HYDROMODIFICATION SCREENING TOOLS: FIELD MANUAL FOR ASSESSING CHANNEL SUSCEPTIBILITY

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Southern California Coastal Water Research Project

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EXECUTIVE SUMMARY

Managing the effects of hydromodification (physical response of streams to changes in catchment runoff and sediment yield) has become a key element of most stormwater programs in California. Although straightforward in intent, hydromodification management is difficult in practice. Shifts in the flow of water and sediment, and the resulting imbalance in sediment supply and capacity can lead to changes in channel planform and cross-section via wide variety of mechanisms. Channel response can vary based on factors such as boundary materials, valley shape and slope, presence of in-stream or streamside vegetation, or catchment properties (e.g., slope, land cover, geology).

Management prescriptions should be flexible and variable to account for the heterogeneity of streams; a given strategy will not be universally well-suited to all circumstances. Management decisions regarding a particular stream reach(s) should be informed by an understanding of susceptibility (based on both channel and catchment properties), resources potentially at risk (e.g., habitat, infrastructure, property), and the desired management endpoint (e.g., type of channel desired, priority functions; see Figure ES1).

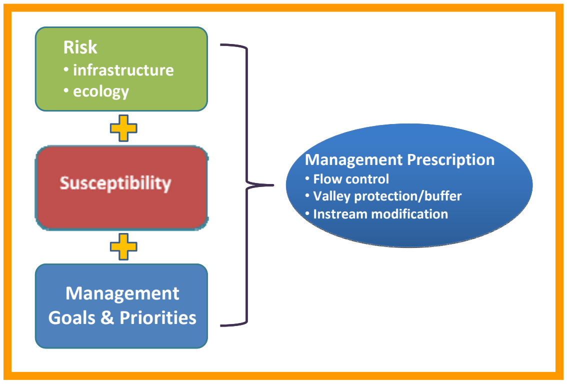


Figure ES1: Decision nodes that influence the management prescription for a particular stream reach.

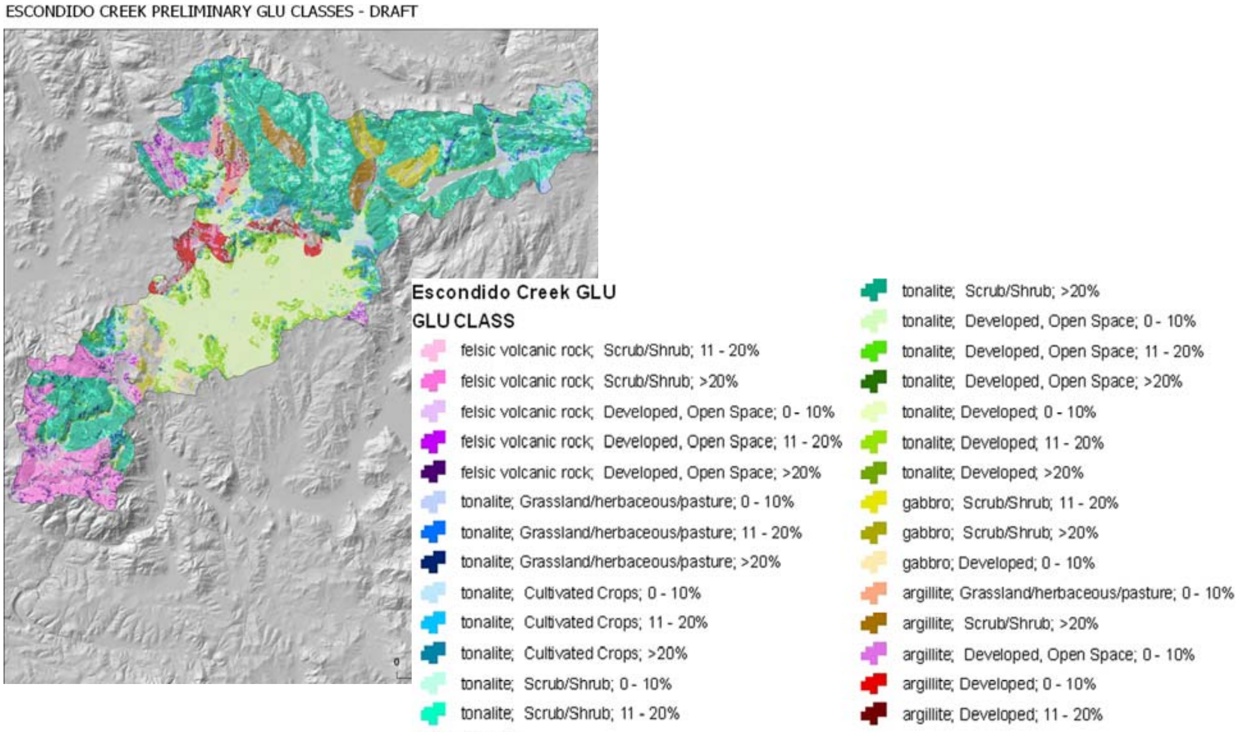
We have produced a series of documents that outline a process and provide tools aimed at addressing the decision node associated with assessing channel susceptibility. The three corresponding hydromodification screening tool documents are:

1. *GIS-based catchment analyses of potential changes in runoff and sediment discharge* which outlines a process for evaluating potential change to stream channels resulting from watershed-scale changes in runoff and sediment yield.
2. *Field manual for assessing channel susceptibility* which describes an in-the-field assessment procedure that can be used to evaluate the relative susceptibility of channel reaches to deepening and widening.
3. *Technical basis for development of a regionally calibrated probabilistic channel susceptibility assessment* which provides technical details, analysis, and a summary of field data to support the field-based assessment described in the field manual.

The catchment analyses and the field manual are designed to support each other by assessing channel susceptibility at different scales and in different ways. The GIS-based catchment analyses document is a planning tool that describes a process to predict likely effects of hydromodification based on potential change in water and sediment discharge as a consequence of planned or potential landscape alteration (e.g., urbanization). Data on geology, hillslope, and land cover are compiled for each watershed of interest, overlaid onto background maps, grouped into several discrete categories, and classified independently across the watershed in question.

The classifications are used to generate a series of Geomorphic Landscape Units (GLUs) at a resolution defined by the coarsest of the three data sets (usually 10 to 30 m). Three factors: geology, hillslope, and land cover are used because the data are readily available; these factors are important to controlling sediment yield. The factors are combined into categories of High, Medium, or Low relative sediment production. The current science of sediment yield estimation is not sophisticated enough to allow fully remote (desktop) assignment of these categories. Therefore initial ratings must be verified in the field.

Once the levels of relative sediment production (i.e., Low, Medium, and High) are defined across a watershed under its current configuration of land use, those areas subject to future development are identified, and corresponding sediment-production levels are determined by substituting Developed land cover for the original categories and modifying the relative sediment production as necessary (Figure ES2). Conversely, relative sediment production for currently developed watershed areas can be altered to estimate relict sediment production for an undeveloped land use and used to assess the impact of watershed development on pre-development sediment production. The resultant maps can be used to aid in planning decisions by indicating areas where changes in land use will likely have the largest (or smallest) effect on sediment yield to receiving channels.



Source: SWS 2008

Figure ES2: Example of Geomorphic Landscape Units for the Escondido Creek Watershed.

The field assessment procedure is intended to provide a rapid assessment of the relative susceptibility of a specific stream reach to effects of hydromodification. The intrinsic sensitivity of a channel system to hydromodification as determined by the ratio of disturbing to resisting forces, proximity to thresholds of concern, probable rates of response and recovery, and potential for spatial propagation of impacts. A combination of relatively simple, but quantitative, field indicators are used as input parameters for a set of decision trees. The decision trees follow a logical progression and allow users to assign a classification of Low, Medium, High, or Very High susceptibility rating to the reach being assessed. Ratings based on likely response in the vertical and lateral directions (i.e., channel deepening and widening) are assigned separately. The screening rating foreshadows the level of data collection, modeling, and ultimate mitigation efforts that can be expected for a particular stream-segment type and geomorphic setting. The field assessment is novel in that it incorporates the following combination of features:

- Integrated field and office/desktop components
- Separate ratings for channel susceptibility in vertical and lateral dimensions
- Transparent flow of logic via decision trees
- Critical nodes in the decision trees are represented by a mix of probabilistic diagrams and checklists
- Process-based metrics selected after exhaustive literature review and analysis of large field dataset
- Metrics balance process fidelity, measurement simplicity, and intuitive interpretability
- Explicitly assesses proximity to geomorphic thresholds delineated using field data from small watersheds in southern California
- Avoids bankfull determination, channel cross-section survey, and sieve analysis, but requires pebble count in some instances
- Verified predictive accuracy of simplified logistic diagrams relative to more complex methods, such as dimensionless shear-stress analyses and Osman and Thorne (1988) geotechnical stability procedure
- Assesses bank susceptibility to mass wasting; field-calibrated logistic diagram of geotechnical stability vetted by Colin Thorne (personal communication)
- Regionally-calibrated braiding/incision threshold based on surrogates for stream power and boundary resistance
- Incorporates updated alternatives to the US Geological Survey (USGS; Waananen and Crippen 1977) regional equations for peak flow (Hawley and Bledsoe In Review)
- Does not rely on bank vegetation given uncertainty of assessing the future influence of root reinforcement (e.g., rooting depth/bank height)
- Channel evolution model underpinning the field procedure is based on observed responses in southern California using a modification of Schumm *et al.* (1984) five-stage model to represent alternative trajectories

The probabilistic models of braiding, incision, and bank instability risk embedded in the screening tools were calibrated with local data collected in an extensive field campaign. The models help users directly assess proximity to geomorphic thresholds and offer a framework for gauging susceptibility that goes beyond expert judgment. The screening analysis represents the first step toward determining appropriate management measures and should help inform decisions about subsequent more detailed analysis.

The GIS-based catchment-scale analysis and the field screening procedure are intended to be used as a set of tools to inform management decisions (Figure ES3). The catchment-scale analysis provides an overall assessment of likely changes in runoff and sediment discharge that can be used to support larger-scale land use planning decisions and can be applied prospectively or retrospectively. The field screening procedure provides more precise estimates of likely response of individual stream reaches based on direct observation of indicators. The field assessment procedure also provides a method to evaluate the extent of potential upstream and downstream propagation of effects (i.e., the analysis domain). In concept, the catchment-scale analysis would be completed for a watershed of interest before conducting the field analysis. However, this is not required and the two tools can be used independent of each other. It is not presently possible to describe a mechanistic linkage between the magnitude of the *drivers* of hydromodification (i.e., changes in the delivery of water and sediment to downstream channels), the *resistance* of channels to change, and the net expression on channel form. For this reason, the results of the catchment and field analyses must be conducted independently and the results cannot be combined to produce an overall evaluation of channel susceptibility to morphologic change (Figure ES3).

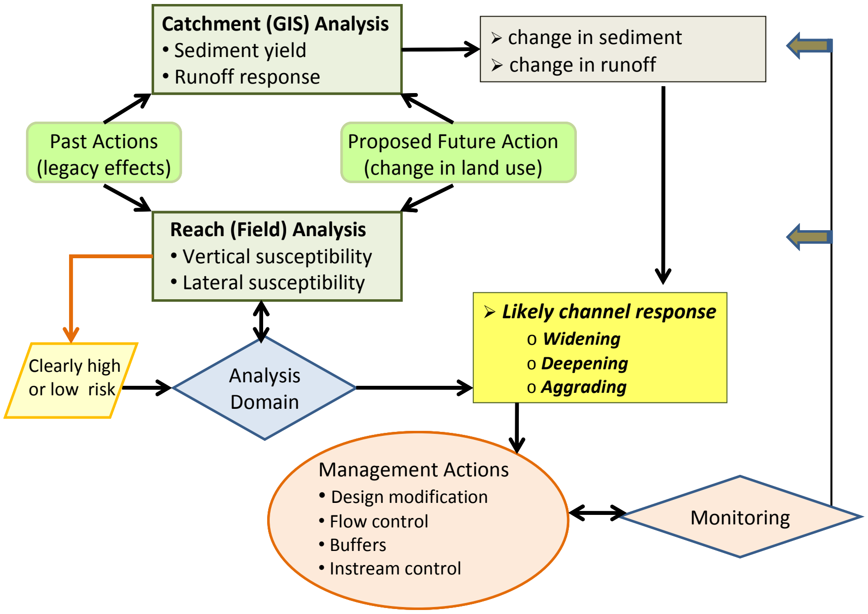


Figure ES3: Relationship of catchment and field screening tools to support decisions regarding susceptibility to effects of hydromodification.

Finally, it is important to note that these tools should be used as part of larger set of considerations in the decision making process (see Figure ES1). For example, the tools do not provide assessments of the ecological or economic affects of hydromodification. Similarly, they do not allow attribution of current conditions to past land use actions. Although the screening tool is designed to have management implications via a decision framework, policy/management decisions must be made by local stakeholders in light of a broader set of considerations.

Table of Contents

List of Figures

INTRODUCTION

Hydromodification, the response of streams to changes in flow and sediment input, is an area of active investigation and emerging regulation. Previous research that led to screening tool development has concluded that 1) urbanization markedly affects the flow regimes of streams in southern California, 2) the corresponding imbalances in sediment-transport capacity result in substantial geomorphic instabilities across most stream settings, 3) channels in southern California may be more sensitive than streams in other regions of the United States (US) for equivalent flows, bed-material sizes, valley slopes, and bank heights/angles, and 4) widely varying degrees of susceptibility to hydromodification are clearly reflected across the field study sites as an interaction between flow energy and the resistance of channel boundaries to lateral and vertical adjustments (Hawley 2009).

Many management schemes currently use a one-size-fits-all approach to managing hydromodification effects, whereby a single criterion is applied to all streams within a given area. However, factors such as dominant bed material, channel planform, grade control, vegetation, and existing infrastructure can influence the rate and manner in which streams respond to changes in flow and sediment. Consideration of these differences in management programs requires a tool to rate stream reaches in terms of their relative susceptibility to hydromodification effects.

This document provides the steps and process to apply a process-based hydromodification susceptibility screening tool. The tool builds on studies conducted in other regions, as summarized by Bledsoe *et al*. (2008), to provide a means to rank stream reaches in terms of their relative likelihood of response to hydromodification. The screening tool consists of two elements: 1) Geographic Information System (GIS) based landscape-scale analyses of relative runoff and sediment yield to stream channels, and 2) field-based assessment of channel condition. Together these two elements can be used to assess susceptibility of a specific stream reach based on both landscape and local influences (**Figure 1**). The GIS based analysis is intended mainly as a planning tool to allow potential changes in runoff and sediment yield to be considered during the siting and design of new developments. This tool is presented in the companion to this document. The field-based tool is intended to provide a rapid assessment of the relative susceptibility of a specific stream reach to effects of hydromodification. This tool is presented in this document.

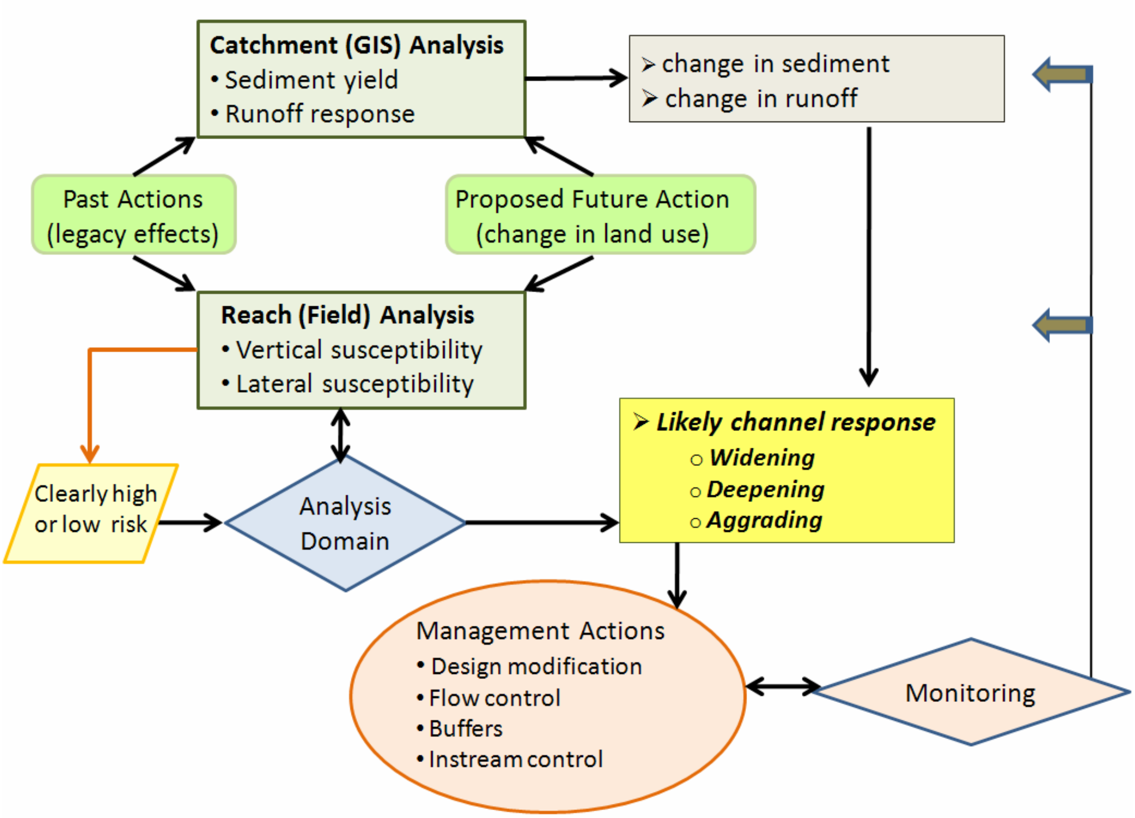


Figure 1. Conceptual application of GIS- and field-based screening tools.

General features of the field screening tool:

- Integrated field and office/desktop components
- Separate ratings for channel susceptibility in vertical and lateral dimensions
- Transparent flow of logic via decision trees
- Critical nodes in the decision trees are represented by a mix of probabilistic diagrams and checklists
- Process-based metrics selected after exhaustive literature review and analysis of large field dataset
- Metrics balance process fidelity, measurement simplicity, and intuitive interpretability
- Explicitly assesses proximity to geomorphic thresholds delineated using field data from small watersheds in southern California
- Avoids bankfull determination, channel cross-section survey, and sieve analysis, but requires pebble count in some instances

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- Does not rely on bank vegetation given uncertainty of assessing the future influence of root reinforcement (e.g., rooting depth/bank height)
- Channel evolution model (CEM) underpinning the field procedure is based on observed responses in southern California using a modification of Schumm *et al.* (1984) five-stage model to represent alternative trajectories

The Field Screening Tool DOES NOT:

- ⊗ **Make policy/management decisions**: although the screening tool is designed to have management implications via a decision framework, policy/management decisions must be made by local stakeholders
- ⊗ **Incorporate ecological/economic considerations**: the screening tool is exclusively focused on geomorphic stability and does not include ecological/economic aspects that stakeholders may consider
- ⊗ **Assess historical attribution**: the screening tool is designed to assess the current susceptibility of a channel, independent of attributing degraded conditions to historical land users, and policies.

OFFICE AND FIELD COMPONENTS FOR FIELD SCREENING TOOL

Office Components

The screening tool presented in this report is predominantly designed for field-based assessment. The field tool requires some preparatory office work to provide context and familiarity with the site prior to conducting the field evaluation. The following addresses:

- Examination of Overall Setting (using Google Earth or equivalent aerials)
- Quantification of important remotely-sensed parameters (using GIS software)
- Identification of Analysis Domain (tentatively defining upstream and downstream extents of field reconnaissance, locations of likely grade control, and valley transitions)

Overall Setting

Using satellite imagery/aerial photography, gather a baseline understanding of the watershed. Consider aspects such as development extent, fires and vegetation coverage, sediment sources and bottlenecks, ecologically-sensitive areas, etc. Examine the valley setting near the project in greater detail, identifying tributary confluences, potential grade control (e.g., road crossings), and infrastructure (e.g., stormwater outfalls, drainage 'improvements', etc.) *sensu* Chin and Gregory (2005). Specifically consider:

- Geologic setting, basin type, valley context, and tributaries
- Recent watershed history – urbanization and fire
- Obvious grade-control locations, human influences, and existing infrastructure

Printed screen shots of aerials, specifically near the project site, may be helpful in the field. In addition, the results from the GIS-based assessment (if completed) should be reviewed prior to beginning the field assessment.

GIS Metrics

Using publicly available GIS data, measure four readily quantifiable watershed- and valley-scale variables that will be used to compute the simple, but statistically-significant, screening indices (i.e., flow, screening index, and valley width index). Measurement details in Form 1 (**Figure 2**).

- Spatial: contributing drainage area
- Topographic: valley slope at site(s)
- Precipitation: mean annual area-weighted precipitation
- Geomorphic Confinement: valley bottom width at site(s)

These variables are explained in more detail in Form 1 Table 1 (**Figure 2**). A digital data entry form is available as well (Data Entry Form.xls).

Analysis Domain

The effects of hydromodification may propagate for significant distances downstream (and sometimes upstream) from a point of impact such as a stormwater outfall. Accordingly, it may be necessary to conduct geomorphic screening reconnaissance across a domain spanning multiple channel types/settings and property owners.

The maximum spatial unit for assigning a susceptibility rating is defined as a *ca.* 20 channel width reach not to exceed 200 m. Before conducting the field screening, the analyst should identify the following attributes as part of the office analysis to estimate the maximum extent of the analysis domain for field refinement.

Begin by defining the points or zones along the channel reach(es) where changes in discharge or channel type are likely to occur (e.g., potential locations of outfalls or tributary inputs). Document any observed outfalls for final desktop synthesis and define the upstream and downstream extents of analysis as follows:

- **Downstream** – until reaching the closest of the following:
    - at least one reach downstream of the first grade-control point (but preferably the second downstream grade-control location)
    - tidal backwater/lentic waterbody
    - equal order tributary (Strahler 1952)[1]
    - a 2-fold increase in drainage area[2]

OR demonstrate sufficient flow attenuation through existing hydrologic modeling

- **Upstream** – extend the domain upstream for a distance equal to 20 channel widths OR to grade control in good condition – whichever comes first. Within that reach, identify hard points that could check headward migration, evidence that head cutting is active or could propagate unchecked upstream

Within the analysis domain there may be several reaches that should be assessed independently based on either length or change in physical characteristics. In more urban settings, segments may be logically divided by road crossings (Chin and Gregory 2005), which may offer grade control, cause discontinuities in the conveyance of water or sediment, etc. In more rural settings, changes in valley/channel type, natural hard points, and tributary confluences may be more appropriate for delineating assessment reaches. In general, the following criteria should trigger delineation of a new reach and hence a separate susceptibility assessment:

- 200 m or ca. 20 bankfull widths – it is difficult to integrate over longer distances
- Distinct or abrupt change in grade or slope due to either natural or artificial features
- Distinct or abrupt change in dominant bed material or sediment conveyance
- Distinct or abrupt change in valley setting or confinement
- Distinct or abrupt change in channel type, bed form, or planform

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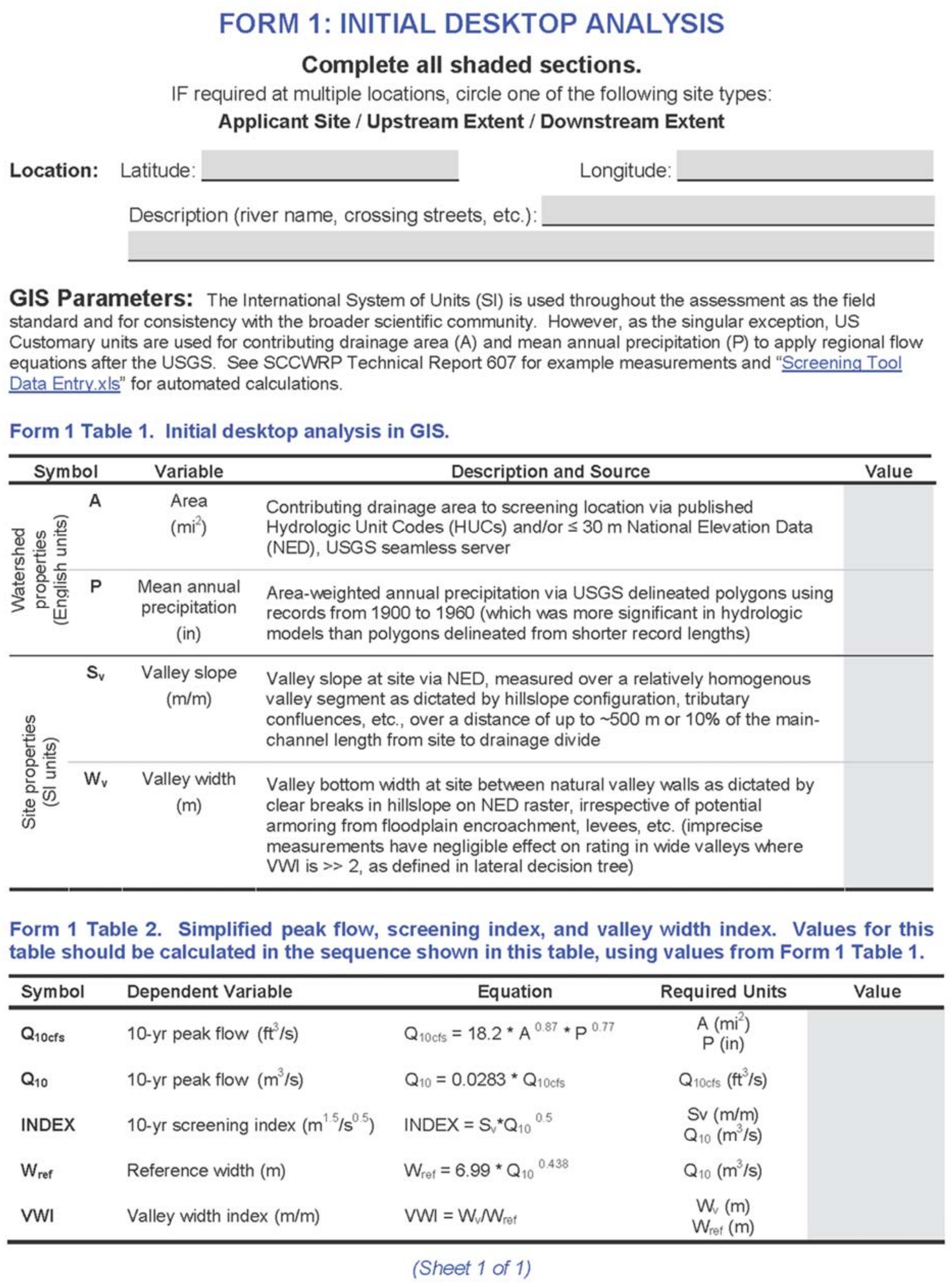
[1] In the absence of proximate downstream grade control or backwater, the confluence of an 'equal order tributary' should correspond to substantial increases in flow and channel capacity that should, in theory, correspond to significant flow attenuation; however, there is no scientific basis to assume that downstream channels of higher stream order are less susceptible than their upstream counterparts. This (practically-driven) guidance should not supersede the consideration of local conditions and sound judgment. Stakeholders may elect to use a more regionally-preferred guidance.

[2] An increase in drainage area greater than or equal to 100% would roughly correspond to the addition of an equal-order tributary



FORM 1: INITIAL DESKTOP ANALYSIS

Complete all shaded sections.

IF required at multiple locations, circle one of the following site types:

Applicant Site / Upstream Extent / Downstream Extent

Location: Latitude: __________ Longitude: __________

Description (river name, crossing streets, etc.): __________

____

GIS Parameters: The International System of Units (SI) is used throughout the assessment as the field standard and for consistency with the broader scientific community. However, as the singular exception, US Customary units are used for contributing drainage area (A) and mean annual precipitation (P) to apply regional flow equations after the USGS. See SCCWRP Technical Report 607 for example measurements and "Screening Tool Data Entry.xls" for automated calculations.

Form 1 Table 1. Initial desktop analysis in GIS.

Symbol		Variable	Description and Source	Value
Watershed properties (English units)	A	Area (mi^2)	Contributing drainage area to screening location via published Hydrologic Unit Codes (HUCs) and/or ≤ 30 m National Elevation Data (NED), USGS seamless server	
	P	Mean annual precipitation (in)	Area-weighted annual precipitation via USGS delineated polygons using records from 1900 to 1960 (which was more significant in hydrologic models than polygons delineated from shorter record lengths)	
Site properties (SI units)	S_v	Valley slope (m/m)	Valley slope at site via NED, measured over a relatively homogenous valley segment as dictated by hillslope configuration, tributary confluences, etc., over a distance of up to ~500 m or 10% of the main-channel length from site to drainage divide	
	W_v	Valley width (m)	Valley bottom width at site between natural valley walls as dictated by clear breaks in hillslope on NED raster, irrespective of potential armoring from floodplain encroachment, levees, etc. (imprecise measurements have negligible effect on rating in wide valleys where VWI is >> 2, as defined in lateral decision tree)	

Form 1 Table 2. Simplified peak flow, screening index, and valley width index. Values for this table should be calculated in the sequence shown in this table, using values from Form 1 Table 1.

Symbol	Dependent Variable	Equation	Required Units	Value
Q_{10cfs}	10-yr peak flow (ft^3/s)	$Q_{10cfs} = 18.2 * A^{0.87} * P^{0.77}$	A (mi^2) P (in)	
Q_{10}	10-yr peak flow (m^3/s)	$Q_{10} = 0.0283 * Q_{10cfs}$	Q_{10cfs} (ft^3/s)	
INDEX	10-yr screening index ($m^{1.5}/s^{0.5}$)	$INDEX = S_v * Q_{10}^{0.5}$	Sv (m/m) Q_{10} (m^3/s)	
W_{ref}	Reference width (m)	$W_{ref} = 6.99 * Q_{10}^{0.438}$	Q_{10} (m^3/s)	
VWI	Valley width index (m/m)	$VWI = W_v/W_{ref}$	W_v (m) W_{ref} (m)	

(Sheet 1 of 1)

Figure 2. Form 1: Initial Desktop Analysis. Complete set of assessment forms in Appendix B.

Conceptual Basis for 10-yr Flow Analysis

The geomorphic thresholds presented in the field-screening sections below correspond to the 10-yr peak flow calculated using the regional hydrologic model presented in Form 1 Table 2 (**Figure 2**; Hawley and Bledsoe, In review). This peak flow model is substantially more accurate for small watersheds in southern California than previously published regional regression equations. The 10-yr flow was selected for several reasons. First, it better represents a channel-filling flow than alternative return intervals such as Q_2. Second, it typically requires a 10-yr instantaneous peak flow to create a geomorphically significant *duration* at the 2-yr flow magnitude (i.e., the 10-yr instantaneous peak flow typically corresponds to a daily-mean flow equal to a 2- to 3-yr peak magnitude). Finally, the 10-yr hydrologic models had the best prediction accuracy of all return intervals. Out of 5 peak-flow model forms (Hawley and Bledsoe, In review), the model based on drainage area and precipitation had the best cross-validation performance. With respect to modeling Q_{10}, the standard error as percentage of mean for validation samples was 41% (arithmetic space), with an R^2 during final calibration of 0.81 (geometric space). Because of the relatively-robust model performance and overall simplicity, we selected the model form of $Q = f(A, P)$ for use in this screening tool.

Field Components

After completing the Initial Desktop Analysis (**Figure 2**), the user should have a first-order estimate of an appropriate analysis domain, a baseline understanding of the watershed, and critical indices to use during the field assessment(s). At this juncture it is essential to examine the stream (and its valley setting) in greater detail. Minimally, the following items should be taken to the field, although Form 2: Pebble Count (**Figure 4**) is not needed in every case:

- Assessment forms and/or field book for sketches/notes
- Digital camera for photographic documentation
- Pocket rod and/or tape for some basic measurements and reference/scale in photographs
- Protractor (e.g., gravity-driven) for measuring bank angle (**Figure 3a**)
- Gravelometer (i.e., US SAH-97 half-phi template) for standardized pebble count (**Figure 3b**)

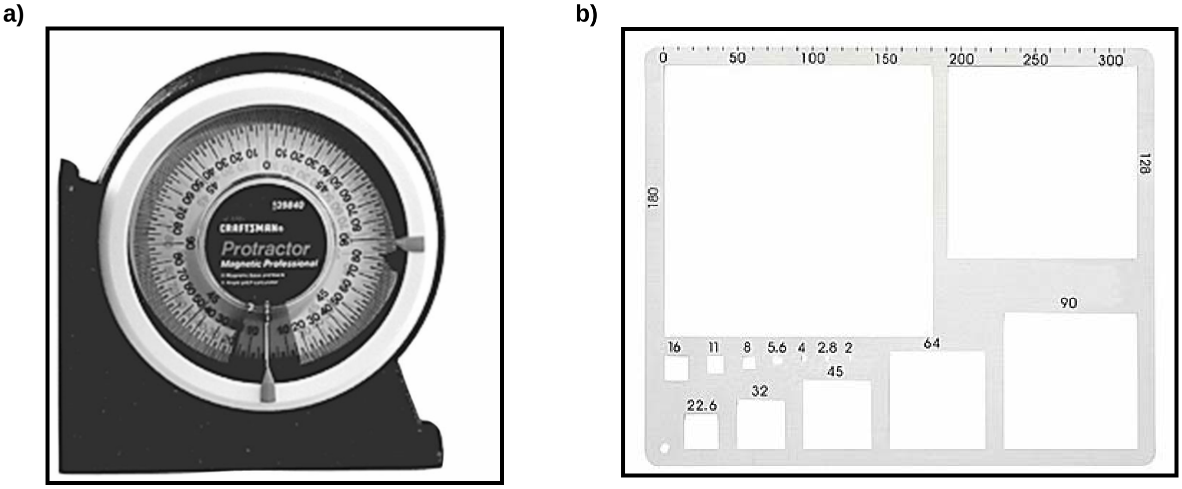
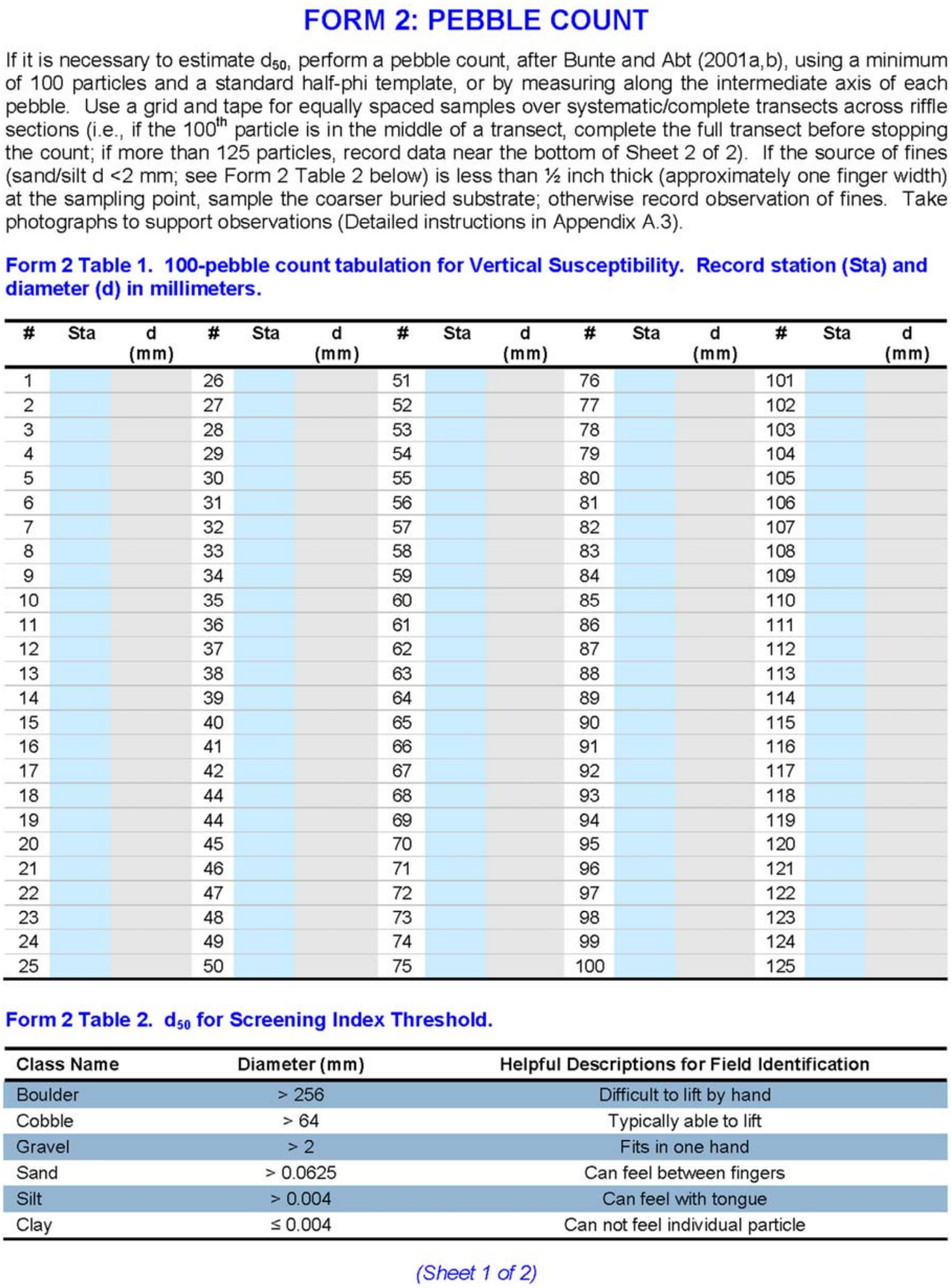


Figure 3. Craftsman magnetic protractor (a) and US SAH-97 half-phi template gravelometer (b).



FORM 2: PEBBLE COUNT

If it is necessary to estimate d_{50}, perform a pebble count, after Bunte and Abt (2001a,b), using a minimum of 100 particles and a standard half-phi template, or by measuring along the intermediate axis of each pebble. Use a grid and tape for equally spaced samples over systematic/complete transects across riffle sections (i.e., if the 100th particle is in the middle of a transect, complete the full transect before stopping the count; if more than 125 particles, record data near the bottom of Sheet 2 of 2). If the source of fines (sand/silt d <2 mm; see Form 2 Table 2 below) is less than ½ inch thick (approximately one finger width) at the sampling point, sample the coarser buried substrate; otherwise record observation of fines. Take photographs to support observations (Detailed instructions in Appendix A.3).

Form 2 Table 1. 100-pebble count tabulation for Vertical Susceptibility. Record station (Sta) and diameter (d) in millimeters.

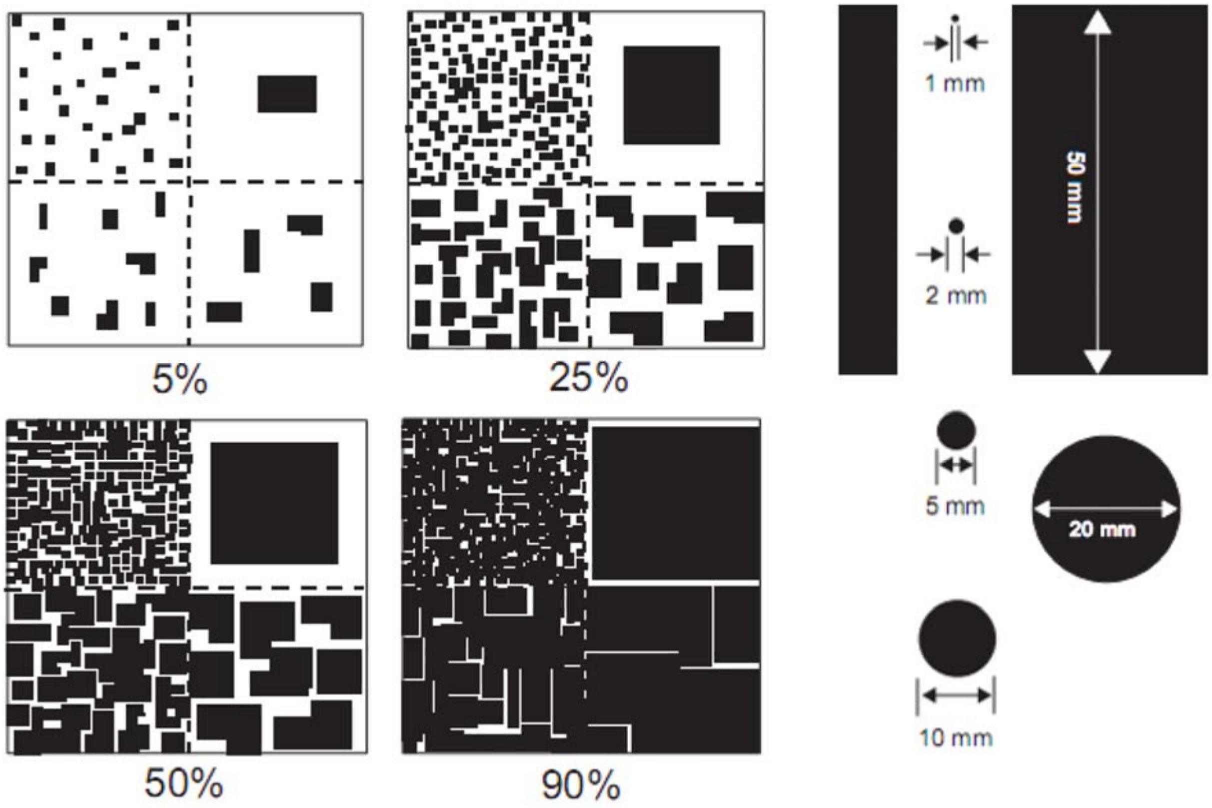
#	Sta	d (mm)	#	Sta	d (mm)	#	Sta	d (mm)	#	Sta	d (mm)	#	Sta	d (mm)
1			26			51			76			101		
2			27			52			77			102		
3			28			53			78			103		
4			29			54			79			104		
5			30			55			80			105		
6			31			56			81			106		
7			32			57			82			107		
8			33			58			83			108		
9			34			59			84			109		
10			35			60			85			110		
11			36			61			86			111		
12			37			62			87			112		
13			38			63			88			113		
14			39			64			89			114		
15			40			65			90			115		
16			41			66			91			116		
17			42			67			92			117		
18			44			68			93			118		
19			44			69			94			119		
20			45			70			95			120		
21			46			71			96			121		
22			47			72			97			122		
23			48			73			98			123		
24			49			74			99			124		
25			50			75			100			125		

Form 2 Table 2. d_{50} for Screening Index Threshold.

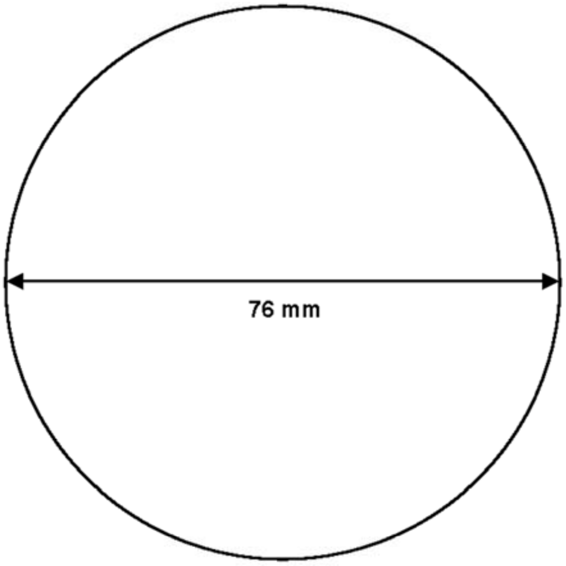
Class Name	Diameter (mm)	Helpful Descriptions for Field Identification
Boulder	> 256	Difficult to lift by hand
Cobble	> 64	Typically able to lift
Gravel	> 2	Fits in one hand
Sand	> 0.0625	Can feel between fingers
Silt	> 0.004	Can feel with tongue
Clay	≤ 0.004	Can not feel individual particle

(Sheet 1 of 2)

Figure 4. Form 2: Pebble Count. Complete set of assessment forms in Appendix B.



Note: Each quadrant within each box contains the same total area covered using different sized objects.



Form 2 Figure 1. Examples of % coverage by volume and substrate sizing adapted from *NRCS Field Book for Describing and Sampling Soils* (Schoeneberger *et al.* 2002) and Julien (1998).

(Sheet 2 of 2)

Figure 4. Continued

Susceptibility Rating Definitions

The field screening tool uses a combination of relatively simple, but quantitative, field indicators as input parameters to a set of decision trees. The decision trees follow a logical progression and allow users to assign a classification of Low, Medium, High, or Very High susceptibility rating (Table 1) to the reach being assessed.

Table 1. Vertical and Lateral Susceptibility rating definitions.

Susceptibility Rating	Definitions of Susceptibility
LOW	• Low ratio of disturbing forces to resisting forces
	• Far from geomorphic thresholds of concern (based on explicit quantification of probability if feasible – < 1% probability of exceedance)
	• Relatively rapid relaxation time
	• Low potential for positive feedbacks, nonlinear response, sensitivity to initial conditions
	• Very limited or no spatial propagation (*ca.* 10 m)
MEDIUM	• Moderate ratio of disturbing forces to resisting forces
	• Not proximate to geomorphic thresholds of concern (based on explicit quantification of probability if feasible – e.g., < 10% probability of exceedance)
	• Moderately rapid relaxation time
	• Low to moderate potential for positive feedbacks, nonlinear response, sensitivity to initial conditions
	• Local spatial propagation, contained within *ca.* 100 m
HIGH	• High ratio of disturbing forces to resisting forces
	• Proximate to geomorphic thresholds of concern (based on explicit quantification of probability if feasible – e.g., > 10 to 50% probability of exceedance)
	• Relaxation time may be relatively long given magnitude and spatial extent of change
	• Moderate to high potential for positive feedbacks, nonlinear response, sensitivity to initial conditions
	• Potential spatial propagation – headcutting/base-level change upstream and downstream but contained within *ca.* 100 to 1,000 m domain of control
VERY HIGH	• High ratio of disturbing forces to resisting forces
	• At geomorphic thresholds of concern (based on explicit quantification of probability if feasible – e.g., $\geq$ 50% probability of exceedance)
	• Relaxation time may be relatively long given magnitude and spatial extent of change
	• High potential for positive feedbacks, nonlinear response, sensitivity to initial conditions
	• Potential widespread spatial propagation – headcutting/base-level change upstream and downstream uncontained within *ca.* 1,000 m domain of control
	• Specifically, the VERY HIGH rating is reserved for the following geomorphic thresholds/states (clear and present danger): o **Vertical** ▪ Currently unstable (Channel Evolution Model (CEM) Type III or IV) with incision past critical bank height for mass wasting and active bank failure ▪ Currently stable (CEM Type I or II) with banks less than critical height, but $p \geq 50\%$ for incision or braiding in labile bed (d_{50} <16 mm) with ineffective/absent grade control o **Lateral** ▪ Currently unstable with active braiding/extensive mass wasting/fluvial erosion (> 50% of banks) in a wide valley ▪ Currently stable consolidated bank in wide valley with High Vertical rating combined with $p > 10\%$ for mass wasting ▪ Currently stable unconsolidated banks with fine toe material in wide valley with High Vertical rating

Recall that it may be necessary to perform the field assessment at several locations based on an analysis domain that could span multiple stream reaches up and downstream (see Analysis Domain above). At each distinct reach type, the user will follow the guidelines below to separately assess susceptibility in vertical and lateral dimensions. Although vertical and lateral responses are often interdependent, vertical and lateral susceptibility are assessed separately for several reasons. First, vertical and lateral responses are primarily controlled by different types of resistance, which, when assessed separately, may improve ease of use and lead to increased repeatability among users compared to an integrated, cross-dimensional assessment. Second, the mechanistic differences between vertical and lateral responses point to different modeling tools and potentially different management strategies. Having separate screening ratings may better direct users and managers to the most appropriate tools for subsequent analyses.

The field screening tool uses combinations of decision trees, checklists, tables and calculations. We attempt to employ decision trees when a question can be answered fairly definitively and/or quantitatively (e.g., median grain diameter (d_{50}) < 16 mm; see Form 2 (**Figure 4**)). Alternatively, checklists are used in places where answers are relatively qualitative (e.g., grade control).

The tool is designed to first classify the current state of the assessment area. Next, the user identifies the type and number of risk factors that are present; risk factors are then combined with current state to determine a final rating. Users should take photographs to support their assessment. If uncertain about a given decision node, the user should use the more precautionary pathway that results in a higher rating of susceptibility. The field-assessment process is described in detail below:

- Decision Trees
    - Vertical Susceptibility
    - Lateral Susceptibility

- Design/Setup
    - Assess the Analysis Domain (defined above), which may include multiple stream types and settings; conduct separate analyses for reaches distinguished by distance, change in valley type, dominant bed material, and other significant geomorphic considerations
    - Assign susceptibility ratings of Low, Medium, High, and Very High (as defined in Table 1 above) independently to the vertical and lateral conditions of each channel reach

- Consult susceptibility decision trees and photographic supplements for rating guidance; to clearly highlight rating endpoints within the decision trees, non-terminal and terminal nodes in the decision trees have been color coded (**Figure 5**) to prompt users to proceed to another step

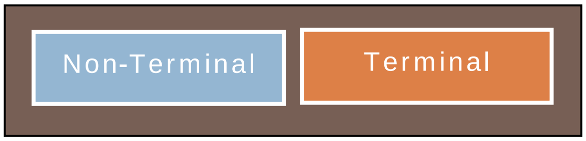


Figure 5. Color scheme for non-terminal and terminal nodes in susceptibility decision trees.

- Overall logic of susceptibility decision trees (**Figure 6**)

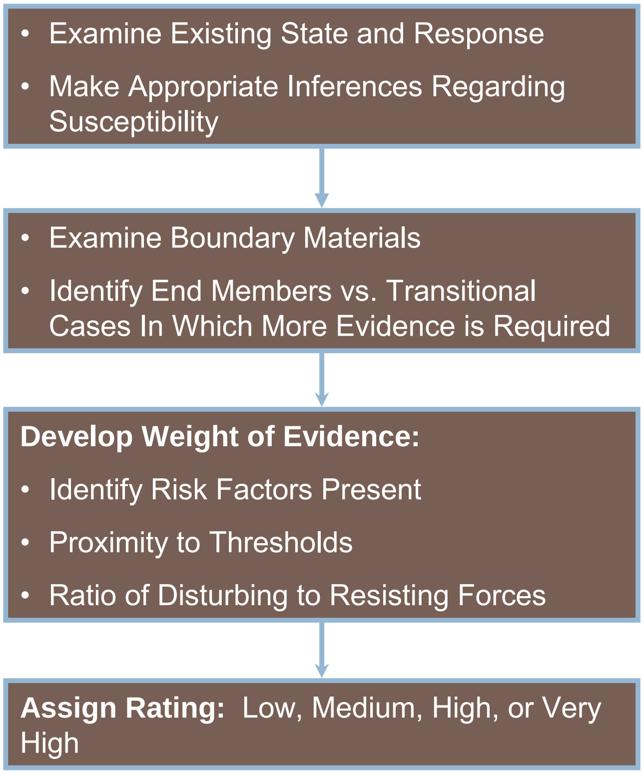


Figure 6. Logical flow of susceptibility decision trees.

CHANNEL SUSCEPTIBILITY DECISION TREES AND FORMS

Vertical Susceptibility

In the Vertical Susceptibility decision tree, there are three potential states of bed material based on broad classes of armoring potential. These states are listed below from most susceptible to least with definitions and photographic examples provided in Form 3 (**Figure 7**):

- Labile Bed – sand-dominated bed, little resistant substrate
- Transitional/Intermediate Bed – bed typically characterized by gravel/small cobble, intermediate level of resistance of the substrate and uncertain potential for armoring
- Threshold Bed (Coarse/Armored Bed) – armored with large cobbles or larger bed material or highly-resistant bed substrate (i.e., bedrock)

Threshold beds composed of boulders and large cobbles and/or highly-resistant bedrock are the region's most resistant channel beds with geologic grade control and a natural capacity to armor (see Form 3 (**Figure 7**)). Consequently, threshold beds correspond to a vertical rating of low. Conversely, labile beds have little to no capacity to self-armor and have a high probability of vertical adjustments in response to hydromodification. Depending on two additional decision tree questions that consider the current state of incision and grade control, labile beds receive a rating of High or Very High. Finally, transitional/intermediate beds are involved in a wide range of potential susceptibility responses and must be assessed in greater detail in order to develop weight of evidence for appropriate screening ratings. Three primary risk factors used to assess vertical susceptibility for channels with transitional/intermediate bed materials:

- Armoring Potential – Form 3 Checklist 1 (**Figure 7**)
- Grade Control – Form 2 Checklist 1 (**Figure 7**)
- Probability of Incision/Braiding based on a Regionally-Calibrated Screening Index – Form 3 Figure 1/Table 1 (**Figure 7**)

These risk factors are assessed using checklists and a diagram, then calculated using the instructions and equation at the bottom of Form 3 Sheet 4 of 4 (**Figure 7**) to provide an overall vertical susceptibility rating for the intermediate/transitional bed-material group.

Vertical Susceptibility Decision Tree

The purpose of the vertical susceptibility decision tree is to assess the state of the channel bed with a particular focus on the risk of incision (i.e., down cutting). Vertical stability is a prerequisite for lateral stability because a stream that incises can increase bank heights to the point of collapse and channel widening. Accordingly, vertical susceptibility is assessed first because it affects the lateral rating in most instances.

Conceptual Basis

Channel bed material is one of the main factors controlling vertical stability. Bed material is assessed using the photographic supplement Form 3 Figure 1 (**Figure 7**), with Form 2 Figure 1 (**Figure 4**) provided as a reference for some particle sizes and to assist with estimating the percentage of surface sand. Some reaches may require a pebble count, Form 2 (**Figure 4**), for a more definitive assessment of bed material size.

For threshold (coarse/armored) beds, document the channel substrate with photographs, and a supporting pebble count[3] if d_{50} is near 128 mm. For labile beds, use supplemental photographs in Form 3 Figure 1 (**Figure 7**) and the diagram of the five-stage CEM presented in Appendix A, Figure A.3, to assess the current state of channel incision. For intermediate/transitional beds, assess: armoring potential using Form 3 Checklist 1 (**Figure 7**), grade-control condition using Form 3 Checklist 1 (**Figure 7**), and risk of incision/braiding using Form 3 Table 1 (**Figure 7**).

Form 3 Checklist 1 (**Figure 7**): Armoring potential is assessed because it is a primary mechanism in which a channel can self-check channel incision/headcutting. Coarser particles naturally provide greater resistance and, therefore, yield a lower susceptibility rating. Additionally, the tighter the particles are packed, the more resistant the armor layer, which can also influence the rating. Finally, the amount of sand-sized particles can adversely affect the resistance of an armor layer (Wilcock and Kenworthy, 2002; Wilcock and Crowe, 2003).

Form 3 Checklist 2 (**Figure 7**): Grade control is another way in which incision/headcutting can be arrested. When channels adjust their slope, the incision typically hinges around a hard point such as a natural or artificial grade control. Grade control has been clearly demonstrated to be a statistically-significant predictor of channel enlargement in southern California (Hawley 2009). Adjustments may also revolve around channel base-level, which could be set by an estuary, large waterbody (such as a lake or reservoir), or confluence with a larger river.

Form 3 Figure 4 (**Figure 7**): Risk of incising or braiding is based on the potential specific stream power of the valley relative to d_{50}. Beyond armoring potential and grade control, channels with intermediate/transitional beds may also have a relatively-energetic valley setting that creates an inherently higher risk for incision than lower energy settings. The threshold is based on regional data from unconfined, unconstructed valley settings and modeled after similar analyses from various regions (e.g., Chang (1988), van den Berg (1995), and Bledsoe and Watson (2001)).

Hawley (2009) performed separate logistic regression analyses on incising and braiding systems relative to their stable, unconfined counterparts that returned similar thresholds. In developing this revised screening tool, we combined unstable states of braided or incising into one model for parsimony. Well over 100 total model variations were developed that segregated unstable (braided or incising) channels from stable, single-thread, unconfined, unconstructed channels, using different measures of erosive energy (i.e., dimensionless shear stress, specific stream power, and screening index) and different hydrologic models to estimate the 2- and 10-yr instantaneous peak flow events.

In addition, a large body of previous fluvial geomorphic research suggests that the behavior and response potential of coarse versus fine-grained systems is markedly different (e.g., Chang (1988), Montgomery and MacDonald (2002), and Simons and Simons (1987)). We assessed both combined and separated models, based on different grain-size discriminators between sand-

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[3] If d_{50} is clearly greater than 128 mm, there is no need to conduct a pebble count, only visual documentation with photographs and general description of substrate type is recommended.

dominated gravels and gravel/cobble armored systems. Out of 108 total models, all but 6 were significant ($p < 0.05$) with the simplified specific stream power and grain-size surrogate(screening index) regularly performing similarly or superior to the more rigorous indices. Indeed, 5 of the 12 models of the screening index for coarse-size fractions offered complete segregation of unstable/stable sites (i.e., 100% correctly classified). Although that clearly delineates a threshold (Form 3 Table 1 (**Figure 7**)) it precludes using the logistic model to represent risk levels in terms of a range of probabilities. This explains why the 90% and 10% lines converge to the 50% risk level for $d_{50} > 16$ mm in Form 3 Figure 4 (**Figure 7**).

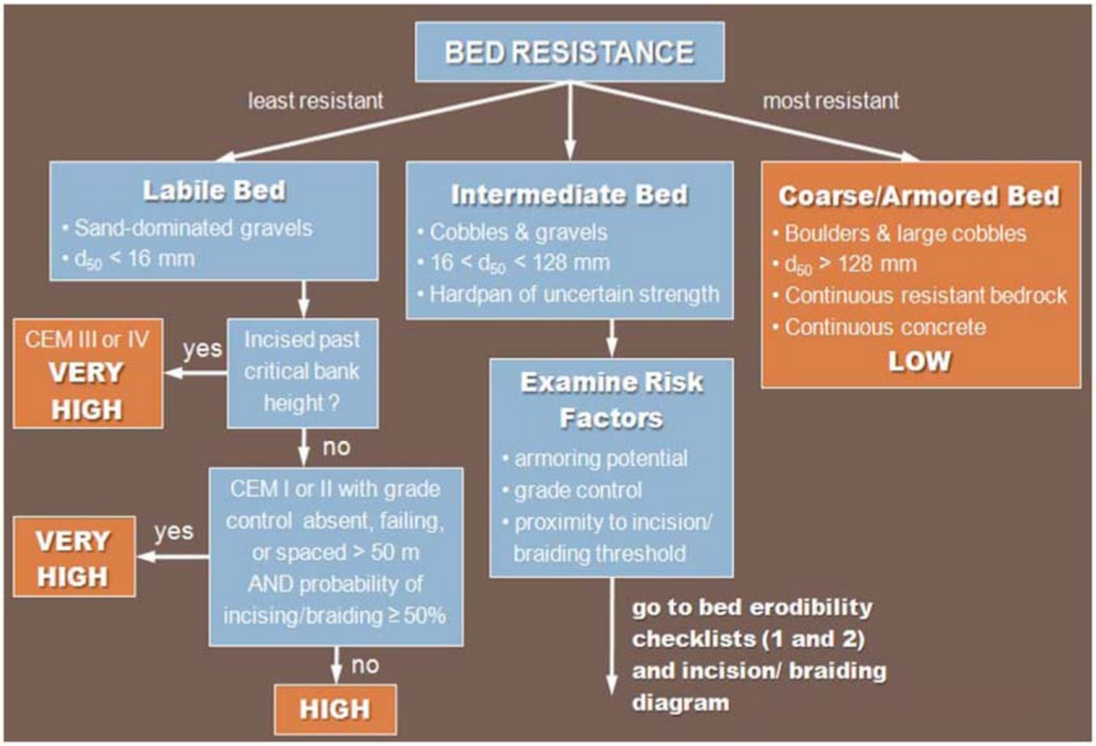
Vertical Flow and Forms

Forms 3: Vertical Susceptibility Field Sheet (**Figure 7**) is used to assess vertical susceptibility. The logical flow of this form is summarized through a series of decisions outlined below:

1) Assess the initial 'state': which of the following (a, b, or c) best describes the bed condition/material
    a. If the bed is Coarse/Armored with $d_{50} > 128$ mm or continuous bedrock/concrete, then Vertical Rating = Low; see Form 3 Figure 1 (**Figure 7**)
    b. If the bed is labile with sand dominated gravels and $d_{50} < 16$ mm, then assess level of incision:
        i. If channel is incised past critical bank height for mass wasting (CEM III or IV), Vertical Rating = Very High; see Form 3 Figure 1 (**Figure 7**) and Form 2 (**Figure 4**)
        ii. If channel is not incised past critical bank height (CEM I or II), assess Grade Control using Form 3 Checklist 2 (**Figure 7**) and Probability of Incision/Braiding using Form 3 Table 1 (**Figure 7**)
            1. If CEM I or II with grade control absent, failing, or spaced at intervals larger than 50 m, AND probability of incising/braiding ≥50%, Vertical Rating = Very High; see Form 3 Figure 1 (**Figure 7**)
            2. If CEM I or II with grade control in good condition and spaced at intervals less than 50 m, OR probability of incising/braiding < 50%, Vertical Rating = High; see Form 3 Figure 1 (**Figure 7**)
    c. If the bed is Intermediate with cobbles and gravels and $16 < d_{50} < 128$ mm or hardpan of uncertain strength, proceed to Form 3 Checklist 1 and 2 (**Figure 7**) to assess Armoring Potential and Grade Control, respectively, and Form 3 Figure 4 (**Figure 7**) to estimate Probability of Incising/Braiding.

FORM 3: VERTICAL SUSCEPTIBILITY FIELD SHEET

Circle appropriate nodes/pathway for proposed site.



BED RESISTANCE

least resistant

most resistant

Labile Bed
- Sand-dominated gravels
- $d_{50} < 16$ mm

Incised past critical bank height ?

yes → CEM III or IV **VERY HIGH**

no ↓

CEM I or II with grade control absent, failing, or spaced > 50 m AND probability of incising/braiding ≥ 50%

yes → **VERY HIGH**

no ↓ **HIGH**

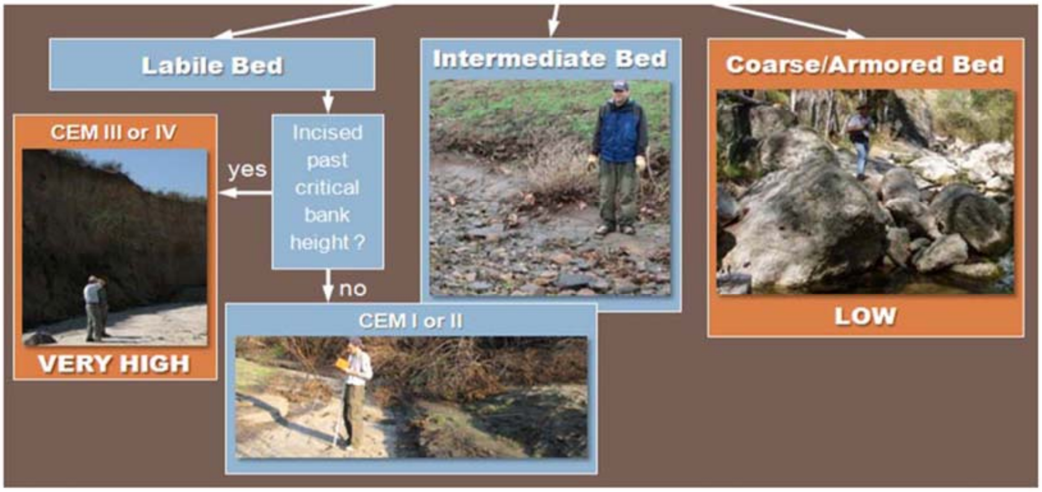
Intermediate Bed
- Cobbles & gravels
- $16 < d_{50} < 128$ mm
- Hardpan of uncertain strength

Examine Risk Factors
- armoring potential
- grade control
- proximity to incision/ braiding threshold

go to bed erodibility checklists (1 and 2) and incision/ braiding diagram

Coarse/Armored Bed
- Boulders & large cobbles
- $d_{50} > 128$ mm
- Continuous resistant bedrock
- Continuous concrete

LOW



Form 3 Figure 1. Vertical Susceptibility photographic supplement to be used in conjunction with Form 3 Bed Resistance above.

(Sheet 1 of 4)

Figure 7. Form 3: Vertical Susceptibility Field Sheet. Complete set of assessment forms in Appendix B.

Form 3 Support Materials

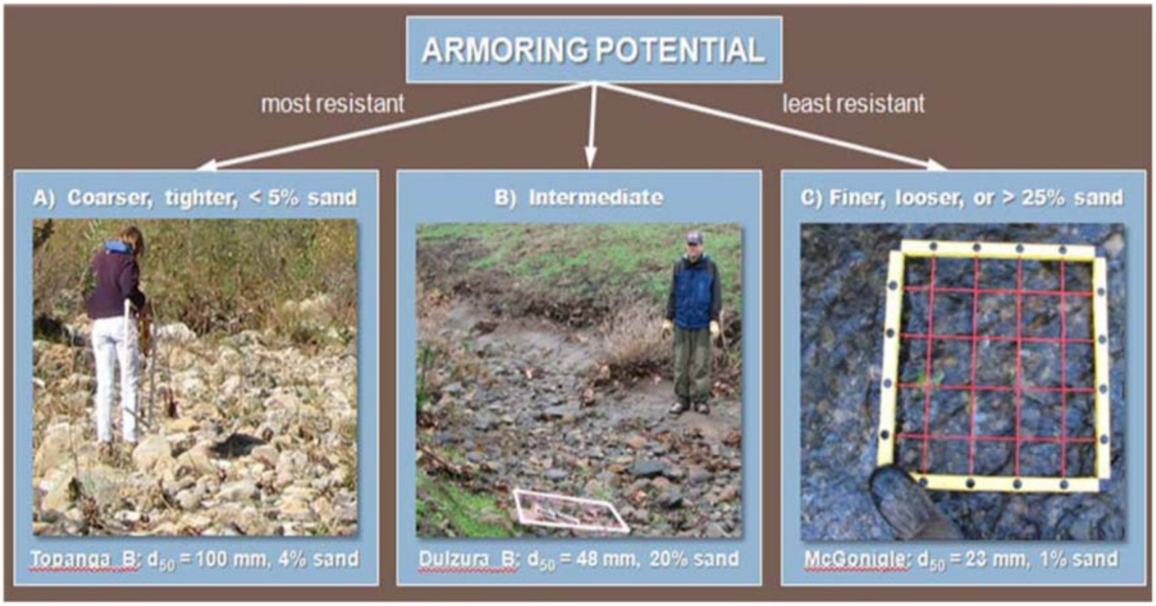
Form 3 Checklists 1 and 2, along with information recording in Form 3 Table 1, are intended to support the decisions pathways illustrated in Form 3 Overall Vertical Rating for Intermediate/Transitional Bed.

Form 3 Checklist 1: Armoring Potential

☐ A A mix of coarse gravels and cobbles that are tightly packed with <5% surface material of diameter <2 mm

☐ B Intermediate to A and C or hardpan of unknown resistance, spatial extent (longitudinal and depth), or unknown armoring potential due to surface veneer covering gravel or coarser layer encountered with probe

☐ C Gravels/cobbles that are loosely packed or >25% surface material of diameter <2 mm



Form 3 Figure 2. Armoring potential photographic supplement for assessing intermediate beds (16 < d_{50} < 128 mm) to be used i**n conjunction with Form 3 Checklist 1.**

(Sheet 2 of 4)

Figure 7. Continued

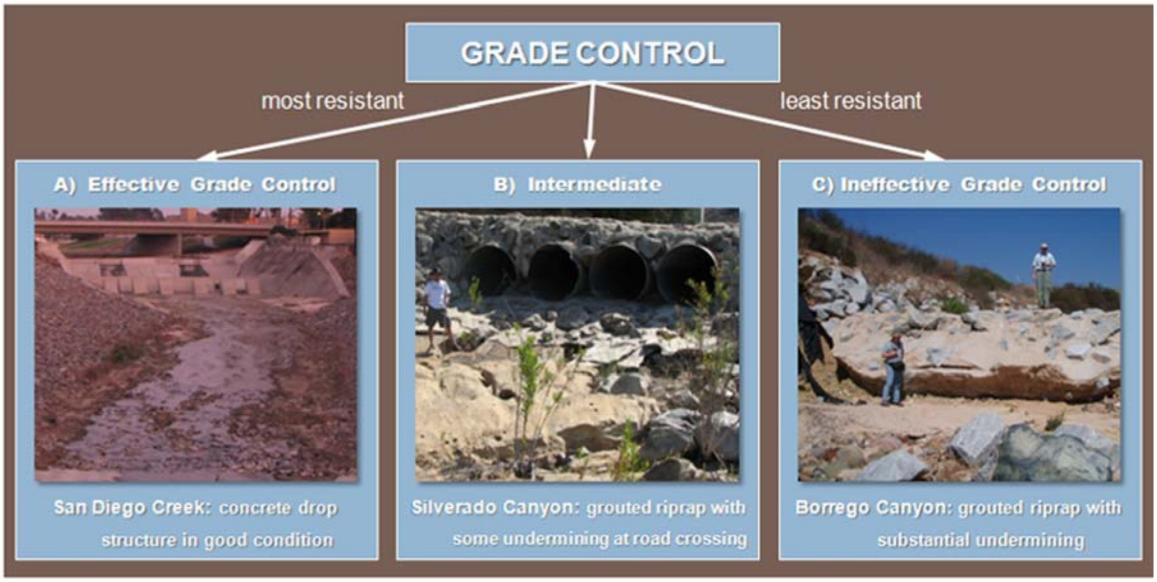
Form 3 Checklist 2: Grade Control

☐ A Grade control is present with spacing <50 m or $2/S_v$ m

- No evidence of failure/ineffectiveness, e.g., no headcutting (>30 cm), no active mass wasting (analyst cannot say grade control sufficient if mass-wasting checklist indicates presence of bank failure), no exposed bridge pilings, no culverts/structures undermined
- Hard points in serviceable condition at decadal time scale, e.g., no apparent undermining, flanking, failing grout
- If geologic grade control, rock should be resistant igneous and/or metamorphic; For sedimentary/hardpan to be classified as 'grade control', it should be of demonstrable strength as indicated by field testing such as hammer test/borings and/or inspected by appropriate stakeholder

☐ B Intermediate to A and C – artificial or geologic grade control present but spaced 2/Sv m to 4/Sv m or potential evidence of failure or hardpan of uncertain resistance

☐ C Grade control absent, spaced >100 m or $>4/S_v$ m, or clear evidence of ineffectiveness



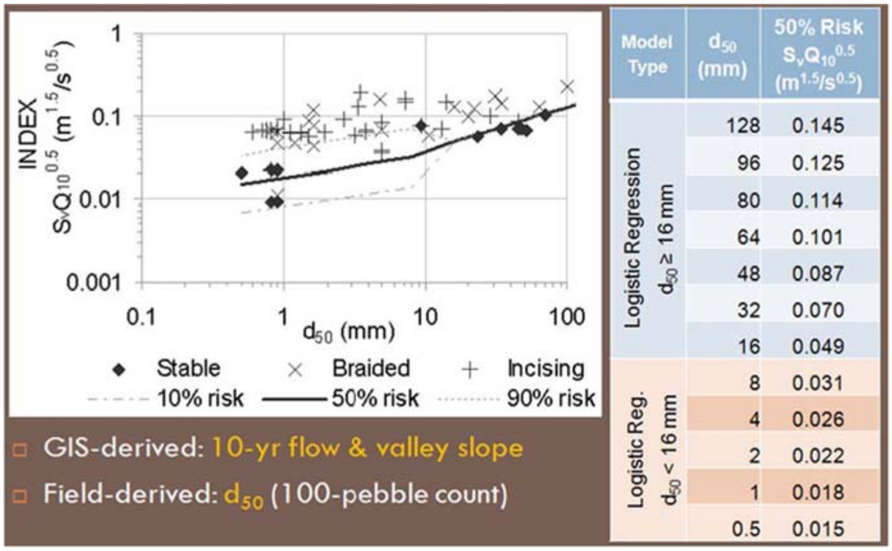
Form 3 Figure 3. Grade-control (condition) photographic supplement for assessing intermediate beds ($16 < d_{50} < 128$ mm) to be used in conjunction with Form 3 Checklist 2.

(Sheet 3 of 4)

Figure 7. Continued

Regionally-calibrated Screening Index Threshold for Incising/Braiding

For transitional bed channels (d_{50} between 16 and 128 mm) or labile beds (channel not incised past critical bank height), use Form 3 Figure 3 to determine Screening Index Score and complete Form 3 Table 1.



- GIS-derived: 10-yr flow & valley slope
- Field-derived: d_{50} (100-pebble count)

Model Type	d_{50} (mm)	50% Risk $S_V Q_{10}^{0.5}$ ($m^{1.5}/s^{0.5}$)
Logistic Regression $d_{50} \geq 16$ mm	128	0.145
	96	0.125
	80	0.114
	64	0.101
	48	0.087
	32	0.070
	16	0.049
Logistic Reg. $d_{50} < 16$ mm	8	0.031
	4	0.026
	2	0.022
	1	0.018
	0.5	0.015

Form 3 Figure 4. Probability of incising/braiding based on logistic regression of Screening Index and d_{50} to be used in conjunction with Form 3 Table 1.

Form 3 Table 1. Values for Screening Index Threshold (probability of incising/braiding) to be used in conjunction with Form 3 Figure 4 (above) to complete Form 3 Overall Vertical Rating for Intermediate/Transitional Bed (below).. Screening Index Score: A = <50% probability of incision for current Q_{10}, valley slope, and d_{50}; B = Hardpan/d_{50} indeterminate; and C = $\geq$50% probability of incising/braiding for current Q_{10}, valley slope, and d_{50}.

d_{50} (mm) *From Form 2*	**$S_v{}^*Q_{10}^{0.5}$ ($m^{1.5}/s^{0.5}$)** *From Form 1*	**$S_v{}^*Q_{10}^{0.5}$ ($m^{1.5}/s^{0.5}$)** *50% risk of incising/braiding from table in Form 3 Figure 3 above*	**Screening Index Score (A, B, C)**

Overall Vertical Rating for Intermediate/Transitional Bed

Calculate the overall Vertical Rating for Transitional Bed channels using the formula below. Numeric values for responses to Form 3 Checklists and Table 1 as follows: A = 3, B = 6, C = 9.

$$Vertical\ Rating = \sqrt{\{(\sqrt{armoring * grade\ control}) * screening\ index\ score\}}$$

Vertical Susceptibility based on Vertical Rating: <4.5 = LOW; 4.5 to 7 = MEDIUM; and >7 = HIGH.

(Sheet 4 of 4)

Figure 7. Continued

Lateral Susceptibility

In terms of lateral stability, there are five primary states of bank characteristics. These states are listed below, roughly in order of most susceptible to least:

- Mass wasting or fluvial erosion/braiding existing and extensive
- Poorly consolidated or unconsolidated with fine/nonresistant toe material
- Poorly consolidated or unconsolidated with coarse/resistant toe material
- Consolidated
- Fully-armored bedrock/engineered reinforcement or fully confined by hillslope

In addition to the present channel state/response and bank materials, there are three primary risk factors used to develop a weight of evidence for lateral susceptibility:

- Valley width index (VWI) from Form 1 (**Figure 2**): a measure of valley bottom width versus reference channel width (calculated in the office) used to assess the potential for lateral movement of the channel; see Forms 4 and 5 (**Figures 12 and 13**, respectively)
- Proximity to a regionally-calibrated bank stability threshold: geotechnical probability diagram based on bank height and angle; see Form 6 (**Figure 14**)
- The Vertical Susceptibility Rating: from Form 3 Sheet 4 of 4 (**Figure 7**)

Lateral Susceptibility Decision Tree

The purpose of the lateral decision tree is to assess the state of the channel banks with a particular focus on the risk of widening. Channels can widen from either bank failure or through fluvial processes such as chute cutoffs, avulsions, and braiding (see Figure A.2 in Appendix A). Widening through fluvial avulsions/active braiding is a relatively straightforward observation. If braiding is not already occurring, the next logical question is to assess the condition of the banks. Banks fail through a variety of mechanisms (see Figures A.4a and A.4b in Appendix A); however, one of the most important distinctions is whether they fail in mass (as many particles) or by fluvial detachment of individual particles. Although much research is dedicated to the combined effects of weakening, fluvial erosion, and mass failure (Beatty 1984, Hooke 1979, Lawler 1992, Thorne 1982), we found it valuable to segregate bank types based on the inference of the dominant failure mechanism (as the management approach may vary based on the dominant failure mechanism).

Conceptual Basis

Cohesive banks have been documented in both flume and field experiments as being much more resistant to fluvial entrainment than non-cohesive banks (Thorne 1982). Despite the fact that most of the banks that observed in southern California had relatively low amounts of cohesion when compared to other US regions, it is generally acknowledged that truly non-cohesive banks are rare in nature given the effective cohesion introduced by pore-water suction even in banks formed in coarse materials (Lawler *et al*. 1997). Furthermore, there was clear evidence of mass wasting at a large number of sites, including the presence of tension cracks and discrete failure surfaces deep within the banks exhibiting corresponding planar, slab, and rotational failures.

Because cohesivity is difficult to assess in the field, Hawley (2009) segregated banks by relative degree of consolidation. Failure in banks composed of recently deposited alluvium with little time to consolidate (i.e., <~10 yrs, unconsolidated) was generally dominated by the resistance of individual particles. Banks composed of much older fluvial deposits with more time to both acquire more cohesive particles and become more consolidated (i.e., well-consolidated) were controlled by mass failure. Intermediate poorly- and moderately-consolidated bank types were generally found to be controlled by mass wasting with the latter and fluvial entrainment with the former; however, the segregation is both subjective and somewhat difficult to determine, especially in stable banks. For the present study, in addition to the current bank condition, we considered key risk factors including 1) the potential for lateral instability triggered by vertical instability, and 2) potential severity of the lateral response based on the available valley width (i.e., how large of a valley bottom is there for the channel to access?).

Lateral Susceptibility Definitions and Forms

- Channel Banks – vertically inclined surfaces that are generally perpendicular to flow and contain approximately the 10-year flow (i.e., the 'walls' of the active channel)

- *Extensive mass wasting* – >50% of banks exhibiting planar, slab, or rotational failures, and/or scalloping, undermining, and/or tension cracks (**Figure 8**)

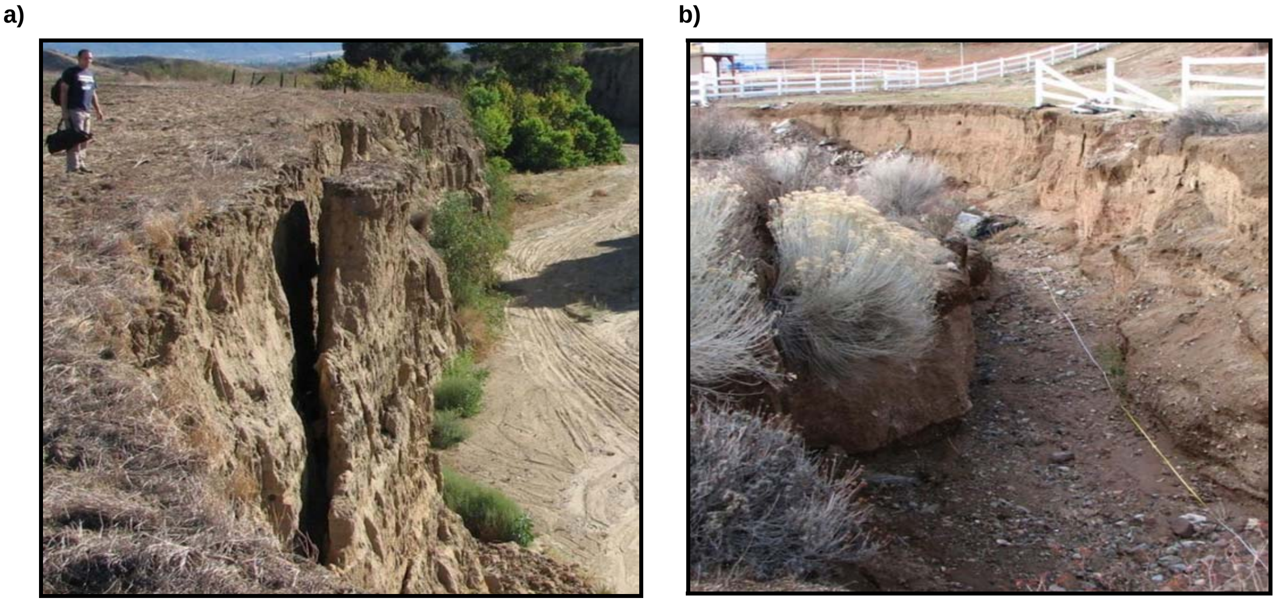


Figure 8. Planar/Slab failure with tension cracks, exhibiting cohesive consolidated banks, at San Timetao, San Bernardino County, CA (a) and Acton, Los Angeles County, CA (b).

- *Extensive fluvial erosion* – significant and frequent bank cuts (> 50% of banks) and not limited to bends and constrictions (**Figure 9**)

Figure 9. Bank failure at Hicks Canyon, Orange County, CA, exhibiting combinations of fluvial erosion, shallow slips, and mass failure in weakly cohesive, poorly consolidated banks.

- *Moderately to highly consolidated* – hard when dry with little evidence of crumbling. Bank appears as a composite of tightly-packed particles that are difficult to delineate even with close inspection of the bank; moderately dry block/ped sample (1 in^2) is not crushable between fingers and bank material stratification not prevalent or contributing to failure (**Figure 10**)

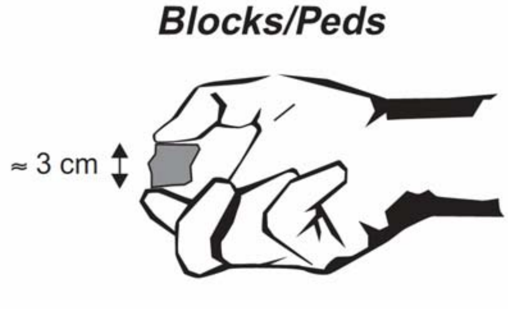


Figure 10. Moderately dry block/ped sample. Figure adapted from Schoeneberger *et al. (*2002); Not to scale.

- *Poorly consolidated to unconsolidated* – relatively weak with evidence of crumbling (**Figure 11**). Bank appears as a loose pile of recently deposited alluvium and block/ped samples (if attainable) can be crushed between fingers

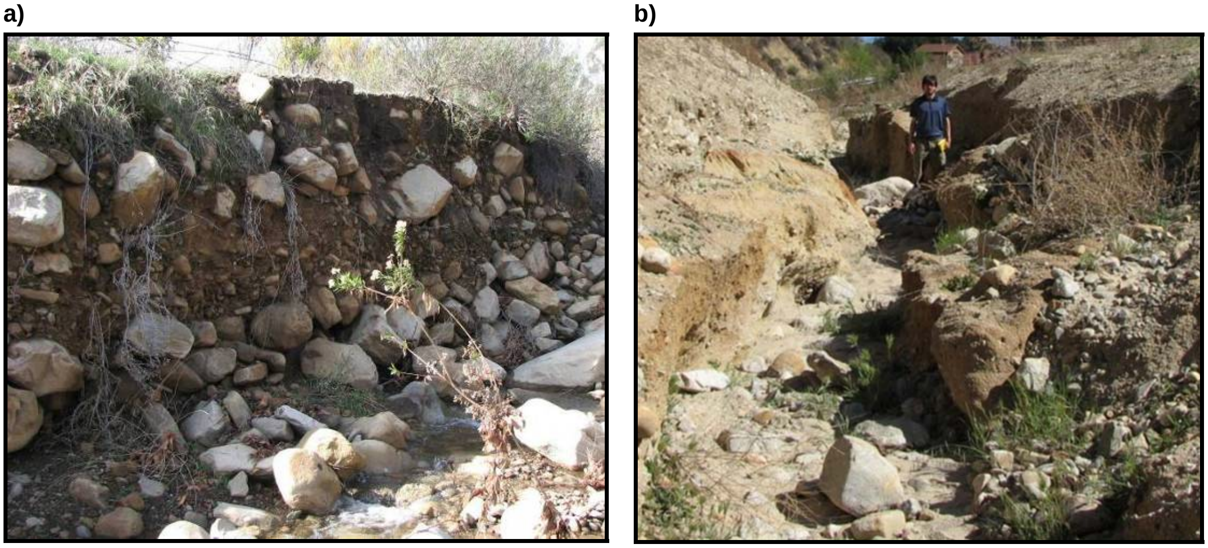


Figure 11. Failure of poorly consolidated banks with some cohesivity, but bank stability largely controlled by resistance of the individual particles of the bank toe in Stewart Canyon, Ventura County, CA, (a) and Hasley Canyon, Los Angeles County, CA (b).

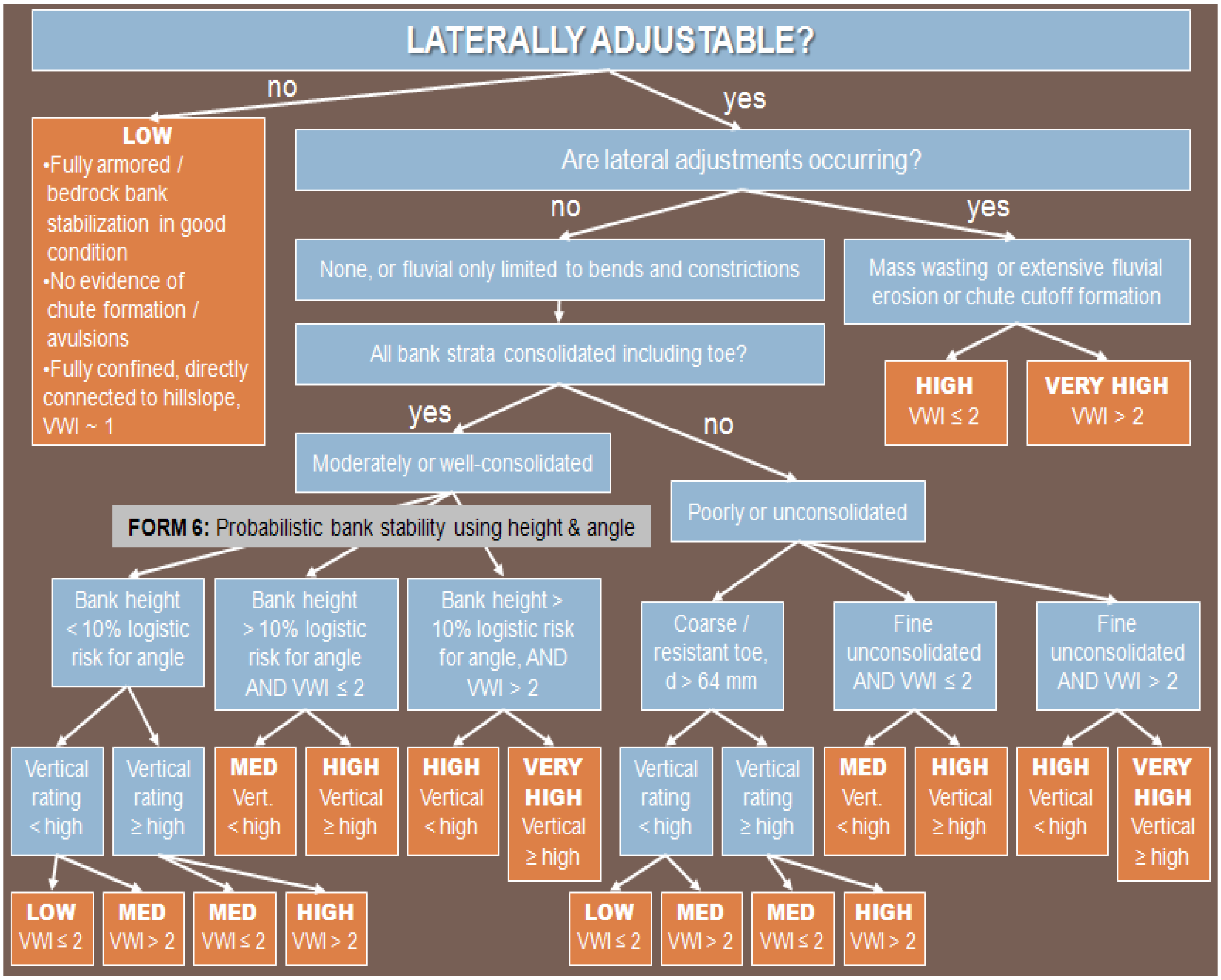
In assessing the potential for incision-induced bank failure we selected a vertical rating of high as a key discriminator. This decision was made primarily because such an approach inherently captures braiding risk as channels with high amounts of erosive energy relative to their bed material and >50% risk of incision/braiding using Form 3 Table 1 (**Figure 7**) would most likely result in a vertical rating of high unless exceptionally resistant and well-protected by armoring. We also defined a VWI of 2 as a key discriminator because doing so successfully distinguished between channels with valley bottoms 'confined by bedrock or hillslope' versus unconfined channels in the field data set. Unconfined valley settings were typically well above a VWI of 2.

The Lateral Susceptibility decision tree in Form 4 (**Figure 12**) and the series of questions in Form 5 (**Figure 13**) are provided for use in conducting the lateral susceptibility assessment. Either may be used depending on the user's preference. Definitions and photographic examples above are intended to support the lateral susceptibility assessment.

Additionally, Hawley (2009) performed logistic regression analysis of stable versus mass wasting in moderately- to well-consolidated banks using bank height and angle, consistent with geotechnical stability theory presented by Osman and Thorne (1988). The model was highly significant ($p < 0.0001$) and correctly classified unstable and stable states with ~95% accuracy, as shown in Form 6 (**Figure 14**), using a shape that was analogous to the Culmann relationship. As an alternative, by including the poorly consolidated sites, the model accuracy was ~90% with a lower 50% threshold and a much broader 10 to 90% risk range.

FORM 4: LATERAL SUSCEPTIBILTY FIELD SHEET

Circle appropriate nodes/pathway for proposed site
OR use sequence of questions provided in Form 5.



(Sheet 1 of 1)

Figure 12. Form 4: Lateral Susceptibility Field Sheet. Complete set of assessment forms in Appendix B.

FORM 5: SEQUENCE OF LATERAL SUSCEPTIBILITY QUESTIONS OPTION

Enter Lateral Susceptibility (Very High, High, Medium, Low) in shaded column.
Mass wasting and bank instability from Form 6, VWI from Form 4, and Vertical Rating from Form 3.

			Lateral Susceptibility
Channel fully confined with VWI ~1 – connected hillslopes OR fully-armored/engineered bed and banks in good condition?	If YES, then LOW		
If NO, Is there active **mass wasting** or extensive fluvial erosion (> 50% of bank length)?	If YES, VWI ≤ 2 = HIGH, VWI > 2 = VERY HIGH		
If NO, Are both banks consolidated?	If YES, How many risk factors present? **Risk Factors:** o Bank instability p > 10% o VWI > 2 o Vertical rating ≥ High	• All three = VERY HIGH • Two of three = HIGH • One of three = MEDIUM • None = LOW	
If NO, Are banks either consolidated or unconsolidated with coarse toe of d > 64 mm?	If YES, How many risk factors present? **Risk Factors:** o VWI > 2 o Vertical rating ≥ High	• Two = HIGH • One = MEDIUM • None = LOW	
If NO, At least one bank is unconsolidated with toe of d < 64 mm	How many risk factors present? **Risk Factors:** o VWI > 2 o Vertical rating ≥ High	• Two = VERY HIGH • One = HIGH • None = MEDIUM	

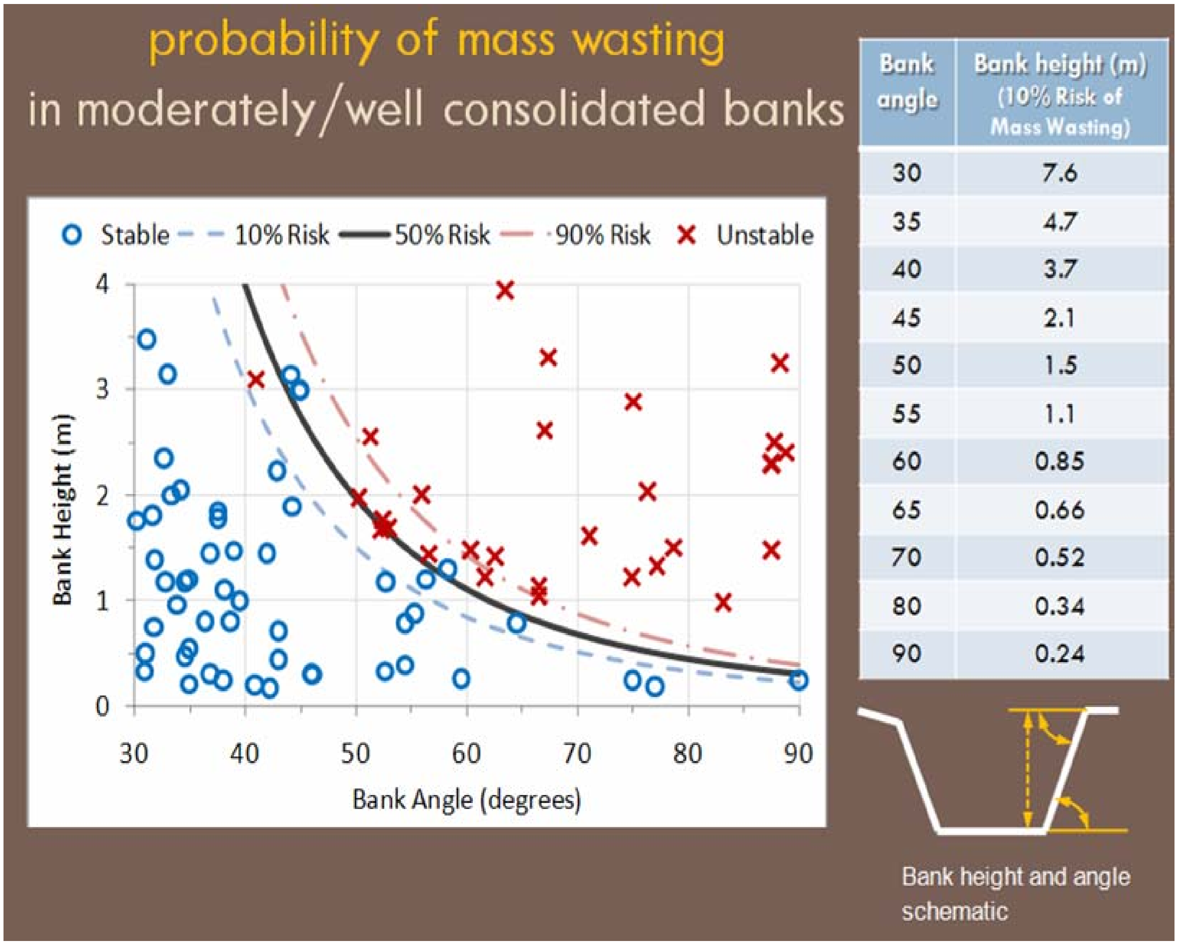
(Sheet 1 of 1)

Figure 13. Form 5: Sequence of Lateral Questions Option for lateral susceptibility assessment. Complete set of assessment forms in Appendix B.

FORM 6: PROBABILITY OF MASS WASTING BANK FAILURE

If mass wasting is not currently extensive and the banks are moderately- to well-consolidated, measure bank height and angle at several locations (i.e., at least three locations that capture the range of conditions present in the study reach) to estimate representative values for the reach. Use Form 6 Figure 1 below to determine if risk of bank failure is >10% and complete Form 6 Table 1. Support your results with photographs that include a protractor/rod/tape/person for scale.

	Bank Angle (degrees) *(from Field)*	**Bank Height (m)** *(from Field)*	**Corresponding Bank Height for 10% Risk of Mass Wasting (m)** *(from Form 6 Figure 1 below)*	**Bank Failure Risk** *(<10% Risk)* *(>10% Risk)*
Left Bank				
Right Bank				


probability of mass wasting

in moderately/well consolidated banks

Bank angle	Bank height (m) (10% Risk of Mass Wasting)
30	7.6
35	4.7
40	3.7
45	2.1
50	1.5
55	1.1
60	0.85
65	0.66
70	0.52
80	0.34
90	0.24

Bank height and angle schematic

Form 6 Figure 1. Probability Mass Wasting diagram, Bank Angle:Height/% Risk table, and Band Height:Angle schematic.

(Sheet 1 of 1)

Figure 14. Form 6: Probability of Mass Wasting Bank Failure for lateral susceptibility assessment. Complete set of assessment forms in Appendix B.

SUMMARY AND CONCLUSIONS

After completing the initial desktop and field components, the user should return to the office to summarize the reconnaissance information. Some values that were measured in the field may require (or be simplified by) computer assistance (e.g., sorting and ranking the pebble count data to determine the median particle size). A data entry spreadsheet (Data Entry Form.xls) has been provided to automate the necessary calculations from your field data.

At a minimum, we suggest outlining the following aspects from the field reconnaissance:

- Aerial photo of analysis domain with demarcation of reaches assessed and locations of critical features such as hard points, outfalls, changes in valley type, etc.
- A minimum of four photos from each assessed reach
    - Overview/cross-section
    - Representative bed material
    - Representative bank from right and left side of channel
- Applicable Vertical Susceptibility forms and final rating from each assessed reach
- Applicable Lateral Susceptibility forms and final rating from each assessed reach

In depth information describing the development and scientific basis of the field screening tool is provided in SCCWRP Technical Report 607, available at www.sccwrp.org We expect that the field screening tool presented herein will be systematically improved over time through a variety of monitoring and adaptive management activities, as well as through user feedback. Accordingly, comments, questions, and suggestions are welcome and may be submitted to Eric Stein at SCCWRP (**erics@sccwrp.org**) and Brian Bledsoe at CSU (brian.bledsoe@colostate.edu).

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APPENDIX A: GENERAL DEFINITIONS

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APPENDIX B: ASSESSMENT FORMS

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