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**Part 654 Stream Restoration Design
National Engineering Handbook**

# Chapter 3 Site Assessment and Investigation

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**Cover photo:** Characterizing the physical, chemical, and biological conditions of a stream involves sampling and the use of assessment tools.

**Advisory Note**

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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## 654.0300 Purpose

This chapter describes procedures for assessing watershed and site conditions. Stream system inventory and assessment techniques are identified and compared. Information is provided on stream stability, as well as geological and biological assessments. A description of the uses, advantages, and disadvantages of various geomorphic stream classification systems is also provided. Finally, this chapter addresses fluvial processes and geologic issues related to ecological function, as well as stream design.

The description in this chapter of assessment requirements and methods focuses on stream systems. A stream system consists of a watershed and ground water component that contributes discharge to the system and a flood plain area that is directly connected to a fluvial channel. In a natural setting, a channel is sized by nature and associated with discharge and sediment loading from upland areas, as well as earth materials in the channel. Other upland influences include anthropogenic changes in rainfall runoff characteristics such as occur with land use change and change in sediment supply. Sediment changes can be associated with land use change and, also, with dam construction. In addition, the system might be influenced by downstream factors such as a bridge, dam, or the confluence of another stream or river.

## 654.0301 Introduction

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) is increasingly providing technical guidance to organizations and individuals who are actively restoring rivers and streams degraded by extreme storm events, as well as human activities. Stream restoration is an interdisciplinary, comprehensive effort that focuses on reversing past damages and assisting nature to restore partial or complete functioning of a stream system.

Watershed hydrologic, hydraulic, geomorphic, and biological processes affect streams, and designers should have an understanding of these basic principles to work in streams. NEH 653 (Stream Corridor Restoration: Principles, Processes, and Practices) provides fundamental information on streams and their corridors, as well as the basics of how to plan stream corridor restorations (Federal Interagency Stream Restoration Working Group (FISRWG) 1998).

A stream inventory and assessment is needed to provide the process-based framework to define past and present watershed dynamics, develop integrated solutions, and assess the consequences and success of restoration activities. This assessment generally includes data collection, field investigations, and a determination of the equilibrium stage of the system or portions of the system. A channel is considered in dynamic equilibrium when the prevailing flow and sediment regimes do not lead to aggradation or degradation or to changes in the channel cross-sectional geometry over the medium to long term. Data collection and assessment forms the foundation for analysis and design and is an essential first step in the design process, whether planning the treatment of a single reach or attempting to develop a comprehensive plan for an entire watershed (FISRWG 1998). Refer also to the National Water Quality Monitoring Handbook, NEH 600 (part 1) and NEH 651 (part 2, draft).

A multidisciplinary investigation is typically performed to assess prior, existing, and future stream system conditions; to better understand the dominant processes acting in a watershed; to identify information and resource needs; and to aid in the selection and design of project alternatives. Key factors that should always be considered are spatial and temporal influences on the system or portion of the system of interest. Numerous methods are available to investigate and assess stream systems. None of these methods are perfect and vary considerably in the information they provide, information they require, the spatial and temporal scales they consider, and the complexity, expertise, and resources required to use each method. Many of these methods, together with factors associated with their use, are briefly described in this chapter. A compilation of numerous inventory and assessment techniques (USDA NRCS 2001c) is presented in NEH654 TS3A, along with a table that describes the principal features and applicability of each method.

## (a) Stream system assessment

Planning for stream system projects includes a systematic investigation of past, existing, and future conditions in the system. A complete analysis requires a team experienced in stream geomorphology, geology, hydrology, ecology, and stream hydraulics. The purpose of this investigation is to:

- identify the dominant fluvial processes in the stream system
- identify the equilibrium state of the system or portion of the system of interest
- determine if there is a problem. If so, is it an anthropogenic problem, a problem associated with the equilibrium state of the system, an existing or potential problem associated with past, current, or future land use, flood plain or riparian zone changes, or a combination of factors
- identify the factors that influence the issues of concern, as well as potential mitigation strategies

Knowledge of dominant processes allows prediction of the proposed project's impact on stream geomorphology, potential changes in the equilibrium of the system, and the impact the natural processes will have on the functionality of the project. The equilibrium state of various stream reaches and the changes occurring in the stream system should be accurately assessed. This assessment is the foundation for understanding future changes in the system and how alternative management, design, or mitigation strategies will work. Solutions are developed to address the goals and objectives of the project. These solutions might be self-sustaining, or require periodic maintenance, or the solutions are meant only to be temporary. In some cases, the best solution might be a river rules concept that simply provides adequate space for the stream to adjust to change.

Many perceived or actual stream problems are associated with a change in sediment supply within the system; change in sediment transport capacity or competency; change in bank erodibility, usually resulting from vegetation removal; or a combination of these factors. Potential causes of these changes are many. They might be due to localized stream modification such as a new culvert or bridge crossing, flood plain modification, or a more systemwide change. They might be due to urbanization, increased impermeable surface area, altered drainage, increased runoff, more discharge, larger peaks, and more frequent high flows. Biological and ecological impacts are sometimes associated with other factors such as changes in water chemistry, changes in low flow regimes, or changes in vegetation on the banks, flood plain and riparian zones. Assessment of these factors is presented later in this chapter.

Bank and meander migration, scour, and deposition are natural stream processes that might be exhibited by high quality streams that are in dynamic equilibrium. Natural meander migration rates vary across hydrophysiographic areas, so that a particular rate may or may not constitute a problem. Major events or significant perturbations may cause a stream to make rapid adjustments to move toward or depart from a state of equilibrium. In some areas, very small rates, perhaps a fraction of a foot per year, might signal a problem, while in other areas many feet of movement in a single event might be normal.

Often, any adjustment is viewed as a problem because it causes an unwanted impact on anthropogenic land use or structures. In these cases, the bank is often hardened. This treatment creates a temporary solution for the human concern, but, in some situations, actually makes the stream more prone to moving out of equilibrium because an additional constraint has been added to the system. Therefore, it is important to recognize that short-term changes in sediment storage, channel shape, and planform are both inevitable and acceptable in natural channels with unprotected banks. A key to preventing problems or to developing self-sustaining solutions is to provide the channel system with adequate space and time for adjustment.

A range of conditions exists for a stable channel, and some stable processes may appear unstable. Specifically, many large river systems have a stable state characterized by low gradient alluvial channels with active channel migration zones. Mistakes have been made in the past due to the lack of recognition of this key process (Wohl 2000; Reid and Dunne 1996).

Stream evaluations can be performed at various levels. The appropriate level of detail depends on the status of the study, the perceived significance of potential problems, the scale of the project, risks, and the resources available. A unique approach of using aerial videography and Geographic Information System (GIS) technology to assess stream stability is described in NEH654 TS3B.

**Basic information requirements**

Comprehensive evaluations of stream systems can require both extensive resources and extensive expertise across a wide range of disciplines. It is important to have adequate expertise and to identify and address the most important issues. For example, it is not uncommon for assessments to focus on hydrology and hydraulics. While both might be vitally important in developing an appropriate solution, the most critical basic information is first-hand knowledge of the stream system and an assessment of the past, current, and future equilibrium state of the stream system. This often requires an assessment of sediment supply and transport.

## (b) Initial stream characterization: flow duration

U.S. Geological Survey (USGS) topographic contour maps may be a first source of information on some important flow characteristics of streams, but the blueline streams may lack the detail to decide which streams need protection (Leopold, Wolman, and Miller 1964; Hansen 2001). Delineating stream networks using the contour crenulations (indentations) with some field verification can improve the identification and location of streams on maps, resulting in better awareness and management of small streams (Strahler 1957).

Perennial and intermittent stream types flow for extended periods beyond storm events. Under normal circumstances, perennial streams typically flow all year. Intermittent streams cease flow during parts of the year. Ephemeral channels primarily flow in response to storm events, but normally do not flow for extended periods afterward. Physical and biological indicators of flow duration and channel response to flow are also useful to help characterize a stream when flow data are not available.

Streams may be classified according to their flow conditions (table 3–1 (Hansen 2001)). The presence of a defined channel may be the best indicator to separate perennial and intermittent streams from ephemeral channels.

Small streams are seldom identified on contour maps beyond indentations in the contours, so they may go unnoticed if field evaluations do not follow office plan-

**Table 3–1** Field criteria used for characterizing streamflow conditions

| Criteria | Streams classified by flow duration characteristics | | |
|---|---|---|---|
| | **Perennial** | **Intermittent** | **Ephemeral** |
| Channel | Defined | Defined | Not defined |
| Flow duration (est.) | Almost always | Extended, but interrupted | Stormflow only |
| Bed water level | Above channel | Near channel surface | Below channel |
| Aquatic insects | Present | Few, if any | None |
| Material movement | Present | Present, less obvious | Lacking or limited |
| Channel materials | Scoured, flow sorted | Scoured or flow sorted | Mostly soil materials |
| Organic material | No organic buildup | Lacks organic buildup | Organic buildup |

ning. Stream and water quality protection goals may be difficult to achieve if the watershed streams and their connection and impact on the project area are not well defined.

For larger areas, stream detail can be digitized from topographic maps. Flow networks can also be estimated from digital elevation models (DEM) or triangulated integrated networks (TIN), which can be developed from digital topographic contours with flow routing methods using GIS software. If detailed digital elevation data are available, 10-square-mile data are preferred over 30-square-mile data, and noninteger elevations are preferred. Light Detection and Ranging (LIDAR) imagery, if available, may also be used to identify stream systems in great detail. Substantial editing of computer-generated stream networks may be needed to verify streams according to the contour crenulations.

Unusual flow patterns and paths can complicate stream type identification. Perennial streams may be interrupted as surface flow travels underground in coarse substrates, crevices, or through debris deposited in landslides. In karst topography, perennial streams may appear from underground flow networks, and substantial surface runoff may enter ground water directly through sinkholes and other solutioned features in karst limestone.

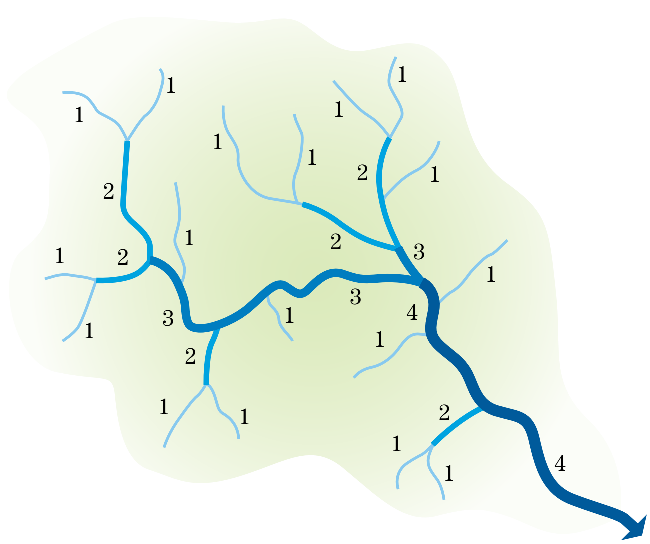
Soil types and plant species are not listed specifically for determining stream types, but the presence of hydric soils, hydrophytic plant species, or associated hydrologic indicators may be important in determining stream types (U.S. Army Corps of Engineers (USACE) 1987). Hydric soil indicators adjacent to streams include gleyed color and mottling and can be used to help estimate depth to the permanent water table or saturation zone. Plant species and rooting adaptations common to high moisture conditions may provide additional information.

## (c) Initial stream characterization: stream orders

Identification of the stream network and stream orders (Strahler 1957) can be done through analysis of 1:24,000 scale topographic quadrangle maps (Leopold, Wolman, and Miller 1964), digital orthophotoquads (DOQ), or DEM. First-order streams are identified as the unbranched channels that drain from headwater areas and develop in the uppermost topographic depressions, where two or more contour crenulations (notches or indentations) align and point upslope. These first-order streams may, in fact, be field ditches, gullies, or ephemeral gullies. The combination of two streams of the same order forms the next higher order (fig. 3–1). The density and pattern of the streams may vary with drainage size, geology, landform, and type of stream channel.

The use of stream orders is a valuable quick reference and has been used to correlate information. However, it does have limitations. Since the intersection of a channel with a lower order does not raise the order of a stream, a long, skinny basin may be classified with much lower order streams than a wider, but shorter drainage basin. As a result, stream order comparisons work best when the comparison is within a single drainage basin.

**Figure 3–1** Stream orders in a watershed may be useful in understanding flow conditions, setting goals and objectives, and provide preliminary information for design of solutions.



## 654.0302 Preliminary investigation

Ward and Trimble (2004) recommend that a preliminary investigation be conducted to provide sufficient information to design the study; select analytical methods, models, and procedures; and prepare an estimate of fund requirements to conduct the assessment. The purpose of the study is to:

- assemble and evaluate existing data
- obtain as much information as necessary
- develop a scope of work
- identify data requirements, data deficiencies, and cost resource requirements
- identify system boundaries and boundary conditions
- prepare a preliminary diagram of the physical system
- identify issues that restrict or inhibit the ability to conduct the study or need further study
- use USGS gage data or other records, where available, to assist in analysis of high flows and channel-forming events
- identify biological and ecological assets and concerns

## 654.0303 Reconnaissance

A reconnaissance of the site should always be done. Careful planning and advance preparation is critical. Practitioners should obtain background information by reading reports or previous studies. It is also valuable to obtain available topographic maps and aerial photographs and collect climate, soils, geology, and land use information. Especially useful will be maps, photographs, and surveys from different years in the same location, to indicate changes in the watershed and stream. It is important to talk to people familiar with the location and communicate with local, state, and Federal agencies to determine if there are ongoing or recently completed studies in the region.

Much of the data can be assembled in the office by reviewing old reports, maps, and aerial photos. Historical data are used to identify trends, provide information on rates of landform change in the watershed, and help determine land use impacts on current conditions. The examination and review of geologic information, local historical accounts, historic channel thalweg and cross section information, FEMA maps, biological monitoring, hydrologic models, watershed development and land use patterns, and aerial photographs can be useful in this assessment. Recent gage data should be reviewed to determine if current conditions might be the result of a recent extreme event, rather than long-term or systematic instabilities.

Prior to a site visit, it is recommended that the field team prepare a checklist of needed equipment and materials. The team should prepare written descriptions of each task to be performed, and make sure each reconnaissance team member is aware of the objectives, as well as their assigned tasks. It is useful to consider things that might go wrong and prepare contingency plans before going to the field. This is particularly important if electronic equipment is being used to document findings or take measurements.

For safety and logistical reasons, field work is best accomplished by teams of at least two people. Field work, particularly in urban areas, may raise significant health and safety issues, including crime, needles, and exposure to raw sewage and waterborne pathogens such as hepatitis.

## 654.0304 Detailed field investigation

Following the preliminary investigation, a detailed field investigation is performed to describe the geomorphological landforms of study reaches and to identify potentially destabilizing factors. This effort is often coupled with an identification of potential treatments or projects. This is based on field-gathered evidence of erosion, sediment storage, and deposition in the individual reaches. It is critical that experienced personnel conduct this effort. It is recommended that as a minimum the team consist of a biologist who is familiar with characteristics of aquatic and riparian habitat of the study area; a scientist or engineer who is experienced in stream geomorphology and sediment transport; and engineer(s) experienced in hydraulics, hydrology, design, and construction practices.

Inspections at bridge crossings should be treated with caution, since bridges are frequently placed at constrictions or at bedrock outcrops. These locations may not be characteristic of the stream as a whole. However, valuable indicators of stream stability can be observed at bridges and other points where infrastructure crosses the stream. Field assessments are best made during low-water conditions and during the dormant season when banks are not covered with vegetation and can be more readily examined. However, it is important to recognize that conditions may be different at high flows. In assessing streams in the field, it is important to keep in mind that a channel typically has four degrees of freedom: width, depth, slope, and planform.

Basic information on how to conduct field investigations to collect data for a channel stability assessment is contained in the following publications: EM 1110–2–4000 (USACE 1995c); EM 1110–2–1418 (USACE 1994d); and Thorne (1998). Biedenharn, Elliott, and Watson (1997) contains a detailed description of field equipment and features to look for in the field. The collection of field data can be aided with the use of field assessment data sheets, which should be adapted to the specific study needs. Guidance for carrying out detailed reconnaissance surveys is given in Downs and Thorne (1996); Thorne, Simon, and Allen (1996); and Thorne (1998). Example field assessment data sheets are provided in appendices B and C of Copeland et al. (2001).

Generally, the following basic information should be collected:

- descriptions of the watershed development and land use, flood plain characteristics, channel planform, and stream gradient
- assessment of historical conditions—this can be obtained with interviews of knowledgeable landowners. Anecdotal testimony, however, may result in some exaggeration of historical conditions, but multiple sources will help to provide accuracy
- measurements of low-flow and bankfull channel dimensions and channel slope in critical reaches and identification of terraces and active flood plains
- characterization of the channel bed—determine if it is bedrock, erodible cohesive material, armored, or unconsolidated alluvium. Determine the gradation of any armor layer and collect bed material samples of the substrate.
- descriptions of river bank profiles, bank materials, and evidence of bank instability
- descriptions and locations of point bars, pools, riffles, bed instability and evidence of sedimentation processes
- observations of response to channel alterations, and evidence of stream recovery
- descriptions of channel debris, woody material, and bed and bank vegetation
- preliminary stream restoration alternatives should be identified so information can be gathered on possible constraints such as access, utilities, and staging areas.
- photographic records of critical stream and watershed characteristics

There are many possible indicators of the equilibrium state of a stream system. A range of field indicators within a watershed is shown in table 3–2, reproduced from Copeland et al. (2001). These indicators are not absolutes, and items listed as possible indicators of instability may occur in natural or stable streams. Usually, no single indicator will accurately identify the cause of a problem or the equilibrium state of the system. A weight of evidence approach should be used, and it is important that those conducting the field assessment be experienced in the accurate interpretation of stream reconnaissance results.

It is also important to recognize the possible pitfalls of field assessments. These include observer bias, temporal limitations, and spatial limitations. Issues related to observer bias can be partially overcome with the consistent use of trained personnel. This practice will minimize relative differences between observations. Temporal bias can be minimized by examination of historical records, but these may be incomplete. Having the field team walk a continuous reach of stream can reduce spatial bias. Field investigation should extend both upstream and downstream of the project reach and, ideally, should be conducted during different seasons.

**Table 3–2** Possible field indicators of river stability/instability

| | |
|---|---|
| **Evidence of degradation** | Terraces (abandoned flood plains)<br>Perched channels or tributaries<br>Headcuts and nickpoints<br>Exposed pipe crossings<br>Suspended culvert outfalls and ditches<br>Undercut bridge piers<br>Exposed or "air" tree roots<br>Leaning trees (hockey stick trunks)<br>Narrow/deep channel<br>Banks undercut, both sides<br>Armored bed<br>Hydrophytic vegetation located high on bank<br>Points of diversion for irrigation have been moved upstream<br>Failed revetments due to undercutting |
| **Evidence of aggradation** | Buried structures such as culverts and outfalls<br>Reduced bridge clearance<br>Presence of midchannel bars<br>Outlet of tributaries buried in sediment<br>Sediment deposition in flood plain<br>Buried vegetation<br>Channel bed above the flood plain elevation (perched)<br>Significant backwater in tributaries<br>Uniform sediment deposition across the channel<br>Hydrophobic vegetation located low on bank or dead in flood plain |
| **Evidence of stability** | Vegetated bars and banks<br>Limited bank erosion<br>Older bridges, culverts, and outfalls with bottom elevations at or near grade<br>Mouth of tributaries at or near existing main stem stream grade<br>No exposed pipeline crossings, bridge footings, or abutments |

During field work, it is important to locate and observe both stable and unstable areas within the study reach. By observing the areas with the worst problems, the upper limits of erosion, sedimentation, and flooding can be established. It is equally important to visit reaches of the system where these problems are absent or not as severe. This approach will provide an envelope of values associated with the study area and better describe the variability and physical characteristics of the stream reach.

The information gathered in the reconnaissance and detailed field investigations should be used to divide the channel into geomorphologically similar reaches. When establishing reach limits, consideration should be given to differences in channel slope, tributary locations, presence of geologic controls, planform changes, location of channel control structures (grade control structures, dams, culverts, low-water crossings), changes in bed-material size, major sediment sources (mines, construction activities, sediment laden tributaries), instream gravel mining, maintenance dredging, changes in channel evolution type, and other significant hydrologic or geomorphic changes. Initial reach limits may be made early during the field investigation, but may be refined following more detailed analyses. The choice of an assessment technique should be made with consideration of the study goals. An example of some basic assessments is shown in table 3–3 from Copeland et al. (2001).

**Table 3–3** Reach condition assessment

| Condition | Bed | Bank |
|---|---|---|
| Stable | The channel bed is as close to a stable condition as can be expected in a natural stream. The reach exhibits few signs of or minimal rates of local bed scour or deposition | The channel banks are as close to a stable condition as can be expected in a natural stream and appear to have a low potential to erode. Banks are predominantly covered with extensive vegetation, boulders, or bedrock formations. Local bank erosion is within an allowable rate of change |
| Moderately stable | The channel bed in the reach is in a moderately stable condition. However, the reach may be in transition. Bed aggradation or degradation occurs at a low rate of change. Moderate to high rates of local bed scour or deposition occur (rapid aggradation immediately above and scour immediately below a minor debris blockage, such as a single tree blocking the channel | The channel banks in the reach are in a moderately stable condition and exhibit medium erodibility. Banks are partially vegetated with moderately erodible soils. Typically, parallel flows do not result in bank erosion. The reach may be in transition. Banks exhibit moderate local bank erosion that does not appear to be spreading (in an otherwise stable reach, a single section of the bank could fall into the stream and result in local, moderate bank erosion) |
| Unstable | The channel bed in the reach is unstable. The bed is undergoing widespread bed aggradation or degradation at a moderate rate. Moderate scour occurs, and many of the pools are filled with loose sediment | The channel banks in the reach are predominantly unstable. Banks are experiencing widespread erosion at a moderate rate. Channel banks are undergoing local bank erosion at a high rate of change and where the erosion is not likely to be self healing |
| Very unstable | The channel bed in the reach is in a very unstable condition. Typically the channel shows no signs of approaching equilibrium with the current shape and planform. The bed is undergoing widespread aggradation or degradation at a high rate. Reaches are severely scoured, and all of the pools are filled with loose sediment | The channel banks in the reach exhibit high erodibility and do not have any controls that restrict extensive changes in planform or shape. Riparian root masses are not present to slow rapid bank retreat. Any parallel or impinging flows will cause extensive bank erosion. Reaches have near vertical to overhanging banks |

At the conclusion of a field investigation, channel stability in each reach is summarized. General classification techniques are descriptions based primarily on observation and can be useful both in compiling observations and in communicating with stakeholders. Channel typing is an elementary level of stream classification that uses generic terms. Many techniques are available, and they range in complexity and required effort. The channel description may include parameters such as channel and flood plain geometry, bed and bank material, planform, vegetation, bedforms, evidence of aggradation or degradation, and grade control.

Geomorphic channel classification involves the selection of a classification system and categorizing a channel based on factors and measurements such as dominant mode of sediment transport, entrenchment ratio, and sinuosity. Some of the most widely used classification systems are described in chapter 2 of EM 1110–2–1418 (USACE 1994d) and in the FISRWG (1998). Streams can also be classified by their biota, habitat conditions, baseflow levels, and direct measures of water quality.

In summary, data obtained during the field investigation and historical data collection can be used to determine the target stream type in terms of boundary sediments, riparian vegetation, and meander patterns. In many cases, the type and density of bank vegetation will be different from that present in the reference reaches due to ecological, aesthetic, and recreational objectives. It is important that target vegetation is identified prior to channel design because it influences flow resistance. Otherwise, the stability of the restored channel could be affected.

Examples of useful tools for organizing and analyzing stream geomorphology data are the STREAM toolbox developed by the Ohio Department of Natural Resources (NEH654.10) and a streambank inventory and evaluation spreadsheet developed by Illinois NRCS that is described in NEH654 TS3C. This information also describes stream stability and equilibrium, along with a channel evolution model as background material. A detailed procedure for data collection and analysis is presented to better understand the dynamics of a target stream. Another useful tool is Stream Channel Reference Sites: An Illustrated Guide to Field Techniques (Harrelson, Rawlins, and Potyondy 1994). This publication helps in organizing and guiding field assessments and stream measurements.

## (a) Geologic assessment

Geologic factors can often be complex, yet they are the foundation of the stream system. Studying both the surface and subsurface geologic conditions is fundamental to a complete understanding of the stream's morphology.

This process should begin with a study of the available geologic maps that are available at a variety of scales from both state agencies and the USGS. Geologic maps generally show whether the materials in a valley are consolidated or unconsolidated, and they indicate the parent material both underlying the stream channel and in the watershed above it. This information can be used to estimate engineering properties and erodibility of the parent material and streambanks, type and amount of sediment available for transport, and potential materials for armoring. It is critical to verify this information in the field.

The engineering properties of the parent material and its resistance to erosion can have significant effects on the morphology and stability of a stream. Where bedrock hard points are part of the streambed, downward migration is limited, and the cross-sectional flow area must be accommodated by lateral erosion. Alternately, if bedrock hard points occur in a streambank, lateral migration is limited, and the cross-sectional flow area will be accommodated by downcutting.

Determining the type and amount of sediment available for transport within the watershed is an important part of the design process. In areas of high erosion rates, significant amounts of sediment can be delivered to the channel, and the quantity and particle-size distribution must be considered. For example, sparsely vegetated desert conditions can contribute enough sediment during rare, but high flows to overwhelm the stream completely. Badland conditions, such as those in the Dakotas, can form in soft, unvegetated shales, and also contribute significant amounts of sediment.

The geology can vary significantly even across small reaches, and its effects can be different depending on the location within the stream system. Different aspects of the geology may be important depending on whether the stream is in the erosional reaches near the headwaters, in the transporting portion of the mid-stream reaches, or in the depositional reaches near the lower end of the channel system.

Changes that have occurred at the site through geologic time must also be considered. The tectonic history, climatic changes such as ice ages, and other surficial processes are reflected in the current morphology of the stream channel. For example, faults can create soft zones in otherwise hard bedrock that will be more susceptible to erosion and channel development. In addition, the materials in the streambanks are a reflection of the stream's former positions within the landscape (upland, hillslope, fan, terrace, valley bottom, delta) and its previous erosional and depositional history.

In most of North America, the climate has changed drastically since the end of the Pleistocene Epoch, about 100,000 years ago. The climate was significantly wetter, runoff was generally higher, and glacial meltwater carved huge channels still in evidence today. Paleochannels that formed during that time have not experienced significant changes in areas with no active tectonic forces. For example, the Missouri River in northern Montana was pushed south from its original channel by continental glaciers during the last ice age. The Milk River, a much smaller system, now flows through this old channel, appearing to be underfit to the higher flow conditions that formed it.

The channels that were formed during higher flows are composed of coarser grained materials. They are overlain by finer grained materials deposited by today's lesser flows. This situation can be highly susceptible to erosion, but might not be considered without knowledge of the paleoenvironment. In particular, fines and sand can be washed out of gravel deposits during bankfull flows, especially on outside curves. This can undermine the streambank, creating an overhanging condition that fails under its own weight. Finer materials above may be cohesive, exhibiting increased shear strength, but once undermined, will fail and add sediment to the stream.

Coarser grained deposits provide higher resistance to flow than fine-grained deposits. Gravelly stream channels are considered to have formed from lateral accretion, or the extension of gravel bars, and finer textured deposits are considered to have formed from vertical accretion.

Some geologic conditions promote higher bank stability. For example, preconsolidated glacial till and wind-deposited loess both create stable bank configurations, even with high, vertical banks. Peat that is formed in marshy conditions also may form a stable, vertical streambank, if it is not interlayered with other materials.

In general, geologic conditions play an important role in the development of the stream morphology. These conditions should always be thoroughly considered in an interdisciplinary stream study.

## (b) Biological assessment

Watersheds are complex systems that integrate many factors. For this reason, a select group of indicators is often examined to infer watershed condition. For instance, instream habitat features, such as riffles, can be used to assess fish productivity potential. The U.S. Environmental Protection Agency (EPA) reviewed stream assessment protocols that range from subjective, visual-based protocols to objective, quantitative assessments that are time consuming measurement-based methods (EPA 2004). Some protocols provide unique approaches or particularly useful methods to address aspects of stream assessment and mitigation. For instance, the Eastern Kentucky Stream Assessment Protocol from the USACE Louisville District, incorporates a wealth of biological data into the calibration of the stream assessment method and integrates biotic and abiotic factors of fluvial systems in eastern Kentucky. The Integrated Streambank Protection Guidelines from the Washington Department of Fish and Wildlife (WDFW) (2003) uses a series of sequential or hierarchic matrices to aid practitioners in selection of practices to treat eroding streambanks (EPA 2004).

Like the canary in the mine, the health of indicator species can be used to reflect the general health and well being of a riparian system and watershed. A somewhat unique example of an indicator species is riparian bats (NEH654 TS3D).

### Biotic indicators

Biotic indicators are widely used to assess water quality. Biotic indicators are effective in assessing both past and present human activities on the watershed. While numerous biotic indicators exist, two common practices are briefly described here: the Index of Biotic

Integrity (IBI) and the Ephemeroptera, Plecoptera, and Trichoptera (EPT) Index.

The IBI uses fish surveys to assess human effects on a stream and its watershed. The EPT Index uses benthic macroinvertebrates, such as stoneflies, mayflies, and caddisflies, as indicators to assess land use and water quality within a watershed.

The presence, relative abundance, and diversity of aquatic macroinvertebrates may also be direct or indirect indicators of the surface water regime (Water Quality Field Guide, SCS–TP–160; and Water Quality Indicators Guide, SCS–TP–161). Rocks, sediment, and leaf accumulations can be searched in riffle and pool areas, since they are normally the first and last areas to dry up. The presence of a variety of species from the orders Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), Coleoptera (aquatic beetles), Diptera (cranefly), and others suggest persistent flow. Intermittent streams generally lack macroinvertebrates, though occasionally, a few early successional species can invade and dominate that niche during wet periods. With no persistent flowing water, pools, or saturation, ephemeral channels normally do not have aquatic insects. The presence of other organisms, such as freshwater mussels, crayfish, or snails, may be helpful when compiling evidence to determine stream type.

Biotic factors, particularly characteristics of stream biota, have been used with great success to evaluate watershed conditions and are one of the oldest approaches to assess water quality. However, biotic indicators have disadvantages in comparison to other indicators. Biotic indicators are not as visible as habitat indicators. For example, a stream habitat feature, such as a sloughing bank and the resulting increase in sediment, is more easily documented than the subtler effect of sediment on biotic communities in the stream.

*IBI*—The IBI was developed to help resource managers sample, evaluate, and describe the condition of small warm-water streams in central Illinois and Indiana (Karr 1981). The IBI became popular for assessing warm-water streams throughout the United States. Karr and his colleagues explored the sampling protocol and effectiveness in several different regions and on different types of streams. As the IBI became widely used, different versions were developed for different regions and ecosystems. The original version had 12 metrics that reflected fish species richness and composition, number and abundance of species, trophic organization and function, reproductive behavior, fish abundance, and condition of individual fish. The metrics were scored and summed to arrive at an index ranging from 60 (best) to 12 (worst). Newer versions generally retain most of the original metrics, but some have been modified to improve sensitivity to environmental degradation in a particular region or type of stream. The IBI has also been tailored to reflect differences in fish species within a region, and in other types of ecosystems such as estuaries, impoundments, and natural lakes.

Fish are useful in measuring degradation for many reasons:

- Fish are sensitive to a wide array of stresses.
- Fish integrate adverse effects of activities in the watershed.
- Fish are long lived. Their populations show effects of reproductive failure and mortality in many age groups, thereby providing a long-term record of environmental stressors.

To develop an IBI, a 30-foot-wide stream typically requires a four-person team (fig. 3–2). The team samples in an upstream direction using a seine or electroshocker to sample the stream.

**Figure 3–2** To develop the IBI, fish samples are collected by means of seines or electroshocking devices.

A state permit is often required for fish collection. Federal permits from the National Oceanic and Atmospheric Association National Marine Fisheries Service (NOAA Fisheries Service) and/or U.S. Fish and Wildlife Service (USFWS) may be required for fish collection, as well. While techniques for fish sampling vary, some studies use a 300-foot stream length. Others may use species-area curves to determine the stream sample length. For detailed information on sampling techniques and development and analysis of an IBI, see the NRCS National Biology Handbook (NHB), part 190.

Both left and right banks of the stream are sampled, taking care to include all stream habitats such as riffles, pools, runs, snags, undercuts, and deadfalls. Stunned or seined fish are netted and placed in buckets until the end of sampling. At the end of the section, the team pauses and allows the water to clear. The team then returns downstream to the starting point, repeating the sampling procedure along the way. Once back at the starting point, all fish are identified by species, counted, and measured. Sores and fish anomalies are also noted. In general, fish species identification requires a trained biologist or person familiar with fish assemblages in the area. Data are recorded, and fish that can not be identified are preserved and sent to a laboratory for analysis. Fish are then returned to the stream after completion of sampling and data recording. IBI scores are determined in the office, using 10 to 12 metrics tailored for the area. An example of the metrics and a brief description are presented in table 3–4 (North Carolina Department of Environment and Natural Resources (NCDENR) 1997).

The example metrics shown in table 3–4 are from piedmont streams. Metrics are tailored to a particular region and are generally available through state departments of water quality.

**Table 3–4** Example of metrics used to construct an IBI in Piedmont streams

| Metric | Description |
|---|---|
| Number of fish species and individuals | The total number of species and individuals supported by the stream will decrease with environmental degradation |
| Number of darters | Darters are sensitive to environmental degradation. Darter habitats may be degraded as the result of sedimentation, and channelization |
| Number of species of sunfish | These species are particularly sensitive to sediment filling pools and loss of instream cover |
| Number of species of suckers | Suckers are intolerant of chemical and habitat degradation, and because they are long lived and provide a multiyear perspective |
| Number of intolerant species | Intolerant species are most affected by stream degradation, and therefore would disappear by the time a stream is rated as fair |
| Percentage of tolerant species | Tolerant species are present in moderate number, but become dominant as stream degrades |
| Percentage of omnivores (plant eaters), insectivores (insect eaters), and piscivores (fish eaters) | These are the trophic groups. The trophic groups describe what the fish species eats and where it is in the food web. Deviations from what is expected are noted. For example, the cause of a great number of omnivores than insectivores is nutrient enrichment |
| Percentage of diseased fish | Skeletal anomalies, fin damage, disease, and tumors increase with stream degradation |
| Percentage of species with multiple age groups | Determines reproductive success of the fish populations |

*EPT*—Benthic macroinvertebrates are small stream-inhabiting creatures that are large enough to be seen with the naked eye. They spend all or part of their life cycle in or on the stream bottom. The name benthic macroinvertebrate means bottom-dwelling (benthic) small organisms without backbones (invertebrate). Since benthic macroinvertebrates do not move about like fish, they provide an indicator of what has affected the immediate area where they are found. Benthic macroinvertebrates have adapted to life in a stream, using all habitat niches. For example, some are adapted to higher velocity portions of the stream, some live below the bottom of the stream, some crawl for food, while others let the food come to them. Healthy streams can have several hundred kinds of benthic macroinvertebrates.

The EPT Index is named for three orders of aquatic insects that are common in the benthic macroinvertebrate community: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The EPT Index is based on the premise that high-quality streams usually have the greatest species richness. Many aquatic insect species are intolerant of pollutants and are not found in polluted waters. The greater the pollution, the lower the species richness expected, as only a few species are pollutant tolerant. Some basic identification features of stoneflies, mayflies, and caddisflies are shown in figure 3–3. The common mayfly is up to 1 inch in length (without tail), and has three distinct fuzzy or threadlike tails, and green, brown, gray, but usually black color. Mayflies have variable tolerance to pollution, but are usually considered to inhabit cleaner waters. The common stonefly measures less than 1 inch in length (without tail), and has two wings, two sets of branched gills between the underside of the body, and yellow to brown color. The stonefly is not tolerant to low levels of dissolved oxygen and therefore prefers cold, swift-moving streams. Stoneflies are an important source of food for trout. The streamlined, flat body of stonefly nymphs enables them to move about the streambed in rapid currents. The caddisfly (which resembles a caterpillar) has a soft, wormlike body, a hard covering on the head, and yellow or brown, but usually green color. Larvae build hollow cases that either carry or attach to small rocks. Cases are built from sand, twigs, small stones, crushed shells, or rolled leaves, and are used for protection and pupation. Caddisflies have a large range of tolerance to pollution. Note that identification of many species is straightforward, while others require microscopic identification, requiring expert assistance.

**Figure 3–3** Aquatic insects

Common mayfly, Ephemeroptera group

Common stonefly, Plecopetera group

Caddisfly, Trichoptera group

*Features of an EPT Index*—The EPT Index method uses a rapid sampling technique for determining between-site differences in water quality or for watershed studies with a large number of sites, and emergency sampling where it is desirable to rapidly assess the effects of spills and unusual discharges. The EPT Index should not be used in areas that naturally are known to have low EPT species richness (either inherent or human induced) or in areas where more pollution-tolerant groups are of interest.

The EPT Index is a versatile index because of certain characteristics of benthic macroinvertebrates. Benthic macroinvertebrates are sensitive to stress, both natural and human induced. When their environment is affected either by human or natural causes, the population will change, leading to an impaired or imbalanced community. Much like the canary in the coal mine, the response of aquatic insects gives an early warning of possible harm to a water body. Because many aquatic insects spend their entire lives within aquatic systems, they show the effects of physical habitat alteration, point and nonpoint contaminants, and cumulative pollutants over their life cycle. Other important features of aquatic insects are that they:

- are found in all aquatic environments
- exhibit diversity and are sensitive to pollution
- display a wide range of responses to pollution
- are less mobile than many other groups of organisms (fish)
- are often of easily collectible size

Like all biotic indices, the EPT Index can be used when chemical and physical measurements of a complex mixture of pollutants are not feasible. Moreover, these aquatic insects show responses to a wide array of potential pollutants and are sensitive to both short- and long-term conditions affecting water quality.

*Collecting samples to construct an EPT Index*—Benthic macroinvertebrates are collected using a variety of methods. The suite of sample collection techniques described consists of the kick-net sample, sweep-net sample, leaf pack sample, and visual collections (EPA 1999b). These techniques are aimed at sampling the favorite habitats and food sources of the aquatic insects. Stream food resources are larger organic matter particles in leaf litter and large woody material; smaller organic matter particles in suspended materials and sediments; and diatoms, algae, and other materials growing on rocks, wood, and plants; and prey (Hauer and Lambert 1996).

Each macroinvertebrate occupies a certain niche according to its feeding group: shredders, collector-gatherers, scrapers, filterers, or predators. Shredders prefer to feed on larger particles of organic matter such as leaves and twigs, in turn churning these into smaller organic matter that can be fed upon by collector-gatherers. Collector-gatherers feed on small particles of organic matter in or on the bottom of the stream. Scrapers feed on diatoms and algae that are attached to underwater surfaces. Filterers feed by straining small organic matter particles out of the water. Filters can be fanlike appendages on the insect's body or built externally by the insect to resemble little underwater nets.

Predators feed on other macroinvertebrates. In healthy streams, all feeding groups are present. Stream impairment may be indicated when one or more feeding groups are missing from a stream. In general, stoneflies are predators, mayflies are scrapers or collectors, and caddisflies are scrapers, collectors, or shredders. The ratio and number of these macroinvertebrates change with the stream food resources and human impacts and, therefore, can be used as a tool for assessing the ecological status of the biotic community and the water quality.

The kick sample is conducted using a rectangular section of window screening attached between two poles. The net is positioned on the stream floor, downstream of the sampler. One person holds onto the net. The other person disturbs the stream bottom upstream of the net and kicks the invertebrates present into the net. Invertebrates collected on the net are washed into a bucket. A long-handled triangular net is also used to disrupt and sweep areas under banks, root masses, and mud banks. Netted invertebrates are washed into a bucket. This procedure collects mayflies and caddisflies which prefer low-current environments. Leaf packs in the stream, snags, sticks, and small logs are examined and macroinvertebrates separated into a bucket. In general, shredders such as the caddisflies prefer these environments. A final visual search of upturned rocks, cobbles, and logs is conducted to collect adhering macroinvertebrates. For example, rocks in low current areas harbor stoneflies. Macroinvertebrates are separated or picked from the bucket samples with forceps and placed in vials containing ethanol for later classification and counting.

Macroinvertebrates usually require identification in the laboratory by a trained biologist. However, community watch group volunteers, teachers, and students can be trained to make basic identifications of the three groups used in the EPT Index. The NRCS Stream Visual Assessment Protocol (SVAP) also uses aquatic insects to assess stream condition (USDA NRCS 1999b).

*EPT Index score development*—The EPT Index is the total number of distinct taxa within the groups Ephemeroptera, Plecoptera, and Trichoptera. For example, if five species of Ephemeroptera (mayflies), five Plecoptera (stoneflies), and two Trichoptera (caddisflies) are found at a site, the total number of EPT taxa and Index would equal 12. The EPT Index is then compared to values on an EPT rating chart that has been developed for that particular region. Many state water quality departments are a good source of information on how to develop a rating chart for a particular ecoregion. The EPT Index increases with improving water quality; that is, there should be a greater number of EPT insect taxa in cleaner water. Ratings are tailored to account for differences in species pollution tolerance between regions. Table 3–5 (modified from NCDENR 1997) shows an example of EPT criteria developed for the Southern Piedmont of North Carolina. In this example, a site with an EPT Index of 12 would have a rating of fair.

The EPT Index can be used to directly assess the cumulative effects of all activities in the watershed. These results allow establishment of baseline or reference conditions for watersheds to characterize their overall condition, identify potential nonpoint and point source pollutants, target resource efforts in impaired watersheds, and evaluate the effectiveness of pollution control measures.

### Beavers and beaver management

Beavers were among the most widely distributed mammals in North America, and they were eliminated from much of their range by the late 1800s because of unregulated trapping. Beavers eat the leaves, inner bark, and twigs of aspen, alder, birch, cottonwoods, willows, and other deciduous trees. Conifers such as fir and pine are eaten occasionally. They also eat shrubs, ferns, aquatic plants, grasses, and crops such as corn and soybeans. Beaver dams are created by mud, rocks, and whatever other materials are available to the beaver.

Beaver dams create backwaters that flood areas upstream. This provides protection from predators, access to a food supply and their dens, and wet areas that promote the growth of their favorite foods. Because this backwater may also flood roads, fields and other land, much interest has been placed on beaver management. Beaver management involves trapping and relocation (Tippie 2003); installing flow devices to encourage dam building at more desirable locations (Lisle 2004); and using pond levelers to control water depth and reduce flooding (Snohomish County Public Works 2004; Cooperative Extension Service, Clemson University 1994).

**Table 3–5** Example of EPT index ranges and their corresponding water quality ratings for southern Piedmont, NC

| Rating | Excellent | Good | Good-fair | Fair | Poor |
|---|---|---|---|---|---|
| EPT | >27 | 21–27 | 14–20 | 7–13 | 0–6 |

# 654.0305 Stream classification systems

This description of stream classification systems is designed to help users understand the variety of different systems and their relationship to channel stability, basin geomorphology, riparian and aquatic ecosystems, and watershed condition. Its goal is to help stream professionals recognize how the effectiveness and longevity of riparian restoration activities are related to basic stream classification techniques. Readers can learn the basic terminology of each classification system and acquire sufficient background to communicate with peers and producers about the differing systems. While many other techniques exist, four stream classification methods are presented in this chapter. These are listed in table 3–6. The descriptions provided herein attempt to promote an understanding of the strengths, weaknesses, and limitations of the presented systems.

## (a) Overview of stream classification systems

Stream classification systems have been in use in their simplistic forms for at least a hundred years (Davis 1909). Much of the basis for modern stream classification systems, however, began in the 1950s and 1960s with work by Leopold and Wolman (1957), Lane (1957), and Schumm (1963).

River and stream systems are dynamic and continually respond to changes in sediment load, hydrology, and form. Under the current watershed conditions, stream classification systems help users understand the present and expected future status of a stream system. The strengths and weaknesses of these classification systems are described, but the description does not compare one system with another.

Four different types of classification systems are presented in this chapter. The Framework and Integrated Guide includes a listing of classification and mapping criteria. The channel evolution model (CEM) is an example of a system based on nonstable processes. The Montgomery and Buffington system is based on defining channel processes, and the Rosgen system is a classification of the current status of the channel. Each of these classification systems was designed to address a specific set of practical requirements by its developers and as a result, each has specific application areas in which it is strongest and weakest. No one system works for all situations, and professionals working in the field of stream restoration are well advised to match the appropriate classification system to the problem at hand.

**Table 3–6** Stream classification systems

| Stream classification | Full name | Basis |
|---|---|---|
| USDA Forest Service aquatic framework | Framework of Aquatic Ecological Units, and Integrated Resource Inventory Training Guide | Consistency of classification criteria |
| Schumm, Harvey, Watson, and Simon | Channel evolution model (CEM) | Channel response |
| Montgomery and Buffington | Classification of Channel Reach Morphology for Mountain Streams in the Pacific Northwest | Channel processes |
| Rosgen classification | Classification of Natural Rivers | Current channel condition |

## (b) USDA Forest Service: Framework of aquatic ecological units and the Integrated Resource Inventory Training Guide

The USDA Forest Service developed an aquatic framework (Maxwell et al. 1995) that contains standard terms and classification criteria for aquatic systems and their linkages to terrestrial systems at all spatial scales. Its purpose is to ensure consistency in classifying and mapping aquatic systems, and therefore, enhance the analysis of aquatic systems to reflect their varied forms and functions. The Forest Service has also developed the Integrated Resource Inventory Training Guide, Chapter 3, Common Water Unit (USDA Forest Service 1997a) that has tables of the classification criteria based on the aquatic framework (tables 3–7 and 3–8 (Frissell et al. 1986; Montgomery and Buffington 1993a; Paustian et al. 1992; and Rosgen 1994, USDA Forest Service 1997a). Major stream types are defined by channel entrenchment, shape, and sinuosity.

Potential NRCS use of the framework will primarily be as a guide for data collection and field mapping of stream reaches. The framework does not include estimates of what the next evolutionary phase of a stream might be. The stream reach classifications of Frissell et al. (1986), Montgomery and Buffington (1993a), Paustian et al. (1992), and Rosgen (1994) are based on a group of common geomorphic factors that are included in the framework. For use in classification, the most helpful sections of the framework are valley segments and their subdivision, stream reaches. Stream reaches are defined as uniform in flow and channel morphology and have discrete patterns of aquatic habitats and fluvial processes. A small set of stream reaches is nested within any valley segment.

### Strengths

The aquatic framework contains a listing of mapping and classification criteria that are used in several stream classification systems. With the collection of the stream attributes, the user could assign a channel type to a reach in several systems. If the reach is classified in several systems, this method has the advan-

**Table 3–7** Defining criteria for classifying stream reach types

| Variable | Description |
|---|---|
| Channel pattern | The plan view of the stream reach. Geomorphic controls and sediment transport regimes create straight, sinuous, meandering, tortuous, braided, and anastamosing channels. Sinuosity is used to describe the overall channel pattern. Sinuosity is the length of the active channel divided by the length of the valley. This attribute is map and photo interpreted |
| Channel entrenchment | The degree to which the stream is incised into the landscape. This criterion indicates how well floods are contained by a stream channel. It is the width of the flood-prone area divided by the width of the active, or bankfull, stream channel. The flood-prone area is the width of the valley floor at a level corresponding to twice the maximum bankfull depth of the channel. This attribute is field observed |
| Bank stability | Can be reduced by natural events (floods, fire, landslides) or human disturbances (grazing, logging, roads) that change runoff amounts, sediment loads, and bank vegetation<br>Vegetated–stable. Bank is vegetated with no evidence of active erosion or sloughing and no tension fractures<br>Vegetated–unstable. Bank is vegetated, but tension fractures exist at the top of the bank<br>Unvegetated–stable. Bank is not vegetated, but is composed of bedrock or stable boulders or cobbles<br>Unvegetated–unstable. Bank is not vegetated and is composed of bare gravel, sand, silt, or clay, or a matrix of cobbles and these finer particles |
| Woody material | Large woody material usually improves habitat complexity and quality in a stream reach, often forming pools. All pieces of large woody material that span the channel or lie totally or partially within it are counted |
| Temperature | Reflects both the seasonal change in net radiation and the daily changes in air temperatures. It is affected by flow velocity and depth and ground water inflow |

tage of compounding the individual system strengths. This method includes some stream health attributes that could be used to diagnose the condition of the stream reach against a reference healthy stream reach. The system is being used by the USDA Forest Service for mapping of aquatic systems, and data already collected would be available for National forests.

### Weaknesses

The aquatic framework classification does not have specific recommendations to determine evolutionary trends for each type of stream reach.

**Table 3–8** Stream type classes, modifiers, and bed structures

| Class | Channel entrenchment | Width-to-depth ratio | Sinuosity | Description |
|---|---|---|---|---|
| A | <1.4 | >12 | <1.2 | Straight, steep, entrenched, narrow stream |
| B | 1.4–2.2 | >12 | >1.2 | Moderately sinuous, moderately sloped, moderately entrenched stream |
| C | >2.2 | >40 | >1.4 | Meandering, low-gradient alluvial stream with broad flood plain |
| D | n/a | 40 | n/a | Braided, wide, multiple streams with many bars and eroding bank |
| DA | >4.0 | <40 | Variable | Anastomosing, flat, narrow multiple streams with stable banks |
| E | >2.2 | <12 | >1.5 | Tortuous, narrow stream with broad flood plain and stable banks |
| F | <1.4 | >12 | >1.4 | Meandering, low-gradient, wide, entrenched stream with eroding banks |

### Modifiers

| Materials | | Slope | |
|---|---|---|---|
| 1 | Bedrock | h | Hydraulic (over 10%) |
| 2 | Boulder (over 256 mm) | a | Aggressive (4.0–9.9%) |
| 3 | Cobble (64–256 mm) | b | Balanced (1.5–3.9%) |
| 4 | Gravel (2–64 mm) | c | Cumulative (0.5–1.4%) |
| 5 | Sand (0.062–3 mm) | f | Flat (under 0.5%) |
| 6 | Silt/clay (under 0.062 mm) | | |

### Bed structure

| | |
|---|---|
| PR | Pool-riffle (alternating pools and riffles) |
| PB | Plane-bed (lacking distinct bedforms) |
| SP | Step-pool (alternating pools and vertical steps) |
| C | Cascade (tumbling flow over disorganized large rocks) |

## (c) Channel evolution model

During the 1960s, several stream channels in northern Mississippi were channelized to control out-of-bank flooding. Major incision of the channel (down cutting) occurred from the late 1960s through the 1980s. Subsequently, a geomorphic study was conducted on several of the streams, and the investigations identified a sequence of steps through which all the channels had evolved. This channel evolution model (CEM) describes a predictable sequence of change in a disturbed channel system that was characterized as moving from reach types I through V (fig. 3–4a and table 3–9 (Schumm, Harvey, and Watson 1981)).

The model was developed by Schumm, Harvey, and Watson (1981) from investigating three unstable, channelized watersheds in northern Mississippi: Pigeon Roost Creek, Oaklimiter Creek, and Tippah River. The streams in these watersheds have mainly cohesive bank soils. The increased slope of the constructed channels started a process of significant down cutting after the channelization was completed. Starting at the oversteepened reach, the five types of channel reaches generally can be seen going downstream. In Schumm, Harvey, and Watson (1981), the series of five channel reach types as identified for Oaklimiter Creek can be characterized as shown in table 3–9.

Additional information was obtained from a study on Hotophia Creek Watershed in 1987. This study refined the CEM by introducing a ratio for critical bank height to bank height for each channel type. If the bank height (h) exceeds the critical bank height ($h_c$), gravity failure is imminent. For Type I, $h < h_c$; for Type II, $h > h_c$; for Type III, $h > h_c$; for Type IV, $h \sim h_c$; and for Type V, $h < h_c$.

A modification to this model was proposed by Simon (1989). This is the CEM that is most typically preferred. The modification by Simon included an extra step to account for channel modification and is perhaps more widely recognized. It is shown in figure 3–4b. The Simon model identifies six stages through which a stream progresses when subjected to destabilizing influences such as the urbanization described earlier in this chapter. Each of these stages is referred to as a class.

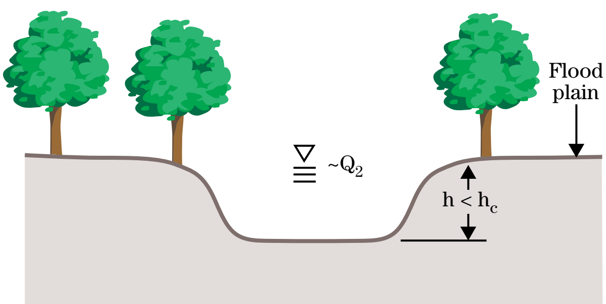
In the Simon (1989) model, class I is the natural channel before modification; class II represents the stream channel morphology directly after human activity such as channel straightening. This class is the new stage added by Simon.

**Table 3–9** Characteristics of channel reaches using the CEM (see fig. 3–4a)

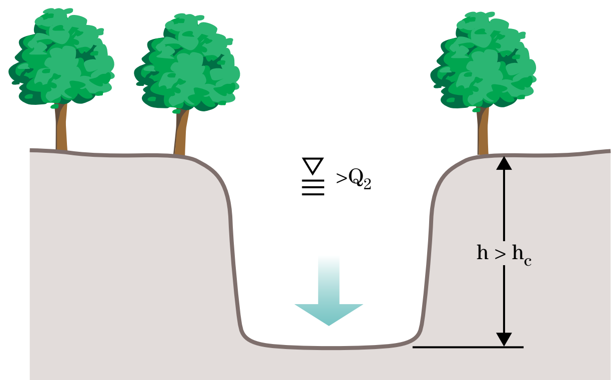
| Types in a downstream direction | Sediment storage | Shape | Location and stability | Width-to-depth ratio (F) |
|---|---|---|---|---|
| Type I | Very little or none | AU ≈ shaped | Upstream of active nickpoints, have oversteepened slopes | Highly variable 4.0–7.0 |
| Type II | Variable | Steep vertical channel banks and increased depth | Immediately downstream of active nickpoints, degrading | 30–4.0 |
| Type III | 1.5–2.0 ft | Banks failing | Active channel widening and degrading | ≈5.0 |
| Type IV | 2.5–3.5 ft | Low water sinuous thalweg | Reduced rate of active channel widening, aggrading, beginning of quasi-equilibrium | ≈6.0 |
| Type V | Up to 6 ft | Alternate bars | Aggrading, quasi-equilibrium | >8 |

**Figure 3–4a** Schumm, Harvey, and Watson (1981) schematic cross sections and longitudinal profile of an incised stream showing features of the five classes of the CEM

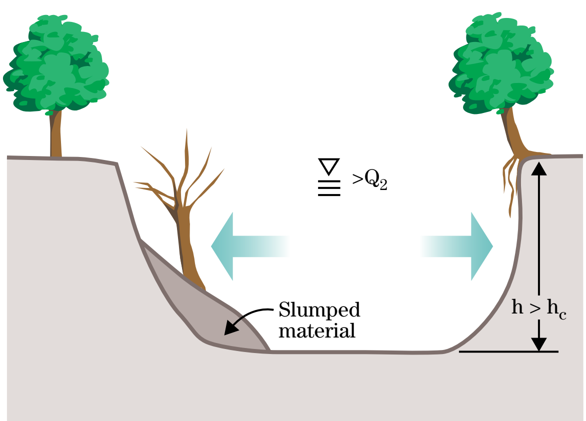
**Type I–Stable**



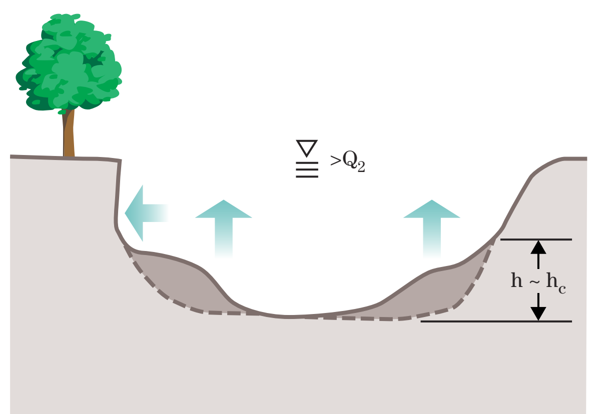

**Type II–Incision**




**Type III–Widening**




**Type IV–Depostion/stabilizing**




**Type V–Quasi-equilibrium stable**

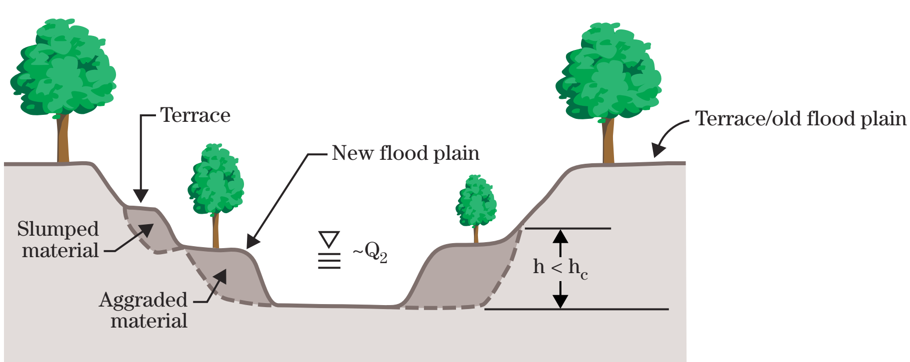
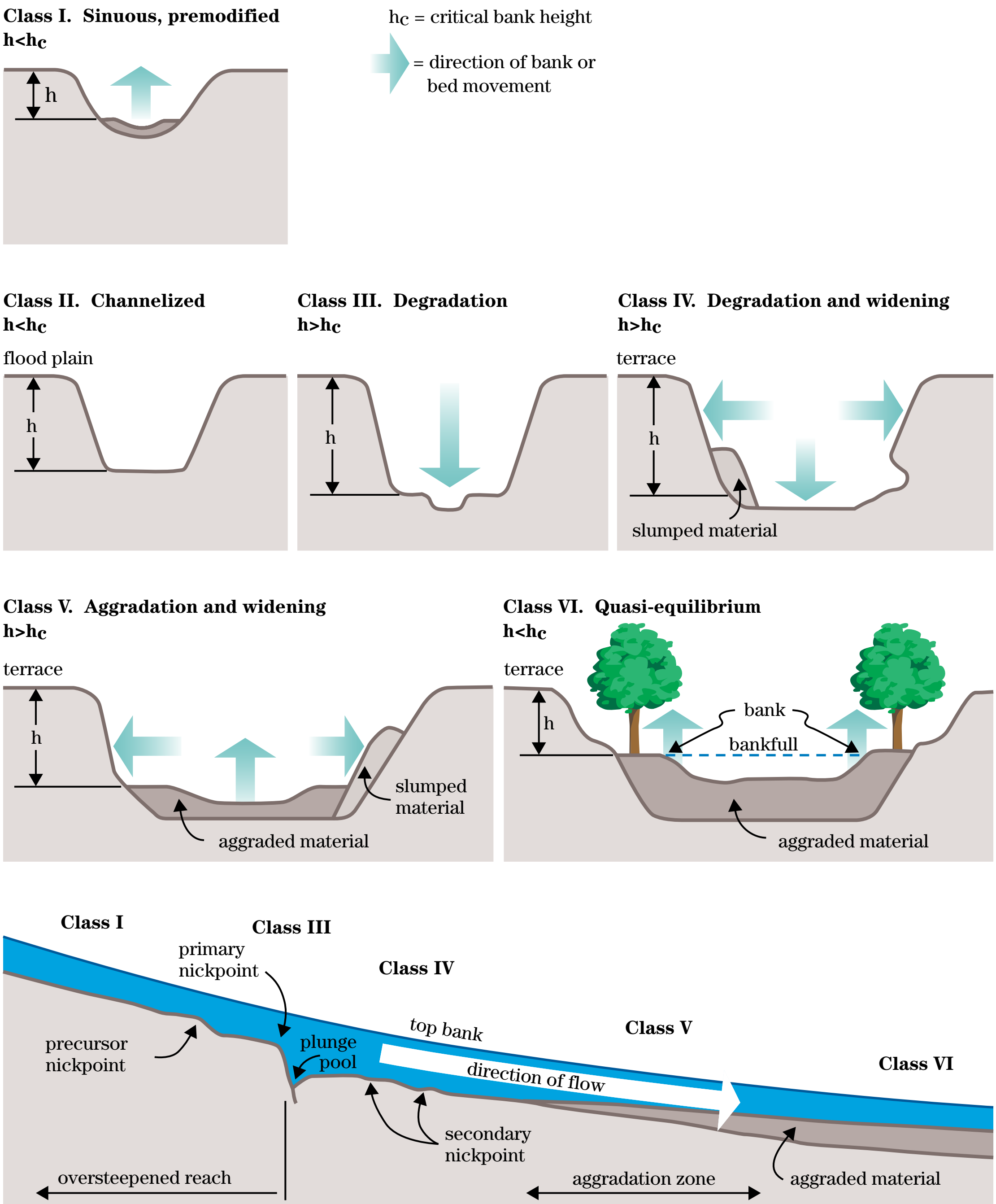


**Figure 3–4b** Simon (1989) schematic cross sections and longitudinal profile of an incised stream showing features of the five classes of the CEM



Class III is then the first sign of an instability problem, with evidence of downcutting or degradation in the channel bottom. Class III of the Simon 1989 model corresponds to Type II of the Schumm, Harvey, and Watson (1981) model.

As the bottom of the channel changes elevation, support for the banks is removed and the streambanks slump, creating a widening channel shape (class IV of the Simon 1989 model). It corresponds to Type III of the Schumm, Harvey, and Watson (1981) model.

At some point, a new equilibrium is being approached. The sediments from the slumped banks begin to form new, vegetated flood plains at a lower elevation (class V) and a smaller, natural channel within the new banks. It corresponds to Type IV of the Schumm et al. 1981 model. The new stream equilibrium (class VI) has abandoned the former flood plain and created a new one at the lower elevation (FISRWG 1998). This new stream equilibrium corresponds to the Type V of the Schumm et al. 1981 model.

Typical streams will exhibit several of the classes defined in the Simon CEM, depending on the location in the stream relative to the disturbance. The last part of figure 3–4b illustrates a nickpoint: the head of an active erosion event in the stream channel, working its way upstream. Class I describes the state of the stream well above the nickpoint where the effects of the disturbance are not yet in evidence. Progressing downstream, this figure illustrates the primary nickpoint (class III), and varying stages of bank instability in the wake of the nickpoint (classes IV and V). If enough time has passed since the disturbance, conditions farther downstream will approach class VI.

**Strengths**

The CEM was developed to help predict the changes a channel makes going through the process of headcutting. The CEM is based on geomorphic measurements of a reach of the channel system both upstream and downstream of a headcut. As a result, it is most accurate in its descriptions of what the next stage will be for the disturbed channel. The CEM is most valuable when verified for the watershed of interest. The CEM provides the kind of condition and trend information that is useful for shareholders and engineers to choose and design practices that are most cost-effective and have a greater probability of success. This model provides a means of segregating stream reaches into those requiring lesser or greater intervention to achieve a stable condition. For example, at Simon (1989) model class III (degradation), achieving a successful restoration is likely to be expensive, if at all possible. On the other hand, at class V (aggrading and widening), little effort may be required other than revegetation to speed the recovery process.

**Weaknesses**

Both the Simon (1989) and the Schumm, Harvey, and Watson (1981) models require a geomorphic study to determine reach stability values. It only applies in watersheds with degraded channels, and it works best in watersheds with fairly uniform soils and geology. Therefore, it is not as useful in systems with highly variable soils, grade, or planform control. The model has three assumptions that may limit its broad application:

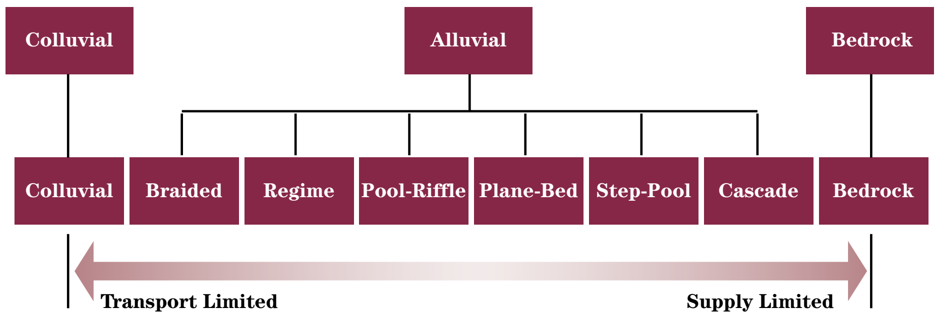
- channel base level will not change
- channel is formed in alluvial material that permits all types of channel adjustment
- land use of the watershed will not change greatly

## (d) Montgomery and Buffington classification system

The Montgomery and Buffington (1993a) system classifies channel reach morphology for forested mountain streams. The authors emphasize that there are very distinct differences between mountain channels and their lowland counterparts. Most of the field observations used to develop their system were made in Washington, Oregon, and Alaska. The persistence of significant quantities of large woody material in these mountain channel systems makes the current application of this classification system somewhat regional and unique. Further testing has definite potential to validate its application to other mountainous regions of the country. The morphological processes described by the authors may serve as a template for developing other regional classification systems.

Mountain streams can be categorized into erosional (sediment supply source), transporting, and depositional reaches (fig. 3–5). Montgomery and Buffington have expanded this process-based concept to include a number of channel types in each of the three geo-

**Figure 3–5** Montgomery and Buffington stream classification system




| | Braided | Regime | Pool-Riffle | Plane-Bed | Step-Pool | Cascade | Bedrock | Colluvial |
|---|---|---|---|---|---|---|---|---|
| **Typical Bed Material** | Variable | Sand | Gravel | Gravel, cobble | Cobble, boulder | Boulder | N/A | Variable |
| **Bedform Pattern** | Laterally oscillary | Multi-layered | Laterally oscillary | None | Vertically oscillary | None | • | Variable |
| **Reach Type** | Response | Response | Response | Response | Transport | Transport | Transport | Source |
| **Dominant Roughness Elements** | Bedforms (bars, pools) | Sinuosity, bedforms (dunes, ripples, bars) banks | Bedforms (bars, pools), grains, LWD, sinuosity, banks | Grains, banks | Bedforms (steps, pools), grains, LWD, banks | Grains, banks | Boundaries (bed & banks) | Grains, LWD |
| **Dominant Sediment Sources** | Fluvial, bank failure, debris flow | Fluvial, bank failure, inactive channel | Fluvial, bank failure, inactive channel, debris flows | Fluvial, bank failure, debris flow | Fluvial, hillslope, debris flow | Fluvial, hillslope, debris flow | Fluvial, hillslope, debris flow | Hillslope, debris flow |
| **Sediment Storage Elements** | Overbank, bedforms | Overbank, bedforms, inactive channel | Overbank, bedforms, inactive channel | Overbank, inactive channel | Bedforms | Lee & stoss sides of flow obstructions | • | Bed |
| **Typical Slope (m/m)** | S < 0.03 | S < 0.001 | 0.001 < S and S < 0.02 | 0.01 < S and S < 0.03 | 0.03 < S and S < 0.08 | 0.08 < S and S < 0.30 | Variable | S > 0.20 |
| **Typical Confinement** | Unconfined | Unconfined | Unconfined | Variable | Confined | Confined | Confined | Confined |
| **Pool Spacing (Channel Widths)** | Variable | 5 to 7 | 5 to 7 | none | 1 to 4 | < 1 | Variable | Variable |

morphic zones (Montgomery and Buffington 1993a; Montgomery and Buffington 1997).

A net reach response is dependent on the size and amount of sediment available to transport compared to the reach's hydraulic transport capacity. Reaches with more sediment supply than sediment transport capacity are erosional or source reaches. These reach types usually occur in the headwaters of mountain streams. Some length of midreach stream tends to achieve a balance between sediment load and transport capacity. These reaches are identified as transport reaches. These middle stream transport reaches may be relatively short in some stream systems and quite long in others, depending on the relative balance of sediment supply and size compared to transport capacity. Middle stream reaches tend to exhibit a net long-term balance between aggradation and degradation which is inherent in most definitions of stream stability. A net, long-term sediment balance within a stream reach may not necessarily translate to stream stability because of extreme fluctuations in sediment load and continuous change instream geometry. Finally, the lower end of mountain stream systems are typically depositional reaches due to a reduction in transport capacity as stream gradients are reduced. These depositional reaches are also identified as response reaches.

Many variables other than sediment supply and transport capacity influence channel characteristics. Important geometric properties of stream channels include width, depth, and alignment. Hydraulic properties include slope, roughness characteristics, hydraulic radius, discharge, velocity, velocity distribution, turbulence, fluid properties, and uniformity of discharge. Other geomorphic factors include grain size of suspended sediment and bedload material, frequency of island occurrence, bar types and numbers, and especially the influence of debris flows and the occurrence of large woody material in forested mountain streams.

The Montgomery and Buffington classification system identifies eight distinct channel types (fig. 3–5). The bedrock channel type can occur in a number of positions on the stream profile, although it is more likely to occur on steeper slopes. The colluvial and bedrock stream reach types are normally associated with the headwater portion of a stream system, but they are quite different in morphologic characteristics. Source channels can be further divided into hillslope (flatter hill or mountain tops), hollow (transitional slopes) and colluvial (steeper sloped) channels. The further division of source channels primarily reflects the position of the channel in the headwater profile and has some implication on the relative amount of sediment load that can be anticipated from each type. The colluvial channels are normally the highest yielding source channel type in the watershed system because they contain significantly more sediment than the stream has capacity to transport. Sediment size (boulders, cobble) may be an important transport factor that may limit sediment loads from source channels in headwater streams.

Under certain circumstances, bedrock channels may also temporarily serve as source channels. Bedrock channels are often associated with headwater stream reaches, but they may also occur in the lower gradient portion of the watershed as well. With respect to sediment, bedrock channels are normally opposite of colluvial channels in that transport capacity significantly exceeds sediment supply. Simply stated, most of the available sediment has been removed down to bedrock. However, the sudden introduction of a sediment source such as a debris flow may temporarily cause a bedrock channel to take on the morphologic characteristics of a colluvial channel. The bedrock channel will ultimately return to its bedrock morphology once the temporary sediment source is removed. The time required to revert back to a bedrock morphology will depend primarily on the volume of the sediment obstruction and the particle size of the material to be transported.

Because the hydraulic capacity of bedrock channels normally exceeds available sediment supply, bedrock stream reaches are categorized as transport reaches. The remaining five channel classes are alluvial reach types. They include the cascade, step-pool, plane-bed, pool-riffle, and dune-ripple classes. Sediment in cascade channels is predominantly supply limited resulting in excess transport capacity. These channels occur on steep slopes that result in high rates of energy dissipation, and flows tend to be continuously in the supercritical range. Channel bed material will typically consist of boulders and cobbles since any finer material will have been mobilized and transported downstream. Much of the turbulent energy in cascade channels is dissipated in converging and diverging flows over and around large boulders and other trapped debris or obstructions.

Step-pool channels are also found in transport reaches, and they occur on steeper slopes, exhibit coarse bed material, and have low to moderate width to depth ratios. Step-pool channels, like cascade channels, are characterized as sediment supply limited with excess transport capacity. The primary distinction is that flow regime in step-pool channels is alternately supercritical in the steeper areas with subcritical flow and energy dissipation occurring in the pool areas. The bedrock, cascade, and step-pool stream reach types are all found in transport reaches.

The three remaining Montgomery and Buffington channel types (plane-bed, pool-riffle, and dune-ripple) are also alluvial channel types, but they fall into the response group. Plane-bed channels include channel reaches described as glides, riffles, and rapids. They typically occur on slopes intermediate between step-pool and pool-riffle channels. Plane-bed channels are usually described as armored bed surfaces. Streambed armoring indicates a lack of bedload transport capacity for larger particle or material sizes ,while finer suspended sediments have been readily transported through plane-bed reaches. Depending on sediment size distribution and discharge, plane-bed channels may exhibit either supply or transport limited morphologies.

Pool-riffle stream reaches are also response reaches. The bed of pool-riffle channels tends to be stable over time even though the bed material is mobilized by intermediate and larger flow events. Bars may develop in pool-riffle systems with high width to depth ratios and where the channel gradients are less than about 0.02 foot per foot. Like the plane-bed channels, sediment transport can be either supply limited or transport limited at various discharges. When sediment bars occur in pool-riffle systems, it is an indication that the composite flow regime is transport limited.

The dune-ripple channel is the third response channel type. A mobilized bed even at low flows characterizes the dune-ripple channel reach. They are typically low gradient, sand bed channels. Channel bed material can easily be put into suspension, but the combined sediment load is almost always greater than the available transport capacity. The bed material is constantly being shifted and moved short distances at all flows, but the overall lack of transport capacity compared to total sediment load results in the dune-riffle channel being transport limited.

Another key concept of the Montgomery and Buffington classification system is the recognition and categorization of a number of forced channel morphologies. A forced channel morphology can result from debris flows, geological barriers, bedrock outcrops, and especially from large woody material (LWM) in the Pacific Northwest. In small channels, trees tend to remain where they fall. Where the dominant trees tend to be longer than the channel is wide, woody material can create a sudden and long lasting constraint to the local stream morphology resulting in a forced stream type. On small mountain streams, LWM may dominate channel morphology by stream blockages that may exist for decades or even centuries.

In larger streams where the stream channel tends to be wider than the dominant tree heights, the LWM is typically mobilized and transported downstream. On these larger rivers, hydraulic processes dominate the impact of LWM on channel morphology. During large floods, LWM may be deposited on bar tops during the hydrograph recession, which may leave the impression that the LWM in the stream system has had little impact on channel morphology. Nevertheless, logjams influence channel pattern and flood plain processes in large forest channels through bank cutting or protection, channel unit and side development, and forcing channel avulsions (Bryant 1980; Nakamura and Swanson 1993; Abbe and Montgomery 1996).

LWM can be characterized as a random variable that creates many forced stream morphologies in Northwest streams. In addition to the impact of LWM on Pacific Northwest streams, there are a variety of other changes that can be anticipated. Montgomery and Buffington describe the array of potential channel changes as:

> *In response to changes in sediment supply or discharge, a channel may widen or deepen; change its slope through aggradation, degradation, or modified sinuosity; alter bedforms or particle size, thereby changing the frictional resistance of the bed; or alter the thickness of the active transport layer defined by the depth of channel scour. Drawing on both theory and empirical evidence, previous researchers developed conceptual models of channel response to changes in sediment load and discharge (Montgomery and Buffington 1998).*

Montgomery and Buffington have created a number of conceptual models of channel response supported by hydraulic geometry. Most of the documented experiences were associated with changes in sediment supply and/or transport capacity. Quantitative measurements of total sediment load including both bedload and suspended sediment are difficult and expensive to obtain. Hydraulic transport capacity is easier to obtain, but the accuracy and data format may not fit sediment modeling needs. For a more detailed description of the hydraulic geometry relationships and experiences with predicted changes and validated responses, see Montgomery and Buffington (1998).

Montgomery and Buffington acknowledge some merit to coarse scale classification systems for general planning purposes, but offer a cautionary note regarding the use of classification systems as a substitute for careful field evaluations of complex morphologic issues. Their cautionary note in its entirety is:

> *Channel classification cannot substitute for focused observation and clear thinking about channel processes. Channels are complex systems that need to be interpreted within their local and historical context. Classification simply provides one of a variety of tools that can be applied to particular problems—it is not a panacea. Classifications that highlight specific aspects of the linkages between channel networks and watershed processes are likely to be most useful, but careless application of any channel classification may prove misleading; no classification can substitute for an alert, intelligent, well-trained observer. Nonetheless, it is difficult to fully understand a channel reach without reference of the context defined by its bed morphology, confinement, position in the network, and disturbance history.*

**Strengths**
The Montgomery and Buffington stream classification system is a geomorphic process-based system that is strongly influenced by extensive experience on mountain streams, especially in the Pacific Northwest and Alaska. This classification system does an excellent job of identifying the morphologic differences in the mountain streams where it was developed. The process-based components of the system can be expected to work well in other mountainous regions, as well. The classification system aids the user in identifying source, transport and response (erosional, transport, and depositional) reaches. Regional variations with the classification system are more likely to occur with forced stream morphologies, especially those resulting from the presence of an abundance of LWM. There is clear reason to test the applicability of this classification system to other mountainous regions across the country, recognizing that the concept of forced stream morphologies may vary significantly.

**Weaknesses**
The nonfluvial geomorphologist initially may have difficulty applying the classification system with consistent results. The documentation in the past was developed within and written for the scientific community. As with many other systems, the procedure is not readily applied without study or training. However, with field experience, a practitioner should be able to define the nine stream classes identified by Montgomery and Buffington.

## (e) Rosgen classification system

The Rosgen Classification of Natural Rivers was developed over 30 years of extensive fieldwork and observations of river systems across North America.

The Rosgen classification system tends to rely on field-measured parameters and is more experience-based than some of the other classification procedures described in this document. Rosgen's classification measures are based on channel dimensions measured at bankfull discharge, also known as channel forming flow. The complete Rosgen system is intended to provide both stream reach classification and guidance for potential restoration. The system includes the addition of a number of practical physical parameters that can be measured in the stream or from photographs and USGS topographic maps depending on the level of classification desired. Use of this method requires fundamental training and experience using this geomorphic method. Not only is a strong background in geomorphology, hydrology, and engineering required, but also an ability to implement the design in the field. The application of the classification system as part of a detailed design process is described in detail in NEH654.11.

The first version of Rosgen's current classification system was published in 1985. The system has continued to evolve with Rosgen (1994) and in Applied River Morphology (Rosgen 1996). The Rosgen system categorizes or classifies an individual stream reach, rather than an entire stream system. The key to the classification system is shown in fig. 3–6. Rosgen (1994) best describes the description of appropriate reach length as follows:

> *The morphological variables can and do change even in short distances along a river channel, due to such influences of change as geology and tributaries. Therefore, the morphological description level incorporates field measurements from selected reaches, so that the stream channel types used here apply only to individual reaches of channel. Data from individual reaches are not averaged over entire basins to describe stream systems. A category may apply to a reach (of) only a few tens of meters or may be applicable to a reach of several kilometers.*

Rosgen (1994, 1996) identifies four levels of detail in stream classification and assessment. This document primarily concentrates on levels I and II stream classifications. Each successive level provides a more detailed or finer definition of the dimension, pattern, and profile of the stream reach being classified.

### Level I stream classification

Level 1 is a general characterization of the stream reach being classified. Level I stream classification is based on geomorphic features that can be interpreted from aerial photography, topographic maps, geologic maps, and a strong individual familiarity with the stream systems and land forms within the watershed of interest (Rosgen 1996).

Level I stream classifications are intended to be preliminary in nature. Level I classification makes use of readily available published information and relies on experience and judgment to the extent possible. The first four delineative criteria for levels I and II classifications are the same, but vary greatly in the intensity of required data. The four required channel characteristics for a level I determination are the number of channels, entrenchment ratio, width-to-depth ratio, and sinuosity. For a level I determination, the four channel characteristics often can be determined using a coarse scale with suitable landform maps.

As a minimum, level I classification requires a judgmental estimate of entrenchment (slight, moderate, or entrenched) based on prior knowledge of the stream system or experienced visual field observations. The specified ranges for width-to-depth ratio are fairly broad with break points at less than 12, 12 to 40, and greater than 40. In level I classification, the width-to-depth ratio is often viewed in terms of the stream reach being described as narrow and deep or flat and wide. With a minimum of experience, judgments of width-to-depth ratio with visual observations are relatively easy in all but borderline cases. The purpose of a level I classification is to designate the eight basic Rosgen stream types of A, B, C, D, DA, E, F, and G. These eight stream types are described in detail in Rosgen (1996).

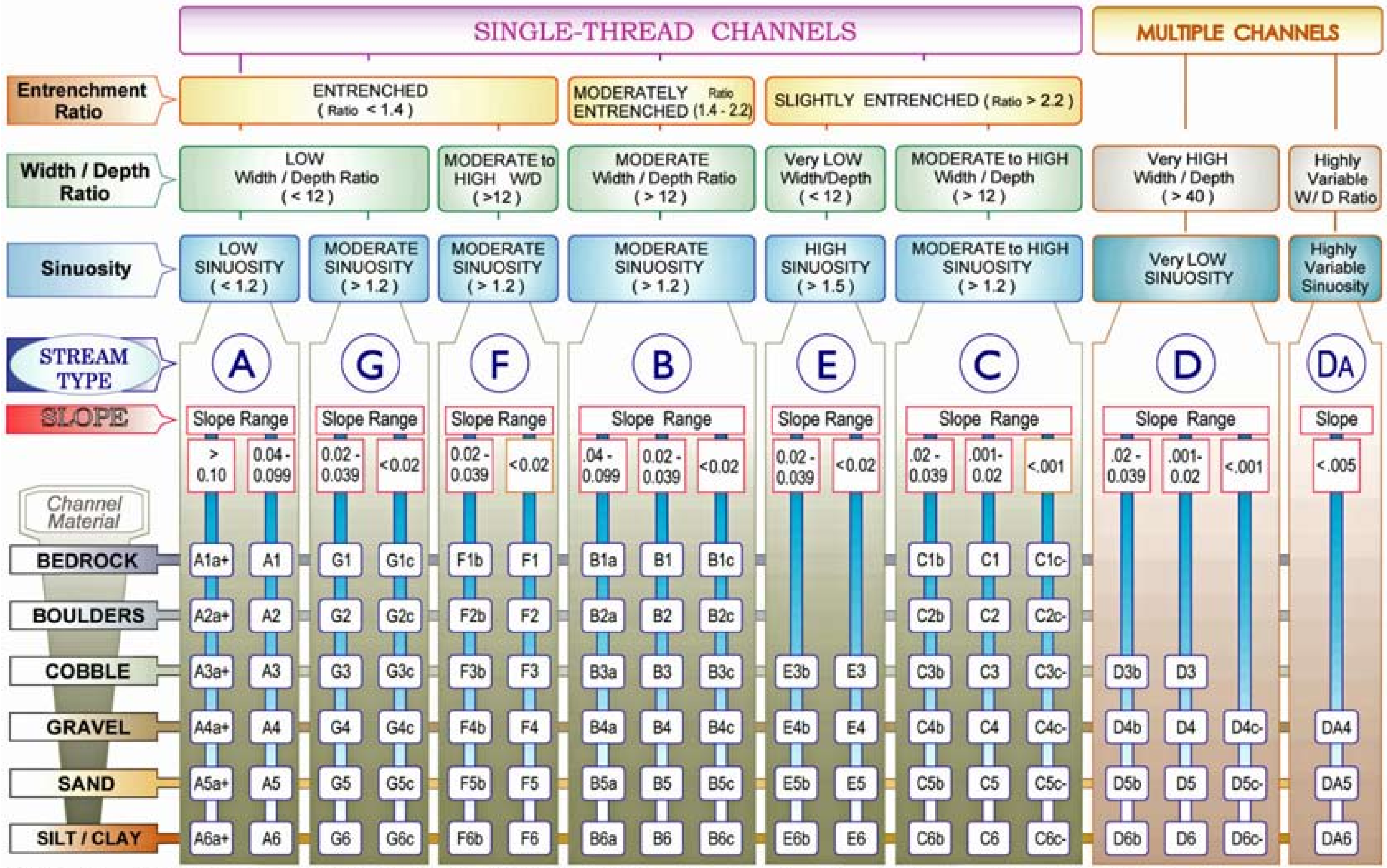
In practice, a level I classification can also include preliminary visual field estimates of bed material (a level II characteristic). An experienced practitioner can differentiate visually between a C channel with a sand bed (C5) and a C channel with a gravel bed (C4) in all but borderline cases. Channel water surface profile slope at bankfull stage (a level II characteristic) is not required to make a level I classification. However, a channel slope measurement from a USGS quadrangle map may be useful in preliminary planning to differentiate between channel types likely to occur on steep slopes versus channel types more likely to occur on flatter slopes. Estimates of channel slope are also useful in characterizing the general stream and valley system morphology.

Level I classification and any additional observations should be clearly identified as preliminary estimates that will have to be supported by actual field measurements in level II classification. Level I classifications can be useful for general discussion purposes, broad inventories, and coarse planning applications. Level I classifications are never suitable for use in the final design of stream restoration activities.

### Level II stream classification

Level II stream classification requires actual field measurements and higher resolution landform mapping to delineate the more detailed and defensible stream classifications. The first four delineative criteria in level II classification are the same as were used for level I classification. The difference is that the number of channels, entrenchment ratio, width-to-depth ratio, and sinuosity must be accurately measured in the field for a level II classification.

**Figure 3–6** Key to the Rosgen stream classification system




KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Level II classification requires physical measurement of a number of associated parameters not required in level I including hydraulic characteristics. The hydraulic geometry portion of Rosgen's Classification of Natural Streams is strongly influenced by the early work of Leopold and Maddock (1953) and the work of Leopold, Wolman, and Miller (1964). This work identified eight interdependent hydraulic variables that could be used to characterize stream morphology. The variables are discharge, velocity, channel width, channel depth, channel slope, sediment size, sediment load, and roughness of channel materials.

Leopold, Wolman, and Miller (1964) recognized that a change in any one of these interdependent variables would produce resultant and often compensating changes in the other seven variables. The compensating effect is not uniform for all variables. For example, an increase in channel width will produce proportional, but inverse reduction in mean channel depth since, in many cases, bankfull channel area tends to remain relatively constant. For the same example, corresponding variables such as velocity and discharge may only exhibit minor reductions in magnitude. Rosgen has both directly and indirectly incorporated a number of the hydraulic geometry relationships into his criteria.

Two key field determinations are critical for obtaining accurate information for use in level II classifications. The first is that the elevation of the bankfull flow must be accurately determined, since it is directly linked to many other parameters. The term bankfull as used by Rosgen can be very confusing to the new practitioner who may visualize the common definition of bankfull as the elevation where water first begins to spill out of the channel banks and onto the flood plain. Rosgen uses the Dunne and Leopold (1978) definition of bankfull:

> *The bankfull stage corresponds to the discharge at which channel maintenance is the most effective; that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of the channels.*

The bankfull discharge and resultant elevation has a typical recurrence interval range of 1.0 to 3.0 years on an annualized frequency curve with a predominance of values occurring in the 1.2- to 1.8-year range. For channel types C, D, DA, and E which are only slightly entrenched, the lay definition of bankfull and the Dunne and Leopold definition are very similar. For the B channel type which is moderately entrenched or the A, F, and G channel types that are entrenched, the Rosgen bankfull is at an elevation well below the top of the banks. A number of good field indicators can be used as reliable indicators such as the top of point bars, a break in bank slope, and the presence of certain riparian vegetative species, which vary by region. An accumulation of indicators aids the practitioner in physically identifying the Dunne and Leopold bankfull elevation in the field. With proper training and concerted practice, individual determinations of bankfull tend to be consistent. Bankfull determinations are not necessary for the general level I classifications, but are a key element for the detailed level II determinations. For a more complete description of bankfull discharge, refer to NEH654.05.

The second important concept in determining level II classifications is entrenchment ratio. Entrenchment or channel incision is basic to geomorphic and geologic literature. Rosgen has established a useful working definition that helps define the relative degree of entrenchment. Rosgen defines entrenchment ratio as the width of the flood-prone area at an elevation twice the maximum bankfull depth, divided by the bankfull width (flood-prone width/bankfull width). Based on Rosgen's database, a total depth equal to twice the maximum bankfull depth constituted a major flood with an approximate recurrence interval of 50 years. Some stream professionals question the validity of this hypothesis. Rosgen defines the total width at two times the maximum bankfull depth as the flood-prone width. Regions outside of the area covered by the database may vary significantly from the flood-prone width/bankfull width relationship established by Rosgen. The procedures for making the necessary field measurements are listed in Rosgen (1996). This reference emphasizes the importance of an accurate determination of the bankfull elevation, since entrenchment ratio and several other parameters are directly related to the bankfull elevation. Important issues and concerns regarding the identification of bankfull indices is addressed in NEH654.05.

The concept of entrenchment ratio is an empirical relationship. Although Rosgen's database includes information from locations across the United States and Canada, some concern remains that this relationship needs to be evaluated on a national basis and that some regional modifications may be appropriate. The current version of Rosgen's Classification of Natural Rivers is presented in hierarchal form in the book, Applied River Morphology. The determinations of six hierarchal parameters are required to make a complete level II classification of a stream reach.

1. Number of channels—On the surface, this appears to be a simple determination that could be made from field observation or the use of current photographs and maps. However, by definition, there must be three active channels at the bankfull elevation to be considered a multiple-thread channel. Therefore, a bankfull determination is required to verify that there are actually three or more active channels at the bankfull stage. Multiple active channels (three or more), where they are verified to exist, identify the stream reach as either a D or DA classification. All other channels are considered to be single-thread channels.

2. Entrenchment ratio is defined as the width at an elevation twice the maximum bankfull depth divided by the bankfull width. The importance of an accurate determination of the bankfull elevation as it applies to this and other parameters has been described previously. Concerns have been expressed that regional variations in this parameter may be required. Geology, slope, vegetation, and other factors may also influence this parameter.

3. Width-to-depth ratio is defined as the width measured at the bankfull elevation divided by the mean depth of the bankfull channel. The magnitude of the parameter depends on an accurate determination of the bankfull elevation.

4. Sinuosity is defined as the ratio of stream length at the bankfull stage to valley length. Sinuosity can best be measured in the field, but it is a time-consuming measurement. Streams with smaller channels and with extensive canopy cover will likely require field measurements to obtain the needed accuracy. For larger streams and streams with limited canopy cover, sinuosity can also be successfully measured using alternative sources such as recent aerial photography with sufficient resolution. A scale of 1/660 (8 in/mi) is preferred; however, a scale of 1/1,320 (4 in/mi) usually gives acceptable precision for larger open-canopy stream channels. Sinuosity can be measured off USGS 7 1/2-minute quadrangle sheets, but this is not suitable for a level II classification. The scale of the 7 1/2-minute quadrangle sheets (2.64 in/mi or 1 in = 2,000 ft), the age of the quadrangle photo base, and the limited detail used in defining the stream channel on the quadrangle are all concerns that limit the utility of using USGS quadrangle sheets for determining level II sinuosity.

   At this point, a level II basic classification, A through E, of the stream reach can be obtained. The difference between the levels I and II classification is that the criteria have been validated with actual field measurements. In actual practice, level II classification is rarely terminated at this point. The remaining delineation criteria for a complete level II classification are:

5. Channel material is a determination of the surface particles that make up both the bed and bank material within the bankfull channel. The Rosgen classification procedure uses a modified version of the Wolman (1954) pebble count procedure for the determination of surface particle sizes. A number of cross sections selected to represent the distribution of pools and riffles within the reach to be classified are sampled using the pebble count procedure. Although the parameter being defined is channel bed material, each cross section is surveyed using equally spaced stations up to the bankfull elevation. Since each data point is counted equally in the process, the procedure is normally heavily weighted toward channel bed material, especially on wide shallow channels. For specific details on making a modified Wolman pebble count, refer to Rosgen (1996). Although exceptions are noted for bimodal particle size distributions, generally the $D_{50}$ particle size determined from the modified Wolman pebble count procedure is used to classify the channel bed and bank materials up to the bankfull elevation. Rosgen's first channel material class based on a field determination is bedrock. The five remaining material classes are based on the $D_{50}$ particle size of the streambed and bank material up to the bankfull stage as determined

from pebble count information. The six Rosgen material classes, including bedrock are:

- bedrock
- boulder—greater than 256 millimeters (10 in)
- cobble—64 to 256 millimeters (2.5 to 10 in)
- gravel—2 to 64 millimeters (0.08 to 2.5 in)
- sand—0.062 to 2.0 millimeters
- silt/clay—less than 0.062 millimeters

The channel material makes up the left-hand side of the Rosgen classification matrix. Pebble counts are more appropriate for boulder, cobble, and gravel bedded streams. Other protocols may need to be developed for sampling fine-grained bed and bank material (sand, silt, and clay).

Classification of sediment into particle-size classes is arbitrary, with class breaks frequently based upon standard sieve sizes. It should be pointed out that the class size breaks and most of the descriptive terms used by Rosgen were derived from the Udden-Wentworth classification system used by geologists (Wentworth 1922). This system employs different size breaks and some differing terminology from the particle size classification systems used by NRCS engineers (Unified Soil Classification System, American Society for Testing and Materials International (ASTM) D2487) or NRCS soil scientists (USDA soil texture classification system).

6. Slope is the local slope of the bankfull water surface within the reach that is being classified. Water surface slope is typically measured over a length equivalent to 20 bankfull channel widths or a minimum of two meander wavelengths. For applications in level II or higher, measurements of the actual water surface on both pool and riffle sections is also a requirement. Ephemeral streams may require the use of computed water surface profiles with sufficient cross section data to define the pool-riffle sequence.

The field determination of the bed material as defined provides the criteria to make a complete level II determination such as A3, which is an A channel with cobble bed material. If the slope of the local water surface profile is outside of the normal slope range for an A3 channel (0.040–0.099), the channel can be further described based on a slope subscript. An example would be an A3a+ which describes an A channel with cobble bed material on a slope greater than 10 percent. Some channel types such as B and C channels may have slope variations that are greater than normal (+) or less than normal (–).

### Level III and IV assessments

Levels I and II are the levels of classification that characterize and describe stream types. Although detailed descriptions of levels III assessment and IV validation are not included here, it is useful to understand their scope. Levels I and II are a classification of the current status of the stream reach based on two distinct levels of data acquisition. Level III assessment is used to evaluate stream condition and its departure from the optimum or potential condition. Level III data are necessary to quantify numerous parameters (sediment load, bedload, bank erosion) that more clearly define trends and expected long-term changes in the current stream status. Level III data are critical as a basis for restoration designs and installation. Level IV is the validation level where the parameters of stream function are monitored over time to either validate a stream's status or the success of a restoration activity.

### Management interpretations

Rosgen (1996) provides examples of how stream classification can be related to numerous NRCS activities. Stream type can be related to expected impacts due to disturbance, recovery potential, sediment supply, streambank erosion potential, and the potential for vegetation to control the dominant channel influence. Rosgen's database may not be completely representative of all regions of the country, and all final decisions should be supported by a field assessment. This method requires field data that represent local stream morphology.

### Strengths

The Rosgen classification system is currently the most widely used of the four systems addressed in this document. While initially applied regionally, the method has been used nationally and internationally. Levels I and II stream classifications have found acceptance among a variety of disciplines. The greatest value of

Rosgen's classification system is in the establishment of a common language for communication among the associated stream disciplines. For example, a geologist in Alaska can talk to a biologist in Florida regarding a (C5) stream type and both will have a common frame of reference.

Rosgen's procedures go beyond levels I and II stream classifications. They are linked to design procedures and criteria for a wide range of stream restoration activities. Rosgen's levels III and IV procedures appeal to disciplines that do not have professional backgrounds in stream mechanics and geomorphology, but have a strong desire to do a better job in stream restoration activities. This may be considered as a strength or weakness depending on the competence of the individual(s) using the procedures.

**Weaknesses**

Combining silt/clay as a similar channel material is inconsistent with the general erosion, stability, and structural integrity characteristics of the two materials. Additional data on silt and clay channels from across the country may resolve this issue. The type B stream classification has been criticized as a catch all category. It represents the only stream type between slightly entrenched and entrenched. It also covers the largest slope range of any of the stream types with a slope range from <0.020 to 0.099. Additional data may warrant additional breakdown of the B stream type.

Other weaknesses are the lack of an upper limit on the width-to-depth ratio for C stream types, and the requirement of three active channels at bankfull for the classification of D stream types.

Levels I and II classifications describe the current condition of the stream reach, but does not address time variability issues such as the rate of entrenchment or rate of lateral migration. A number of time variability issues such as rates of aggradation or degradation and lateral migration are addressed in level III assessment and level IV validation.

Beyond levels I and II stream classifications, there is an often-expressed concern among geomorphologists and stream mechanics engineers that the overly enthusiastic novice in stream restoration may attempt projects that are beyond their technical capabilities. There may be a tendency by well-meaning users to overlook the need for interdisciplinary input. Another concern is that a stepwise procedure may mask the ability of an inexperienced user to fully understand the interrelationship between the watershed and channel processes.

Although Rosgen (1994, 1996) empirically derived boundary values for geomorphic predictors in his classification system, users should be aware that local calibration is very important to determine a tighter range of values more applicable to a given geographic area. Local calibration is even more important if a significant number of projects using the system are planned, or many streams in a project fall on the cusp of classification boundaries. Further, local calibration may highlight elements of the Rosgen classification system as better, more geomorphically significant descriptors of local stream systems than others.

Detailed information concerning the application of the Rosgen stream classification technique is provided in NEH654 TS3E. Design guidance is included in NEH654.11.

## 654.0306 Conclusion

This chapter briefly summarized procedures for watershed assessments and site investigations. Stream system inventory and assessment techniques were identified and compared. Information was provided on stream stability, as well as geological and biological assessments. The uses, advantages, and disadvantages of various geomorphic stream classification systems were also described. This chapter addressed fluvial processes and broader geologic issues related to ecological function, as well as stream design and behavior.