Protocol 5 Calculation Example

Project Context[1]

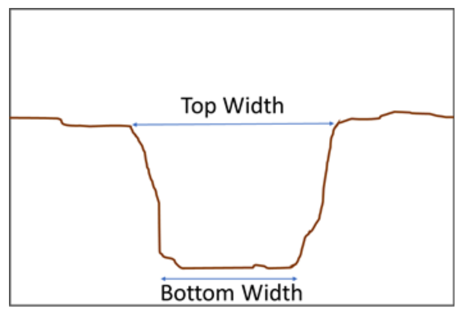
Within the project reach, the channel exhibits highly erodible banks, reduced in-stream habitat, and the potential for further bed and bank instabilities. Proposed project reach length is approximately 471 feet, existing slope ranges from 0.3 to 13%, existing bank height ranges from 6 to 21 feet, and bottom width ranges from 4 to 40 feet.

There are generally three distinct zones of channel bed material along the project reach including Class III riprap (35 linear feet), Class I riprap (81 linear feet), and primarily sand (355 linear feet). Channel bed and bank material along non riprap bank portions of the channel are primarily sand (91%) with approximately 7% silt and clay and 2% gravel. A soil boring completed in the vicinity of the project reach yielded an average of 71% sand, 18% silt, 9% clay, and 2% gravel.

<u>Step 1. Define the Existing Channel Conditions</u>

The following measurements were collected at 3-representative cross-sections within the project reach or generated from a surveyed digital elevation model, prior to construction:

- Bank Height
- Bottom Width
- Pebble Count
- Bulk Density



Base Level Control:

Base level at the project was based on a confluence with a downstream receiving channel. This channel was evaluated in the field is expected to be stable and provide an unchanging base level control.

Bottom Width determination

The bottom width value is based on the average of three surveyed cross sections which gives a value of 17 ft.

<u>Step 2: Define Equilibrium Channel Conditions</u>

Equilibrium Bed Slope Analysis

Channel bed conditions along the existing channel alignment include:

- 35 linear feet of Class III Riprap
- 81 linear feet of Class I Riprap
- 355 linear feet of Sand

The analysis assumed that the Class III Riprap remained stable and was not subject to channel bed erosion or elevation change. Two separate analyses were conducted for the Class I Riprap and sand areas due to the different grain sizes observed.

Sand Bed Equilibrium Slope Analysis

The following equation was used to estimate equilibrium slope for the sand-bed area:

$$S_{eq} = \left(\frac{\tau_c}{\gamma_w y}\right)$$

where S_{eq} is equilibrium slope (ft/ft), τ_c is critical shear stress (lb/ft^2), γ_w is specific weight of water (lb/ft^3), and y is mean flow depth (ft). Specific weight of water is 62.4 lb/ft^3 at 10 degrees C.

Critical shear stress in the above equation is based on Figure TS14B-9 from Technical Supplement 14B of NRCS 2007. The reach-averaged median grain size—0.6 mm—was used to determine representative critical shear stress. Critical shear stress (τ_c) based on a 0.6 mm median grain size and the curve for fine suspended sediment concentration between 1,000 and 2,000 ppm is 0.055 lb/ft^2 (2.63 N/m^2 [Pa]).

Equilibrium slope was calculated for each of the three cross sections collected during the geomorphic assessment based on mean flow depth for the 10-year discharge. Results of the equilibrium slope analysis along the sand-bed area, including average, minimum, and maximum values, are summarized in ***Table 1***.

Table 1: Summary of Equilibrium Slope Calculations for Sand-bed Area

Discharge (cfs)	Recurrence Interval	Equilibrium Slope (%)					
		XS-1	XS-2	XS-3	Average	Min	Max
120	10-YR	0.0518	0.0801	0.0880	0.0733	0.0518	0.0880

Based on this, it appears appropriate to use the average equilibrium slope for the 10-year recurrence interval discharge—0.0733 percent—as the representative value for the analysis along the sand-bed reach.

Riprap Bed Equilibrium Slope Analysis

Equilibrium slope along the Class I Riprap area was evaluated using four relationships identified by NRCS (2007) for estimating equilibrium slope for channel bed material size greater than sand with no upstream sediment supply, including: (1) simultaneously solving the Manning and Shields equations, (2) Meyer-Peter and Muller transport relationship, (3) Schoklitsch equation, and (4) Henderson formula. The following values were used in the Class I Riprap Area:

- Shield parameter θ_c is 0.047
- D_c is equal to D_{90} and both are determined by the pebble count to be 1.0 ft

- Unit discharge (q) is 30 ft^2/s based on the reach average bottom width (4 ft) and the 10-year discharge (120 cfs)
- Manning n value is 0.035
- D_m is determined from the pebble count to be 200 mm
- Q_d is the 10-year discharge, 120 cfs
- D_{50} is determined from the pebble count to be 0.7 ft

The average of the four methods was selected as the appropriate equilibrium slope for this reach. The predicted equilibrium slopes are included in ***Table 2***.

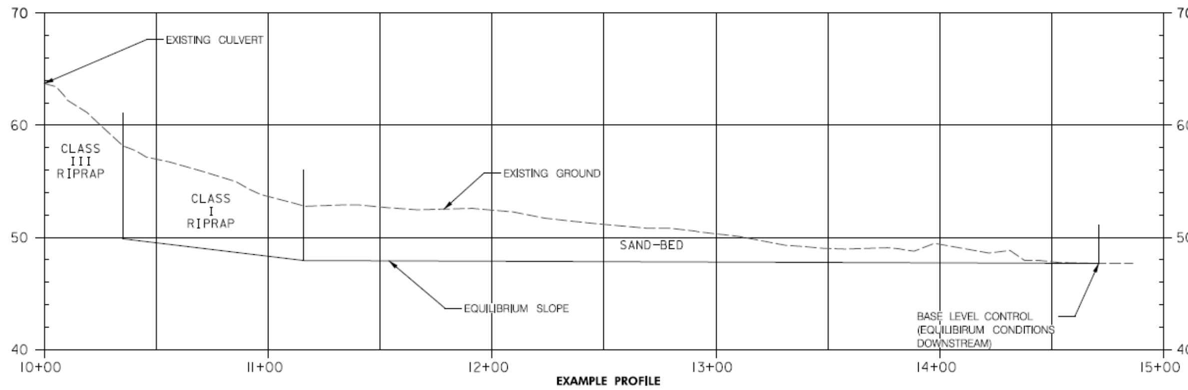
Table 2: Summary of Equilibrium Slope Calculations for Class I Riprap Area

Equilibrium Slope (%)				
Manning and Shields	Meyer-Peter and Muller	Schoklitsch	Henderson	Average
3.5%	2.6%	0.7%	3.2%	2.3%

Results of the equilibrium slope analysis indicate the following:

- Class III Riprap area
  - no change to existing conditions is anticipated/assumed for this analysis
- Class I Riprap area
  - equilibrium slope of 2.3 percent is anticipated/assumed for this analysis
- Sand-bed area
  - equilibrium slope of 0.07 percent is anticipated/assumed for this analysis

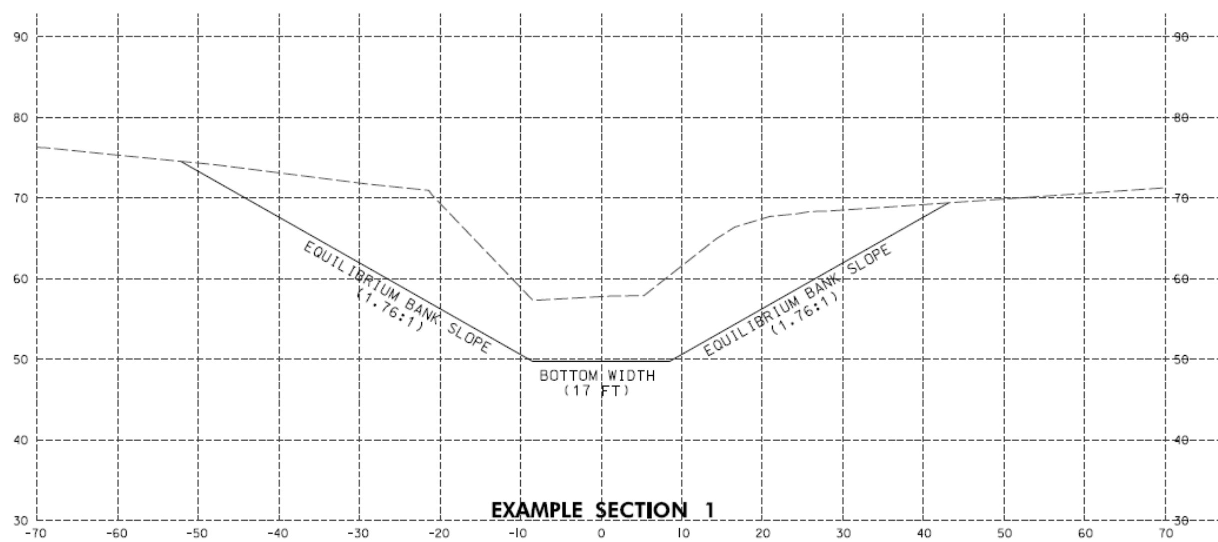
Figure 1: Profile Displaying Equilibrium Slopes

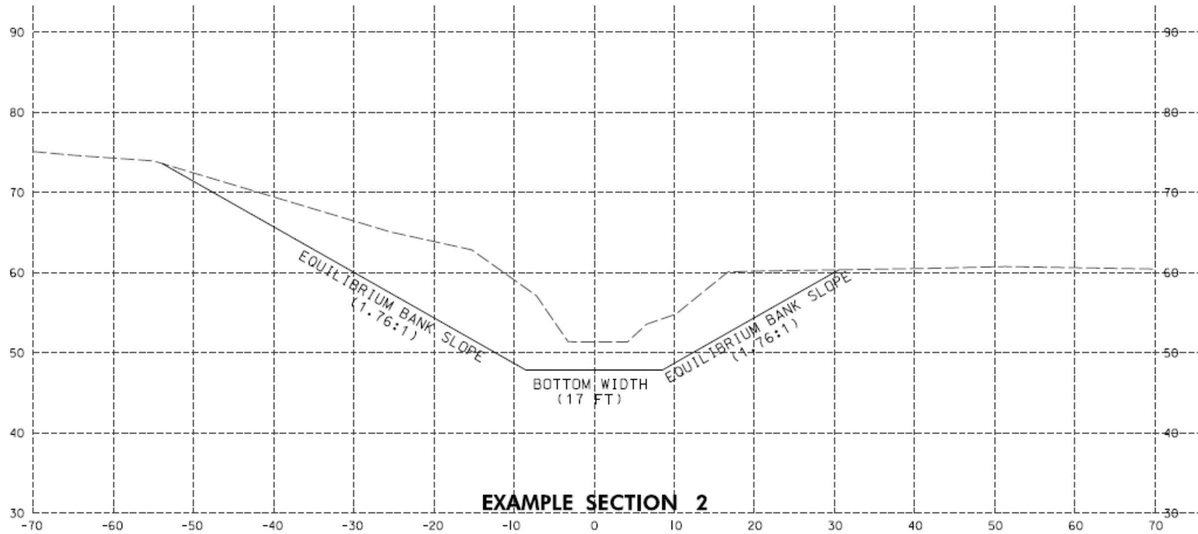


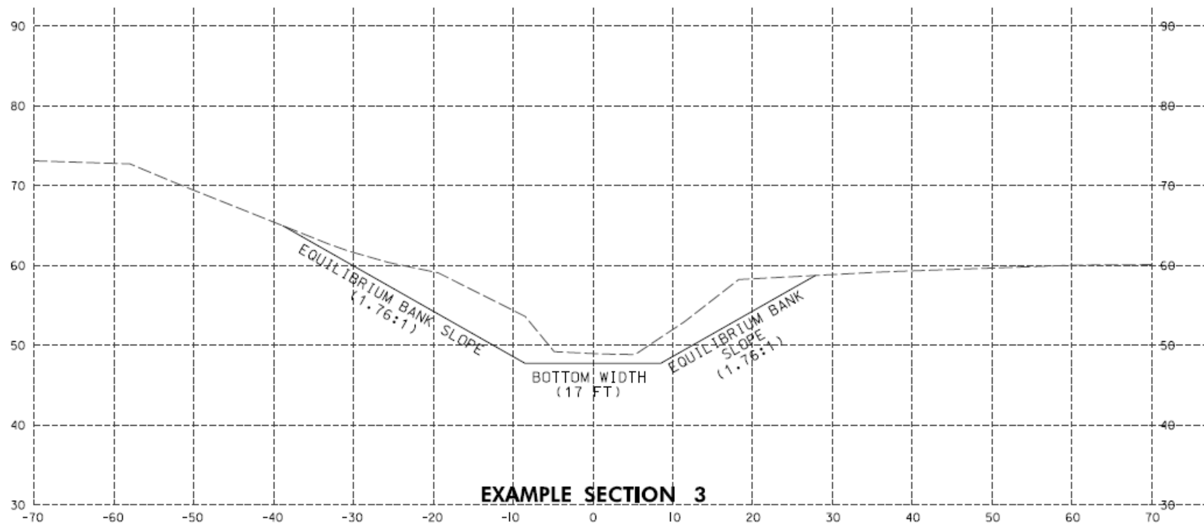
Equilibrium Bank Slope Analysis

Utilizing the value of 1.76 for medium dense sand is likely an appropriate representative value for this analysis and as directed by the protocol.

Figure 2: Example Cross Sections Showing Equilibrium Bank Slope and Bottom Width



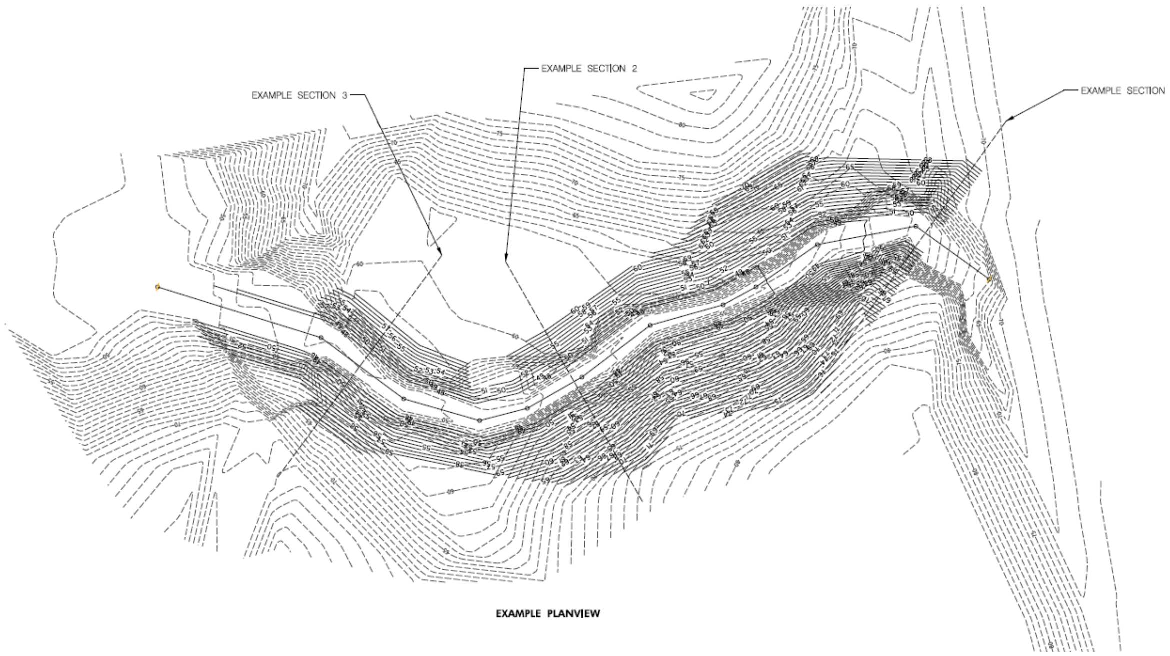




<u>Step 3. Calculate the Total Prevented Sediment</u>

Using the equilibrium channel slope, equilibrium bank slope, and bottom width a 3-Dimensional modeling program, such as MicroStation InRoads, can be used to develop an equilibrium surface. This surface can be compared with the existing surface to determine the amount of material which would be transported out the reach to achieve equilibrium conditions. Results of the erosion estimate based on equilibrium slope, bank stability, and representative bottom width indicate that 139,929 cubic feet (5,182 cubic yards) of sediment would erode from the project reach before equilibrium conditions were achieved. Planview display of estimated equilibrium conditions compared to existing is shown in Figure 3 below:

Figure 3: Example Planview Showing Existing and Equilibrium Conditions



<u>Step 4. Annualize the Reductions</u>

Applying site specific measured bulk density of 80 lb/ft^3 and utilizing a 50% efficiency factor, over the 30-year time period the yearly reduction of sediment is 87 tons per year for sediment load reduction (***Table 3***).

$S_p = 0.5 (S_v / 30)$

Where S_p represents the annual volume of prevented sediment and S_v represents the total volume of prevented sediment calculated in Step 3.

<u>Step 5. Determine the Annual Prevented Nutrients</u>

Using the guidance in Section 2.1.3.1, samples were collected from the project reach and analyzed for TN and TP soil nutrient concentrations. Bank nutrient content was measured at two elevations along both banks at each cross section. The nutrient content varied from 0.01% to 0.05% TN and 0.003% to 0.023% TP, by weight. These values correspond with average nutrient concentrations of 0.25 pounds of TP per ton of sediment and 0.70 pounds of TN per ton of sediment. Yearly reductions of TN and TP are shown with 100% and 50% efficiency factors in ***Table 3***.

Table 3: TMDL Credit through Protocol 5

Pollutant	***Protocol 5***	
	100 % Efficiency	***50% Efficiency***

TN (lbs/yr)	122	61
TP (lbs/yr)	44	22
TSS (tons/yr)	174	87