Sediment Impact Assessment on Streams

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654. 1300 Purpose

Sedimentation analysis is a key aspect of design since many projects fail due to excessive erosion or sediment deposition. A sediment impact assessment is conducted to assess the effect that a full range of natural flows will have on possible significant aggradation or degradation within a project area. This chapter provides a brief overview of several types of sediment impact assessments, along with their rigor and level of uncertainty. The focus of this chapter is primarily on techniques appropriate for the analysis of alluvial channels. However, sediment assessments for threshold channels are also described. There are variants in each of the presented techniques, and more information may be needed to perform the assessments. It is the intent of this chapter to provide an introduction to sediment impact assessments sufficient to select the approach that is most appropriate for most projects. Note that although sediment impact assessment is presented following channel design chapters of this handbook, much of this analysis described should also be done in the sediment assessment phase of the design process that precedes and supports channel design. However, a sediment impact assessment is an important closure loop on any proposed design.

654.1301 Introduction

The success of any restoration that includes channel reconstruction is based on the designed channel's ability to transport the inflowing water and sediment load without excessive sediment deposition or scouring on the channel bed. Therefore, a critical step in any channel design project is a sediment impact assessment. Also, since any bank protection measures may fail if the bed is unstable, an assessment of bed stability is also critical for any bank stabilization project.

Sediment impact assessments can range widely in effort and output. These assessments can be accomplished using visual or qualitative techniques for relatively simple projects or by using a numerical model that incorporates solution of the sediment continuity equation for more complex projects. Several types of sediment impact assessments are described in this chapter. While the focus of this document is primarily on techniques appropriate for the analysis of alluvial channels, threshold channels are also described.

The first step in understanding and implementing a sediment impact assessment is to define the anticipated channel bed response. This is an assessment of bed stability to determine if the channel bed is aggrading, degrading, or is relatively stable. Other aspects of a stability assessment may include bank stability or planform stability. The sediment impact assessment is primarily concerned with the stability of the channel bed.

654.1302 Bed stability

Aggradation and degradation are potential major adjustments of an individual channel or a fluvial system. Since a sediment impact assessment is concerned with predicting these responses, it is important to define what these adjustments are and how they can affect a channel.

(a) Aggrading channel

A channel is considered to be aggrading when long-term sediment deposition occurs on the bed. The channel cross section is filling up or becoming shallower. Channel widening, avulsions, and a reduction in flood capacity are characteristic of an aggrading channel. A channel may experience aggradation due to localized watershed processes such as landsliding or construction activities, or it may be due to natural processes, watershed characteristics, and geology. A constructed channel may aggrade if it is deepened and widened for flood conveyance and does not maintain flows and depths sufficient to transport inflowing sediments under more frequent lower discharges.

(b) Degrading channel

A channel is considered to be degrading when long-term sediment removal occurs from the channel bed. The channel cross section becomes deeper. Bank failure, lowering of water tables, and restriction of a stream's connection to its flood plain can occur in a degrading channel. A channel may experience degradation due to a reduction in sediment supply (as may occur in the stream reach below a dam), an increase in flow (as may occur with development in the watershed), or as a result of a lowering of the base level at the mouth of the reach, triggering headcutting, nickpoints, and degradation. A constructed channel may degrade if bed shear stresses are increased in excess of what the channel boundary was designed to withstand. This can occur due to channel straightening or elimination of flood plain access at high flow.

(c) Stable channel

For the purposes of this chapter, a channel is considered stable (or in dynamic equilibrium) when the prevailing flow and sediment regimes do not lead to long-term aggradation or degradation. A stable channel does not experience changes in its cross-sectional geometry over the medium to long term. Short-term changes in sediment storage, channel shape, and planform are both inevitable and acceptable in natural channels. For example, aggradation or degradation may occur on a streambed over the course of a storm hydrograph, but does not necessarily indicate overall instability. While short-term adjustment may damage bank stabilization or bank habitat structures, these assessments are usually performed in a scour analysis as described in NEH654.14. The focus of the analysis described in this chapter is on long-term, progressive changes.

654.1303 Threshold versus alluvial channels

The choice of the appropriate type of sediment impact assessment depends, in part, on whether the channel at the project location is an alluvial channel or a threshold channel. Therefore, it is important for the practitioner to be able to distinguish between these channel types. In general, the geomorphology of a threshold channel is a product of a process that is no longer at work or not regularly at work. Sediment passes through a threshold channel with very little impact on the channel boundary. In an alluvial channel, there is an exchange of sediment between the channel boundary and the flow. An alluvial channel is more active, and its geomorphology is a product of more frequent events. It is important to note that there is not always a sharp demarcation between threshold and alluvial channels. A channel may behave as a threshold channel under low to moderate flow events, yet behave as an alluvial channel under larger flow events. More information about threshold and alluvial channels is provided in NEH654.09.

A sediment impact assessment is particularly important in alluvial channel design. As described in NEH654.09, stability design for alluvial channels begins by determining the channel dimensions for the channel-forming discharge, using analogy, hydraulic geometry, and/or analytical methods. While a single flow and associated sediment load may have a strong effect on the geomorphology of the stream over the long term, other flows and sediment loads may adversely impact the project. Therefore, once these preliminary dimensions are determined, the next step is to assess how well that channel will maintain sediment continuity for the full range of natural flows. This becomes even more important in cases where the desired channel dimensions cannot be achieved due to project constraints or conflicting project objectives. Alluvial channels typically require more in-depth analyses to assess the potential impacts of sediment, but qualitative techniques can be used in low risk situations.

While the focus of this chapter is primarily on alluvial channels, sediment impact assessment should also be considered for threshold channels. Where the design channel is threshold in nature, the sediment impact assessment may be more qualitative, or it may be integral to the design process itself. For example, the identification of the flow condition that would mobilize the boundary of a threshold channel can be sufficient as a check for potential degradation. In this case, the sediment impact assessment is often referred to as a stability assessment. Many of the approaches for stability assessment of threshold channels are presented in NEH654.08. However, it may also be appropriate to perform a check to assure that any suspended sediment will remain in suspension and not be deposited in the design threshold channel. This analysis can be accomplished by comparing the channel shear velocity to the settling velocity of the sediment, under a variety of expected flow conditions. Finally, the designer should consider possible impacts that may occur if the threshold channel were to transition to an alluvial channel.

654.1304 Types of sediment impact assessments

A variety of techniques may be used to assess the impact of sediment on a project area. The approaches described here are not exhaustive, nor are they applicable in all situations. However, a final sediment impact assessment should be viewed as a closure loop at the end of the design process to:

- validate the efficacy of the design channel geometry
- identify flows which may cause aggradation or degradation over the short term (these changes are inevitable and acceptable in a dynamic channel)
- recommend minor adjustments to the channel design to ensure dynamic stability over the medium to long term

The type of sediment impact assessment used will determine the certainty of the result, as well as the precision of a conclusion that the channel will aggrade, degrade, or remain stable. The selection of the appropriate methodology should be done with a firm understanding of the assumptions, accuracy, data requirements, and limitations of the approach. This chapter outlines some of the most common techniques and offers general guidelines regarding selection criteria. For more details regarding the assumptions and limitations of these methodologies or approaches, the original documentation associated with each should be reviewed. Final decisions regarding the suitability of a particular approach must be determined using engineering judgment on a case-by-case basis.

Most of the following approaches were developed for application with the analysis and design of alluvial channels. However, they can also be used with threshold channels, as well. The following approaches are listed in general increasing level of difficulty.

654.1305 Visual geomorphic assessment

A visual geomorphic assessment is primarily a qualitative check that should be done for both threshold and alluvial streams. This may be the only assessment needed for a potential project, or it may be the first step of a more detailed sediment impact assessment, if required. Visual geomorphic assessments of sediment impacts are generally sufficient where:

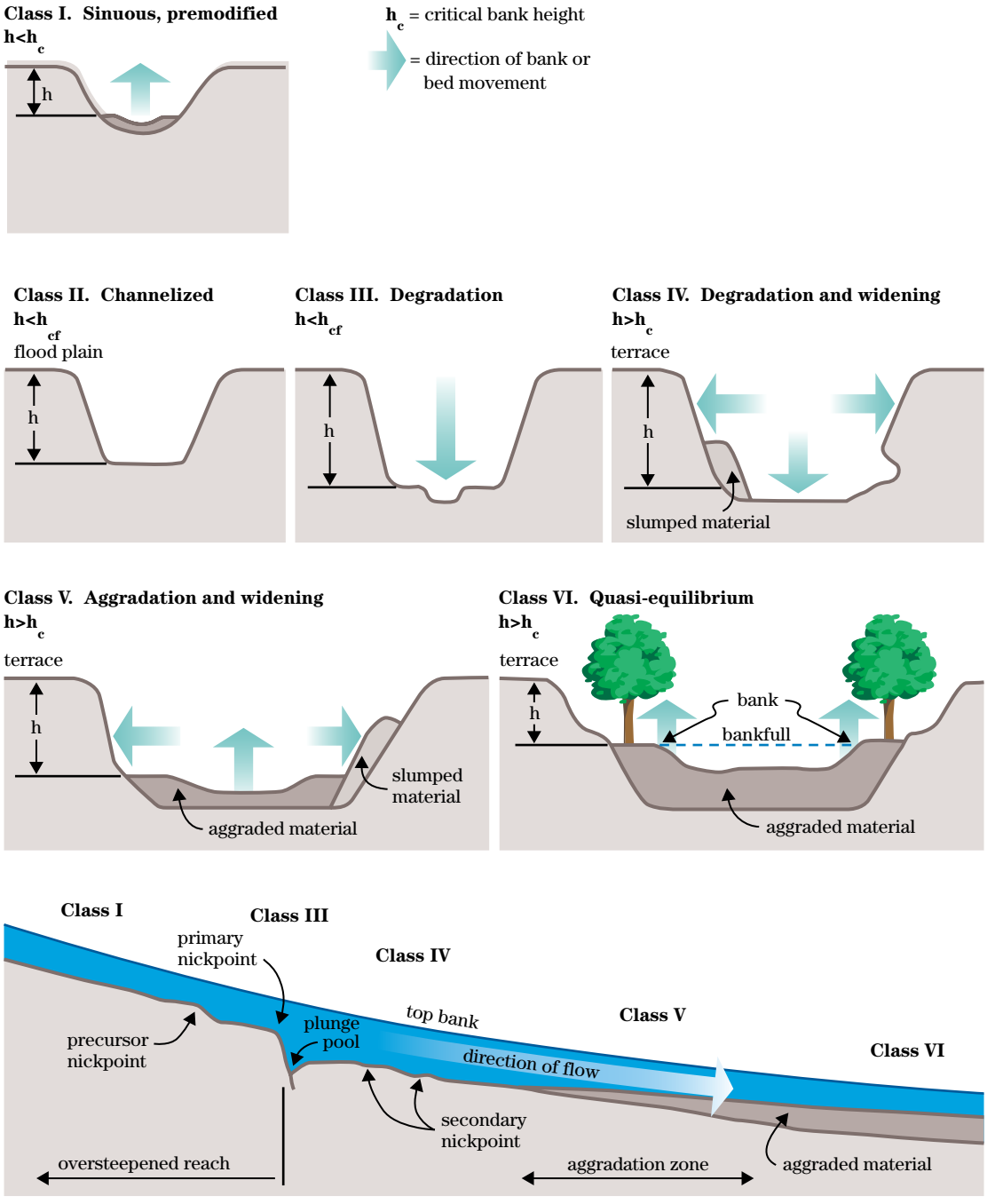
- project failure will have minimal adverse effects
- minimal change to the channel shape is proposed
- the watershed land use and cover and erosion processes are relatively stable

The visual geomorphic assessment includes judgment of current conditions, expected future conditions, and the river's anticipated response to the designed project. It includes the identification of potentially destabilizing processes of erosion, sediment storage, and deposition. A visual assessment can involve the use of channel evolution stage, the use of Lane's stream balance relationship (described in NEH654.1305(c)), and assessments of dominant channel processes. It is critical that experienced personnel conduct this effort. In all cases, the reasoning, judgment, and estimates that support the assessment should be clearly documented and discussed by the stakeholders.

(a) Assessments of channel processes and evolution

The existing shape or morphology of a stream is an indication of ongoing channel evolution processes and has long been recognized as a diagnostic tool in evaluating fluvial landforms. The appropriate channel evolution model can be applied to identify current stream condition, subsequent stages and direction of evolution, and the ultimate expected stable channel form that will evolve, as well as qualitatively estimate the time scale of channel recovery. An assessment of the existing channel evolution stage, as well as the stage that will exist with the proposed project, can be an aid in assessing channel responses. The channel evolution model (CEM) (fig. 13–1 (modified from Simon and Hupp 1986; Simon

Figure 13–1 Six-stage model of channel evolution



1989)) was developed by Schumn, Harvey and Watson (1981, 1984), and modified by Simon and Hupp (1986) and Simon (1989, 1994).

Using space-for-time substitution, the authors developed a conceptual model with reach types that are divided into the following six stages. In a space-for-time substitution, downstream conditions are interpreted as preceding (in time) the immediate location of interest, and upstream conditions are interpreted as following (in time) the immediate location of interest. A reach in the middle of the watershed that previously looked like the channel upstream will, therefore, evolve to look like the channel downstream.

- Stage 1 is a U-shaped channel. It has no sediment storage in the channel as would occur in a newly constructed channel. This stage has also been used to represent a sinuous, premodified, nonincised channel. One of the key features of this stage is the frequent access of the channel flows to the flood plain.
- Stage 2 is a modified or channelized stage. This has also been used to represent the relatively instantaneous change which initiates the following sequence of changes:
  - newly straightened or a steepened slope stage 1
  - reduction in sediment supply
  - increase in discharge
  - lowering of the tailwater
  - advancing headcut
- Stage 3 is a downcutting stage. Rapid degradation is occurring as the channel slope flattens in response to the perturbation imposed on the system in stage 2. A lowering of ground water and undermining of bridge piers may occur in this stage. Stage 3 evolves into stage 4 when the channel bank height exceeds the critical bank height and the banks begin to fail.
- A stage 4 channel is evidenced by a widening channel. The toes of the bank slopes are subject to lateral erosion and undercutting. Usually, both sides of the channel show erosion, not just the outer banks. Stage 4 evolves into stage 5 when the channel widens to a point where it is no longer able to transport the incoming supply of sediment and deposition begins to occur.
- Stage 5 is an aggrading channel. The overwidened channel cannot maintain the velocities necessary to move the sediment that is being supplied from the upper watershed.
- Stage 6 is the quasi-equilibrium stage. The toes of the banks are stabilized with accumulated sediment and vegetation. Alternate bars with perennial vegetation may be evident. Simon (1994) observed that the deposition will likely not be sufficient to return the channel to its preimpacted stage.

These evolutionary stages are linked to rates of sediment transport (Simon 1989), bank stability, sediment accretion, and ecologic recovery (Hupp 1992; Simon and Hupp 1992). The model has been widely used to rapidly identify dominant, systemwide channel processes in watersheds impacted by various human and natural disturbances. Identification of channel process and forms is often accomplished concurrent with the geomorphic assessment and site investigations conducted at the beginning of a project. The CEM was developed from streams responding to straightening and base-level lowering. Specific assessment techniques, including this model, are addressed further in NEH654.03.

While this channel evolution model has been applied in a variety of watersheds throughout the United States, it is most applicable in the Southeast, with its abundant precipitation and deep soils. The use of a channel evolution model may be supported by a study of the watershed and channel history, future land use and development patterns, and appropriate classification of the existing and proposed stream.

(b) Regional hydraulic geometry relationships

Regional hydraulic geometry relationships may also be useful in performing a visual geomorphic assessment. Morphological measurements of width, cross-sectional area, and depth at the project site can be compared to regionally developed relationships or equations and their associated bands of uncertainty. This comparison can provide semiquantitative information on channel stability and sensitivity to change. However, this method only provides an indication of stability, because data points that lie far from the best-fit regression line could be influenced by other factors that are

not common to the rest of the data set such as reach history, land use, or vegetation. Be aware that while observations and hydraulic geometry relations may be used to identify possible stability problems, analytical methods are often required to determine the magnitude of an identified stability problem. More information on the use and limitations of regional hydraulic geometry is provided in NEH654.03 and NEH654.09.

(c) Lane's alluvial channel balance relationship

Lane's balance or Lane's relationship is a qualitative conceptual model that can be used as an aid to visually assess stream responses to changes in flow, slope, and sediment. The model is based on the general theory that if force applied by the flowing water on an alluvial channel boundary is balanced with strength of the channel boundary and the delivered sediment load, the channel will be stable and neither aggrade nor degrade. This equilibrium condition in the channel can be expressed as a balance of four basic factors (Lane 1955b):

- sediment discharge, Q_s
- median grain size of bed material, D_{50}
- dominant discharge or streamflow, Q_w
- thalweg slope or energy slope, S

This balance can be expressed in the proportional relationship (eq. 13–1) or figuratively (fig. 13–2).

$$(Q_s)(D_{50}) \alpha (Q_w)(S) \qquad \text{(eq. 13–1)}$$

Lane's relationship suggests that a stream will remain in equilibrium as along as these four variables are kept in balance. If one variable changes significantly, the stream will respond by aggrading or degrading, and another variable must adjust to restore balance. For example, a decrease in discharge could result in aggradation (as may occur downstream of a flood control dam or due to flow diversion). In contrast, a straightening of a stable channel (which would increase slope) may result in degradation. The increased slope of a straightened channel creates a disequilibrium condition where an increased sediment supply or a larger particle size is needed. Therefore, erosion of the streambed and streambanks will return the reach to an equilibrium condition. Since sediment yield varies over a long time in establishing the equilibrium condition, Lane's (1955a) conceptual relationship fits the concept of dynamic equilibrium established by Schumm (1977) and is, therefore, applicable to most streams and rivers.

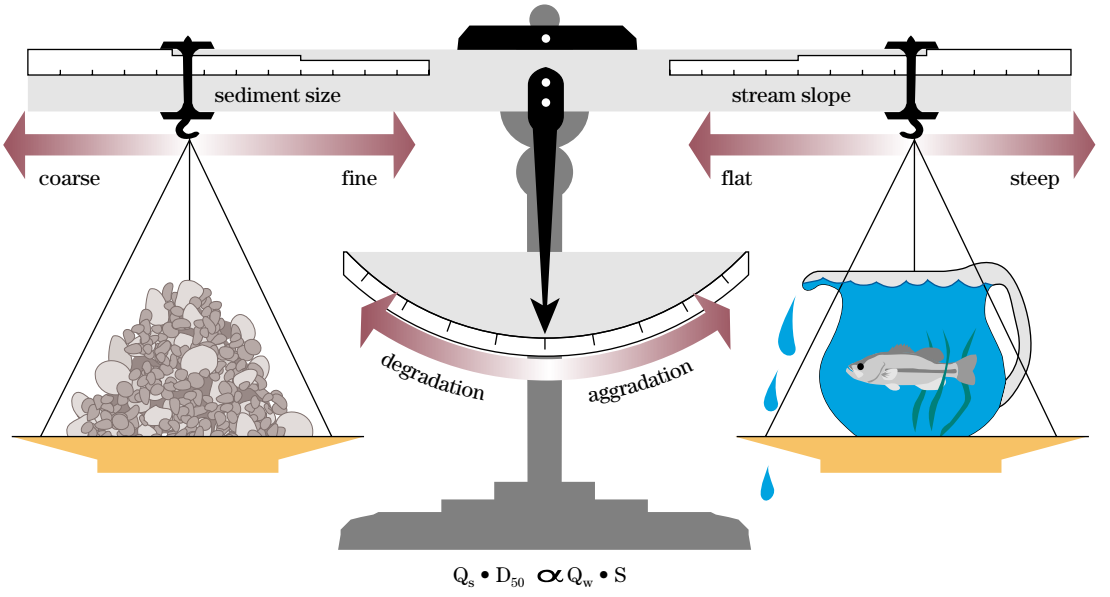
A limitation of this conceptual model is that it does not indicate which variable will adjust, the magnitude of the adjustment, or the timeframe that will be involved. While it may be used to identify possible stability problems, analytical methods are often required to predict, in quantifiable terms, their magnitude. In addition, even while in balance, the stream is free to migrate laterally, maintaining its cross-sectional area. This lateral movement may be unacceptable due to land use or boundary constraints. More detail on Lane's relationship, as well as other qualitative relationships is provided in NEH654.03 and also available in Stream Corridor Restoration: Principles, Processes and Practices (FISRWG 1998).

(d) Assessments of dominant channel processes

Dominant channel processes are the forces at work in the watershed that cause and limit channel change. They are the causal factors, direct and indirect, and controls likely to be present in the study watershed and at a study site. An understanding of these dominant channel forces or processes can assist the designer with the prediction of the proposed project's impact on channel morphology, ecology, and stability. The assessment and evaluation of dominant channel and watershed processes is often accomplished early in the planning and design stages as part of data collection. NEH654.03 addresses this in detail. However, the assessment of dominant processes should be revisited as the project is finalized, to ensure that the design fits the context of the watershed and is consistent with the sediment impact assessment.

Of particular interest should be the characterization of sediment sources based on their relative contribution to the project reach's bed load, suspended load, and wash load. The with-project conditions should be assessed within the context of this overall sediment balance. The designer should focus on significant sediment sources and sinks within the study reach and how they may be affected by the proposed project. The broad elements that should be examined are:

Figure 13–2 Lane's balance as represented in Federal Interagency Stream Restoration Working Group (FISRWG) (1998)



From Rosgen (1996), from Lane, Proceedings, 1955.
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- spatial and temporal patterns of watershed sediment production
- sediment storage within the channel and in adjacent tributaries
- patterns and behavior of sediment movement through the system
- rates of sediment transport
- sediment deposition rates on the flood plain
- changes in sediment load due to changes in watershed land use

Much of the assessment of dominant processes can be accomplished by an examination and review of geological information, local historical accounts, historical thalweg and cross-sectional information, gage data, Federal Emergency Management Agency (FEMA) maps, biological monitoring, hydrologic modeling, and watershed development and land use patterns. Aerial photographs, maps, and old reports can also be useful in this assessment. Recent gage data can be analyzed and reviewed to determine if current conditions might be the result of a recent extreme event, rather than long-term and systemic instabilities.

Historical analysis can provide meaningful information. Well-documented stream history may provide a reasonably accurate assessment of future stream trends: will it aggrade or degrade? Historical data can be used to identify trends, provide information on rates of landform change in the watershed, and help determine land use impacts on current conditions. These effects can be due to watershed development that has altered streamflows, stream morphology, and sediment yields. Effects could have occurred gradually over a long period of time, such as changes in land use, population, or agricultural crops and farming practices. Streams in these watersheds may be adjusting naturally to an aggraded condition by slowly downcutting. Landslides and gravel nourishment, as well as gravel mining activities, can also have short-term, but profound impacts on reach dynamics and project performance. Finally, geologic aspects of the watershed should be considered. For example, as streams and rivers migrate laterally within their valleys in glaciated regions, they can encounter glacial till and coarse-grained glacial outwash, altering sediment loads and sediment particle sizes. A slug of sediment that enters the stream and moves downstream in pulses during high runoff is also common along streams where sediment load is dominated by landslides and debris flow torrents.

Onsite field assessments are needed to augment analysis and existing information sources. Observe conditions in tributaries and abandoned channels in the project reach, and identify indications of channel behavior and geomorphic conditions. Anthropogenic features, such as bridge abutments and piers, grade control structures, low-flow crossings, and bank protection can also provide an indication of possible channel responses to the project. Finally, determine whether the channel bed is aggrading, degrading, or stable.

Evidence of degradation will be different, depending on the project's location within a watershed, whether it is in the upland, middle, or lowland zone. Some field indicators of river stability/instability are given in table 13–1 (modified after Sear and Newson 1994) for each of these zones in a watershed. These are not absolutes, and exceptions and additions will be encountered.

While an assessment of the dominant processes and the application of engineering judgment are valuable and necessary for any design, the limitations of what is essentially a qualitative approach must be recognized. Issues that should be considered in weighing the impact of these assessments include observer experience and bias, temporal limitations, and spatial limitations. Issues related to observer bias can be partially overcome with the consistent use of trained personnel and consistent inventory procedures. This will minimize relative differences between observations. Temporal bias can be minimized with an examination of historical records, but these may be incomplete. While an assessment of the dominant processes may be used to identify possible stability problems, analytical methods are often required to determine the magnitude and direction of change in the instability.

Table 13–1 Field indicators of river stability/instability

	Location within watershed		
Condition	**Upland**	**Middle**	**Lowland**
Degradation	• Perched boulder berms • Terraces • Old channels • Old slope failures • Exposed pipe crossings • Suspended culvert outfalls and ditches • Undercut bridge piers • Exposed or 'air' tree roots • Leaning trees • Narrow/deep channel • Bank failures, both banks armored/ compacted bed • Deep gravel exposure in banks that are topped with fines	• Terraces • Old channels • Exposed pipe crossings • Suspended culvert outfalls and ditches • Undercut bridge piers • Exposed or 'air' tree roots • Leaning trees • Bank failures, both banks • Vertical banks • Compacted/compacted bed • Deep gravel exposure in banks that are topped with fines • Undercut stone and concrete walls • Abandoned streambeds that appear to be a deposition bar	• Old channels • Exposed pipe crossings • Suspended culvert outfalls and ditches • Undercut bridge piers • Exposed or 'air' tree roots • Leaning trees • Narrow/deep channel • Vertical banks • Bank failures, both banks • Deep gravel exposure in banks that are topped with fines • Undercut stone and concrete walls • Abandoned streambeds that appear to be a deposition bar
Aggradation	• Buried structures such as culverts and outfalls • Buried soils • Large uncompacted point bars • Eroding banks at shallows • Contracting or reduced bridge space • Deep, fine sediment over coarse gravels in bank • Many unvegetated point bars • Outlet of tributaries buried in sediment • Rills or remnant channels in riparian areas	• Buried structures such as culverts and outfalls • Buried soils • Large uncompacted point bars • Eroding banks at shallows • Contracting or reduced bridge space • Deep, fine sediment over coarse gravels in bank • Many unvegetated point bars • Angular bed material in an environment where rounded is expected • Outlet of tributaries buried in sediment • Rills or remnant channels in riparian areas	• Buried structures such as culverts and outfalls • Buried soils • Large silt/clay banks • Eroding banks at shallows • Contracting or reduced bridge space • Deep, fine sediment over coarse gravels in bank • Many unvegetated point bars • Angular bed material in an environment where rounded is expected • Outlet of tributaries buried in sediment • Rills or remnant channels in riparian areas
Stability	• Vegetated bars and banks • Compacted weed covered bed • Bank erosion rare • Old structures in position • Armoring of sediment • Older culverts and outfalls exiting at or near grade • Mouth of tributaries at or near existing main stem stream grade • Vegetated banks • Roots of large trees anchored in soil • Evidence of frequent overbank flows • Algae growth on substrate	• Vegetated bars and banks • Compacted weed covered bed • Bank erosion rare • Old structures in position • Older culverts and outfalls exiting at or near grade • Armoring of sediment • Mouth of tributaries at or near existing main stem stream grade • Vegetated banks • Roots of large trees anchored in soil • Evidence of frequent overbank flows • Algae growth on substrate	• Vegetated bars and banks • Weed covered bed • Bank erosion rare • Old structures in position • Older culverts and outfalls exiting at or near grade • Armoring of sediment • Mouth of tributaries at or near existing main stem stream grade • Vegetated banks • Roots of large trees anchored in soil • Evidence of frequent overbank flows • Algae growth on substrate

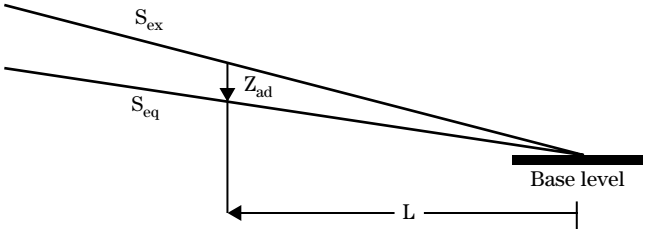
654.1306 Equilibrium slope calculations

Equilibrium or stable slope calculations are often used to support or refine visual assessments. The calculation of a stable or equilibrium slope may also serve as a form of sediment impact assessment, as well as being an integral part of the restoration design.

The equilibrium slope of a channel is defined as the slope at which the sediment transport capacity of the reach is in balance with the sediment transported into it. If the sediment transport capacity were to exceed the sediment supply, channel bed degradation will occur until the channel bed slope is reduced to the extent that the boundary shear stress is less than what is needed to mobilize the bed material. This new, lower slope is the equilibrium slope, S_{eq}. Possible causes of the sediment transport capacity exceeding sediment supply could include an upstream reduction in sediment yield (such as in a stream reach below a dam), an increase in sediment transport capacity during high discharges, or construction of a straight channel, resulting in increased stream gradient. This lowered, degraded bed may result in undermining or collapse of riparian structures or bank instability.

Equilibrium slope calculations are typically used for threshold streams. In the context of a sediment impact assessment, they are applied to a range of design flows. As illustrated in figure 13–3, slope adjustment in a threshold reach occurs by degradation proceeding from the upstream end to the downstream, and the downstream extent of degradation is often limited by a base level control. The z_{ad} is often referred to as the general scour depth.

Figure 13–3 Definition of equilibrium slope, S_{eq}. Relationship between existing slope, S_{ex}, equilibrium slope and the potential bed reduction, z_{ad}, for a reach of length L with base-level control



A variety of techniques can be used to calculate the limiting or equilibrium slope. One approach that is suitable for gravel-bed streams is the Meyer-Peter and Müller bed load transport equation, rearranged as follows:

$$S_L = \frac{K_1 \times D_{50} \times \left(\frac{n}{\frac{1}{D_{90}^{6}}} \right)^{\frac{3}{2}}}{d} \qquad \text{(eq. 13–2)}$$

where:
S_L = limiting slope
n = Manning's n
K_1 = conversion constant
D_S = particle size
d = flow depth

Similar equations, based on range in sediment particle size application, should be applied for other channel types. Note that the calculated equilibrium bed slope may be limited by resistant layers in the bed (such as bedrock) or by the formation of an armor layer. The overall depth of scour required to leave a stable armor layer can be assessed with the following equation:

$$\Delta Z = \frac{2 \times D_a}{P_c} \qquad \text{(eq. 13–3)}$$

where:
ΔZ = scour depth
D_a = size of armoring material (threshold grain size for incipient motion)
P_c = percent of material coarser than armoring size

The threshold particle size for incipient motion, the largest particle that can be lifted and transported by the flow, can be calculated as follows:

$$D_a = \frac{\tau_c}{0.047(\gamma_s - \gamma)} \qquad \text{(eq. 13–4)}$$

where:
D_a = particle size
τ_c = grain resistance boundary shear stress ($\frac{1}{8} f \rho \upsilon^2$)
γ_s = 165.4 lb/ft^3
f = friction factor ($= 8\frac{g}{C^2}$)
C = $\frac{1.49}{n} R^{\frac{1}{6}}$
R = hydraulic radius
ρ = 1. 94 slugs
υ = velocity (designer should account for bends)
n = near-field Manning's n (0. 025)

The assessment of this potential degradation for different flow levels is often used to determine the appropriate spacing and size of grade control structures. Further information about these analytical techniques and equations is provided in NEH654.08 and in NEH654 TS14C.

654.1307 Sediment rating curve analysis

The sediment rating curve analysis is a relatively simple technique that can be used to assess the sediment transport characteristics of an existing or proposed stream project. The approach is to use sediment rating curves to compare the sediment transport capacity of the supply reach to the existing and proposed project reach conditions. This approach relies on the technique of analogy. If the existing channel is stable, then sediment transport capacity in the project channel may be compared to that in the existing channel. If the supply reach is not fully alluvial, a carefully chosen reference reach may be used as a surrogate for the supply reach. This analysis is suitable for streams where the sediment supply is not limited in either the upstream (supply) or project reaches; that is, where the stream is certainly alluvial in nature. It is generally not suitable for threshold streams.

This qualitative technique does not require stream gage data or sediment gage data. It does require an estimate of the sediment grain size distribution from the supply reach, an estimated range of peak flows, and a description of hydraulic characteristics of both the study and supply reaches. By comparing the sediment rating curves of the two reaches, an estimate can be made of the sediment transport capacity of the study reach, relative to the capacity of the sediment supply reach. The basic steps are:

Step 1 Collect hydraulic information for the upstream, existing, and proposed project reaches. Hydraulic information can come from normal depth calculations, hydraulic modeling (such as the U.S. Army Corps of Engineers (USACE) HEC–RAS) based on new surveys, or with the use of existing flood plain information, such FEMA's flood plain maps.

Step 2 Collect sediment gradation for upstream, existing, and proposed project reaches. Guidance for sediment sampling is provided in NEH654 TS13A.

Step 3 Estimate a range of peak flows for the project reach. Peak flows can be estimated using regional regression curves or hydrologic modeling.

Step 4 Calculate sediment transport capacity for the range of peak flows in the upstream, existing, and proposed reaches. Information useful for the selection of appropriate sediment transport relationships is provided in NEH654.09.

Step 5 Create a sediment rating curve for the upstream, existing, and proposed reaches.

Step 6 Compare the sediment rating curves for these conditions to assess project performance.

By comparing the sediment rating curves of the two reaches, an estimate can be made of the sediment transport capacity, relative to the capacity of the sediment supply (fig. 13–4).

The comparison of the two sediment rating curves shown in figure 13–4 indicates that there is a strong possibility that the existing study reach is depositional for flows above Q_1. The proposed project conditions can be assessed in a similar manner as illustrated in figure 13–5.

A comparison of the two sediment rating curves in figure 13–5 indicates that the project reach should be able to transport the incoming sediment load through a discharge of Q_2. Above this discharge, deposition is possible, for example, at Q_3. These discharges can be compared to the peak discharges of estimated storm frequencies to provide a qualitative estimate of project life. This estimated condition should be checked by field observations to detect evidence of an aggradational trend, as well as the assessment of dominant channel processes. To improve channel stability, the sediment rating curve for the project channel should be as close as possible to the sediment rating curve for the supply reach.

Since there is no calibration of gage data or use of flow-duration data, the actual quantity of sediment deposition cannot be estimated. In addition, this approach does not account for changes in sediment transport capacity that may occur as sediment is deposited in the section and changes its geometry. However, this technique does provide the designer with a qualitative appraisal of anticipated project performance.

Figure 13–4 Sediment rating curve analysis for existing conditions

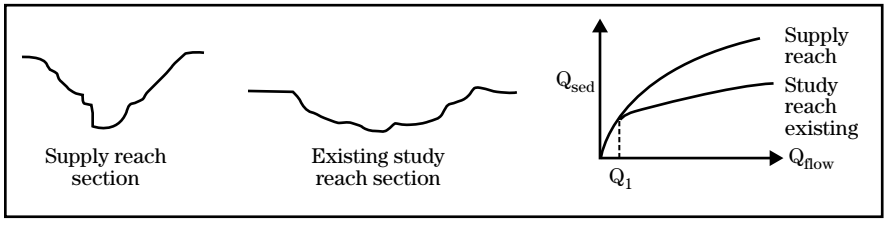
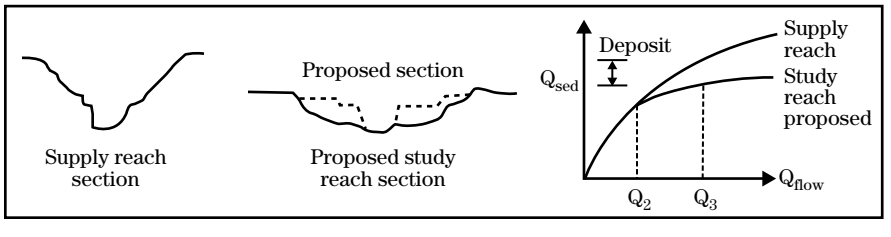


Figure 13–5 Sediment rating curve analysis for proposed conditions



654.1308 Sediment budget analysis

A sediment budget analysis is a quantitative assessment of channel stability using the magnitude and frequency of all sediment-transporting flows. A sediment budget analysis should be conducted for all realigned and constructed alluvial channels, after preliminary dimensions are determined, using the channel-forming discharge. Slight adjustments to the design may be required, after which another sediment budget analysis is conducted.

The stream's sediment budget is estimated by comparing the mean annual sediment load for the project channel with that of the supply reach(es). The mean annual sediment load from each reach is calculated by numerically integrating the annual flow-duration curve with a bed-material sediment rating curve. While the sediment load is typically calculated for annual conditions, it may also be assessed for a flow event of interest, depending on project conditions and purposes. If more sediment comes into the project area than can be passed, the excess will likely be deposited in the reach. If more sediment can be transported than what is coming into the reach, then erosion or degradation can be anticipated.

The following steps are recommended for conducting a sediment budget analysis.

Step 1 Assemble information about the stream. Collect data from the supply reach(es) upstream, the project reach, and downstream from the project reach. This includes geometric, sediment, and hydrologic information. Much of this information may have been collected during initial assessments and data collection. It may be necessary to construct flow-duration curves from 15-minute data (rather than daily) in areas where a large amount of sediment transport can occur during storms of duration much less than 24 hours. All sediment sources should be quantified, especially nonalluvial sources such as mass failures, landslides, debris flows, and soil creep. Additionally, the rates and volumes of sediment stored in the landscape should be estimated including in the channel, in wetlands, in lakes and ponds, on the flood plain, and on alluvial fans.

Step 2 Calculate hydraulic parameters for a typical or average reach for a range of discharges. This range should extend from the average annual low flow to the peak of the design flood. Average hydraulic parameters can be determined from normal depth calculations for a typical cross-sectional geometry, or from a backwater computer program such as HEC–RAS.

Step 3 Select an appropriate sediment transport function for the study reach. This can be achieved by comparing calculated sediment transport to measured data, taking care to ensure that bed-material load is being compared. When no data are available, one may rely on experience with similar streams in the region. Data ranges used in the development of various sediment transport functions are provided in NEH654.09. A review of this information may serve as guidance in selecting the appropriate function. However, if there are no available data for calibration, this analysis becomes more qualitative in nature.

Step 4 Calculate sediment transport rating curves. Apply calculated hydraulic parameters to the selected sediment transport functions for a range of flows. Curves should be developed for the existing channel in the assessment reach, upstream of the assessment reach (the supply reach), and downstream. Sediment transport rating curves should also be determined for any tributaries that might be affected by the assessment reach.

Step 5 Calculate sediment yield. Sediment yield should be calculated using the flow-duration sediment discharge rating curve method for the supply reach, assessment reach, and downstream reach. Use a flow-duration curve to obtain average annual sediment yield and a flood hydrograph to obtain sediment yield during a flood event. The calculation of average annual sediment yield is typically accomplished with the flow-duration sediment discharge method (USACE 1995a). This method requires sufficient gage data to develop the flow-duration curve and requires either measured bed-material load data or calculation of a sediment discharge rating curve, using an appropriate sediment transport relationship.

Often, sufficient gage data are not available to calculate a flow-duration curve for the project reach. If so, two approaches can be used to com-

pute average annual sediment yield. The first is to synthesize a flow-duration curve using either the drainage area flow-duration curve method or the regionalized duration method (Biedenharn et al. 2000). Then use standard methods to compute sediment yield.

If information is available for calibration, this technique can be used to estimate the actual quantity of deposition. Even without calibration information, this technique can provide relative comparisons of stability for various alternatives. Note that this approach typically uses average reach conditions. It does not account for changes in sediment transport capacity that may occur as sediment is deposited in the section and changes its geometry. The level of confidence that can be assigned to the sediment budget approach is a function of the reliability of the available data about the stream and the project. Specific techniques are addressed in more detail in NEH654 TS13A and TS13B, Thomas et al. (1994), and EM 1110–2–4000 (USACE 1995a).

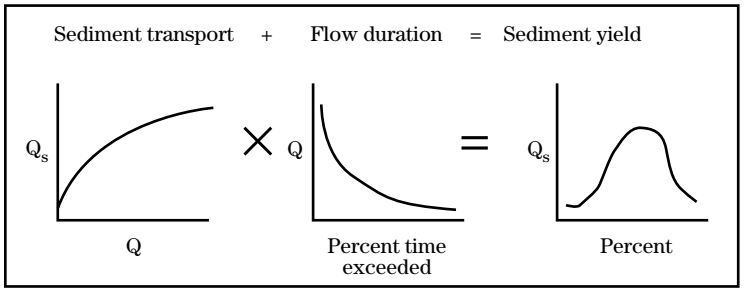
Step 6 Calculate trap efficiency by comparing the supply reach and assessment reach sediment yields. A positive trap efficiency indicates deposition and a negative value indicates erosion. If the assessment reach is stable, the trap efficiency is near zero.

An example sediment budget analysis conducted as part of the reconnaissance level planning study for a flood damage reduction project is provided in NEH654 TS13B.

654.1309 Computer models

Sediment budget analysis is typically accomplished using a computer program such as the USACE SAM or HEC–RAS program. However, a sediment budget can be analyzed with a spreadsheet program, as well. Where bed-material sediment transport is significant and highly variable, it may be necessary to use a numerical model that incorporates solution of the sediment continuity equation. Most computer models involve integrating a sediment transport function to a flow-duration relationship to estimate sediment yield —either by event, annually, or for multiple years (fig. 13–6).

Figure 13–6 Sediment budget



654.1310 Nonequilibrium sediment transport

A sediment impact assessment should include a nonequilibrium sediment transport model for high risk or high cost projects. River systems are governed by complicated dependency relationships, where changing one significant geometric feature or boundary condition affects other geometric features and flow characteristics, both temporally and spatially. Changes at any given location in a stream system are directly related to the inflow of sediment from upstream.

HEC–6 (USACE 1993c) is a one-dimensional, moveable boundary, open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible). This model simulates the sediment transport capacity of a reach by mathematically modeling the interaction between the sediment inflow and the hydraulic properties of the reach. In this model, a continuous discharge record is partitioned into a series of steady flows of variable discharge and duration. For each discharge, a water surface profile is calculated, providing energy slope, velocity, depth, and other variables at each cross section. Potential sediment transport rates are then computed at each section. These rates, combined with the duration of the flow, permit a volumetric accounting of sediment within each reach. The amount of scour or deposition at each section is then computed, and the cross-sectional geometry is adjusted for the changing sediment volume. Computations then proceed to the next flow in the sequence, and the cycle is repeated using the updated cross-sectional geometry. Sediment calculations are performed by grain-size fractions, allowing the simulation of hydraulic sorting and armoring.

HEC–6 is a powerful tool that allows the designer to estimate long-term response of the channel to a predicted series of water and sediment inflows. The use of a complex program such as HEC–6 involves a significant investment of engineering skill and time. The time required to perform a HEC–6 analysis can be upwards of 10 times that of the USACE SAM type analysis (Fripp, Webb, and Bhamidipaty 1996). However, it is often more advantageous to invest in this effort than to deal with the consequences of project failure. The critical decision to use a numerical model should be based on whether significant changes are expected to occur in the system as a result of the proposed design work.

The primary limitation of HEC–6 is that it is one-dimensional; that is, geometry is adjusted only in the vertical direction, and average hydraulic parameters are assumed in the computations. Changes in channel width or planform cannot be simulated. This analysis is typically based on one-dimensional, steady-flow models, while natural flows are three-dimensional and unsteady. In most cases, the three-dimensional effects of meander bends are accounted for with empirical geomorphic approaches and professional judgment (Copeland et al. 2001). For more complete information on details regarding the assumptions and limitations of specific models, the original documentation associated with each of them should be reviewed.

Finally, while a computer model such as USACE SAM or HEC–6 might provide a more precise answer, there is no reason to suppose that it gives a more certain answer. Computed answers might be highly precise, but are tied to original assumptions, which may not be accurate. Complicated models do not necessarily provide more accurate answers by themselves. If too little information is available as input to the models and no verification data are collected, it is unlikely that a detailed model will provide a more accurate answer than a simpler model. In all cases, field measurements and local experience should be used to complement the use of computer models.

654.1311 Choosing the appropriate technique

The choice of the appropriate technique to estimate the sediment impact of a proposed project includes not only an assessment of the project goals and watershed condition, but also the potential impacts of project failure. Visual and qualitative assessments are appropriate for sites where there is low risk and minimal change to an otherwise stable system. These can be accomplished with the aid of primarily judgment-based tools. As a project becomes more complex, and where there is a higher risk to life and property, more analytical approaches are used. Many analytical techniques are available that typically require the calculation of hydraulic parameters for the range of natural discharges, such as velocity and shear stress. All of these techniques require data determined from field observations and measurements, as well as calculations. Table 13–2 illustrates typical assessment techniques for estimating the impacts of sediment on different project types and watershed conditions.

As the risk and uncertainty increase, the use of more detailed models is recommended. Table 13–2 shows increasing complexity, from Lane's stream balance approach, to USACE SAM, to HEC–6. However, the use of increasingly complicated models is not necessarily recommended. On its own, a more complicated analysis will not necessarily be sufficient or more accurate. Any model is dependent on the skill and experience of the practitioner, as well as the input data. Engineering judgment becomes more critical with increasing risk, and the required field work and data collection become more labor intensive. Therefore, the suitable assessment column should be regarded as a cumulative recommendation that increases with increasing risk.

Since each stream system and project is unique, practitioners should review the assumptions and data requirements and consider their own experiences when determining the appropriate technique to use.

Table 13–2 Selection guidance for sediment impact assessment technique

Project type	Site/watershed assessment	Risk to life, property, or project investment	Suitable sediment impact assessment
Bank stabilization No significant change to cross section, slope, or planform	Relatively stable watershed and site	Low	Confirm that there is no significant change in the local hydraulic conditions from pre- to post project and note watershed stability
Bank stabilization No significant change to cross section, slope, or planform	Moderately active watershed and site	Moderate	Assess stable channel grade at design flows. Field check indications of future channel evolutionary change
Bank stabilization No significant change to cross section, slope, or planform	Moderately active watershed and site	High	Rating curve comparison of above and through site
Channel modification Small change to cross section, slope, or planform	Moderately active watershed and site	Low	Rating curve comparison of above and through site, as well as pre- and post project
Channel modification Significant change to cross section, slope, or planform	Moderately active watershed and site	Moderate	Sediment budget analysis with USACE SAM* type analysis
Channel modification Significant change to cross section, slope, or planform	Active watershed and site	High	Long-term numerical modeling with HEC–6* type analysis

* SAM and HEC–6 are now incorporated into HEC–RAS.

654.1312 Conclusion

It is strongly recommended that a sediment budget analysis be conducted for all projects that will involve a significant change to the existing stream channel. Sediment impact assessments can range widely in effort and output, but assess the stability of the project based on conditions of flow, coupled with sediment yield and transport. Visual or qualitative techniques may be used for relatively simple projects, analytical techniques for more complex projects. While no model or assessment eliminates all possibility of a project not performing as intended, the use of the appropriate tool as described in this chapter reduces the possibility of poor project performance.