2005)
Kinematic Viscosity, v (ft2/s) :	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	
Particle Reynolds Number, Re :	5.82E+04	9.61E+04	1.11E+05	9.58E+04	1.60E+05	Eq. 6.9 (HEC-15, 2005)
Computed F* :	0.059	0.083	0.093	0.083	0.124	Table 6.1 (HEC-15, 2005)
SF :	1.06	1.18	1.22	1.17	1.37	Table 6.1 (HEC-15, 2005)
Minimum Stone Diameter, D50f (in) :	5.7	5.0	5.3	4.9	4.8	Eq. 6.8 (HEC-15, 2005)
RR Stability Factor :	1.05	1.82	1.68	1.82	2.48	

Robinson	SP4-DD1	SP4-DD2	SP4-DD3	SP4-DD4	SP4-DD5	Notes
Minimum Stone Diameter, D50f (in) :	4.4	4.6	5.8	6.0	7.0	Eq. 1 and Eq. 2 (Robinson et al. 1998)
RR Stability Factor :	1.4	1.9	1.5	1.5	1.7	

Channel Capacity

	SP4-DD1	SP4-DD2	SP4-DD3	SP4-DD4	SP4-DD5	Notes
Design Channel Depth, (ft) :	2.5	2.5	2.5	2.5	2.5	
Channel Freeboard, (ft) :	2.1	2.0	1.8	1.5	1.3	