Rapid Stream Risk Classification for Hydromodification Mapping

Stream Classification Methodology

1. Primary Criteria

1.1. Shear Ratio

Shear ratio SR is used as an indicator of a channel's bed shear stress sensitivity to increased discharge. The bed shear stress is first evaluated for bankfull discharge using the normal depth approximation for a given channel slope. The discharge is then doubled and the corresponding channel shear stress evaluated for a given distribution of flow conveyance between the main channel and the overbanks. The ratio of the increased shear stress to the bankfull shear stress is between 1.0 and 1.5 (can be proven theoretically for a rectangular shape). The lower range (SR from 1.0 to 1.3) is considered a medium-risk classification, while the upper range (SR from 1.3 to 1.5) is considered a high-risk classification. A low-risk classification applies only if the stream meets the criteria for a low-risk channel (aggrading channels, channels with continuous hardened beds and banks engineered to withstand erosive forces).

The approach adopted here provides a much better indicator of the channel's shear stress sensitivity to increased discharge than Rosgen's entrenchment ratio because the latter does not account for the actual distribution of flow conveyance between the main channel and the overbanks. The shear ratio methodology proposed here directly evaluates bed shear stress based on the geometry of a cross section (depth). The procedure can be easily carried out using the uniform flow option in HEC-RAS (Figure 1).

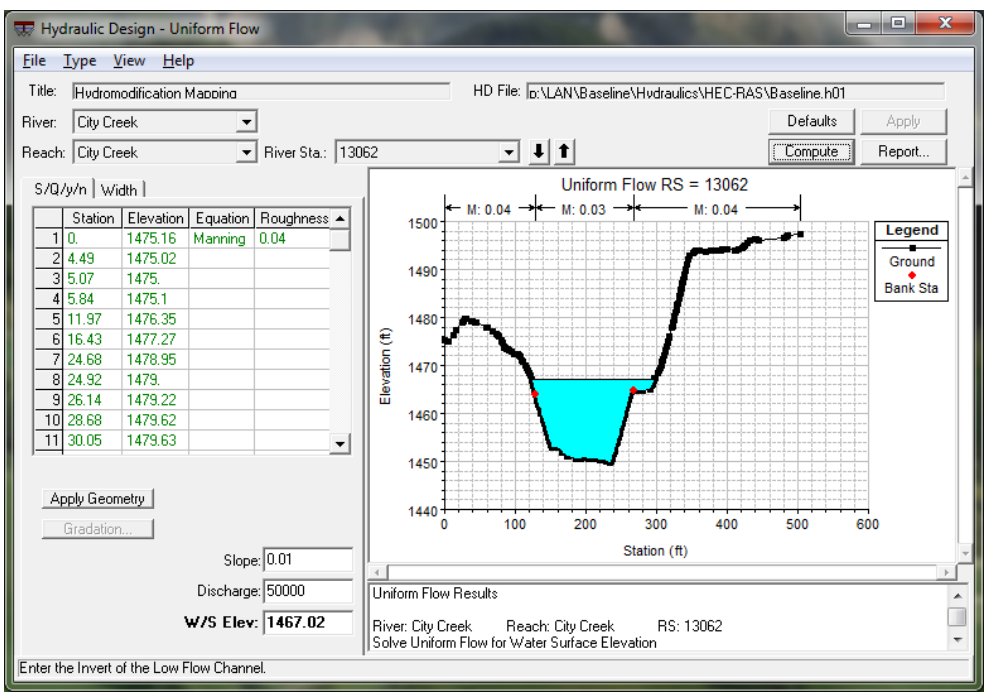

Figure 1. HEC-RAS Uniform Flow Module.

1.2. Entrainment Ratio

Entrainment ratio ER is the ratio between bankfull shear stress τ_o and critical shear stress τ_{cr} for a given grain size in the streambed. It represents the channel erosion potential. The procedure is to find bankfull shear stress and compare it to the critical shear stress that will entrain the median bed sediment size (D_{50}). If the bankfull shear stress is calculated as the total shear stress acting on the entire channel boundary (from a simple force balance), the incipient motion analysis for sand-bed channels usually shows that all particles in the bed material are capable of being moved (i.e. ER >> 1) for even very small discharges. Therefore, only the shear stress acting on individual particles in the streambed should be considered. An equation based on the vertical velocity profile is proposed here to find the bankfull shear stress (Mussetter et al., 1994):

$$\tau_o = \frac{\rho V^2}{\left[5.75 log\left(12.27\frac{H_o}{k_s}\right)\right]^2}$$

where V = average channel velocity; H_o = bankfull depth; k_s = absolute roughness of the bed material (here approximated by $4D_{50}$); and ρ = water density. The critical shear stress is calculated as:

$$\tau_{cr} = (\gamma_s - \gamma)D_{50}\theta_{cr}$$

where γ_s and γ = specific weights of sediment and water, respectively; and θ_{cr} = dimensionless shear stress (Shields number) ≈1.9 for sand-bed channels carrying bankfull flow (Parker, 2004).

Based on this approach, a <u>medium-risk</u> classification is proposed for ER < 1.0, while a <u>high-risk</u> classification is proposed for ER ≥ 1.0. A <u>low-risk</u> classification applies only if the reach is aggrading or has a continuously hardened bed.

1.3. Geotechnical Stability Number

The first two criteria are mainly pertinent to longitudinal (streamwise) channel stability. The third criterion is a measure of lateral channel stability. Lateral migration and widening of natural channels occurs through bank retreat resulting from fluvial erosion at the toe of the bank and subsequent mass failure. Therefore, the goal is to evaluate the geotechnical stability number (GSN), which is the ratio of the actual bank height to the critical bank height, as an indicator of the stability of channel banks. It is proposed that the critical bank height be calculated for each bank separately using the Osman and Thorne (1988) model for wedge-type failures through the toe, similar to those that have been observed in incising channels in the Southwest (Figure 2). The lower range (GSN < 1) is considered a <u>medium-risk</u> classification, while the upper range (GSN > 1) is considered a <u>high-risk</u> classification. The high risk classification is also triggered if toe or bank erosion is observed in the field. A <u>low-risk</u> classification applies only if the channel banks are engineered to withstand erosive forces or in the case of a wide shallow channel. The geotechnical parameters for the critical bank height should be based on in-situ soil properties (internal friction angle ϕ and cohesion C). In the absence of in-situ soil properties, the average values of C = 300 psf and ϕ = 30° can be used.

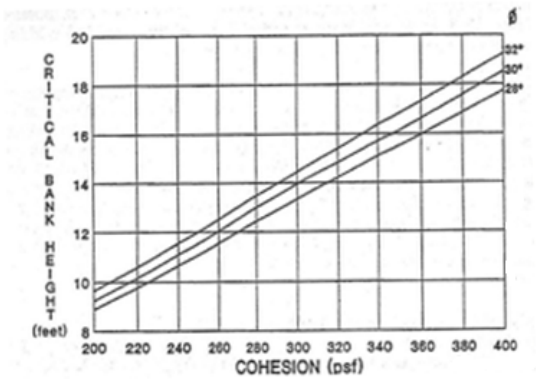

Figure 2. Critical Bank Height (Osman & Thorne, 1988).

2. Secondary Criteria

2.1. Confinement Class

Confinement is a measure of the amount of room that exists for the channel to actively move laterally. It can be a useful indicator of a channel's vulnerability to erosion. Confinement classes are assigned based on the width of the valley bottom W as a function of channel width B: a) Well confined (WC) channels are in valleys that are less than 2 channel widths wide. They usually have very limited meandering potential; b) Moderately confined (MC) channels are in valleys that are 2-4 channel widths wide. They tend to have minor amount of meandering, which commonly results in bank erosion that oscillates from side to side; c) Unconfined (UC) channels are in valleys with large floodplains, and exceed 4 channel widths wide. They are generally less influenced by hillslope processes and local sediment supply. It is proposed to classify WC and MC channels ($W/B \leq 4$) as high-risk, and UC channels ($W/B > 4$) as medium-risk. A low-risk classification applies only if the channel banks are fixed in place.

2.2. Bank Conditions

This criterion is based on detailed field observations. In general, the following factors that contribute to banks' resistance to erosion would classify as low-risk: bank stabilization in good condition, presence of bedrock, dense vegetation, highly consolidated bank material, no stratification, no signs of active erosion, toe in good condition. The opposite would classify as high-risk.

2.3. Streambed Conditions

This criterion is based on detailed field observations to assess the streambed sedimentation/erosion characteristics. A low-risk classification is triggered by the following factors: not braided or sand bed, highly armored, erosion resistant bedrock, no active headcuts, small degradation (< 1 ft), presence of downstream hard point in good condition (< 100 ft away), no widening, no aggradation, no obvious sources of sediments from bank failures of upstream sources. The opposite classifies as high-risk.

3. Stability Index

Each of the six criteria above are assigned a numerical value (low-risk = 0, medium-risk = 0.5, high-risk = 1) and a weighting factor (between 0 and 1). The weighted scores are added to find the total weighted score which determines the level of risk for future channel/reach instability (stability index). The weighting coefficients for the primary criteria should be larger than for the secondary ones because the latter are more subjective. Another option is to select weighting coefficients based on random sampling (Monte Carlo method) in order to incorporate elements of a risk-based analysis.

References

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Osman, A.M. and C.R. Thorne, 1988, "Riverbank Stability Analysis I: Theory," *Journal of Hydraulic Engineering*, ASCE, HY2, v. 114, pp. 134-150.

Parker, G., 2004, "1D Sediment Transport Morphodynamics with Applications to Rivers and Turbidity Currents, Part 1, Chapter 3: Bankfull Characteristics of Rivers," e-book, University of Illinois at Urbana-Champaign.