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A Framework and Strategies for Determining Reference Conditions for Streams with Legacy Sediments on Military Installations

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March 2009



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Final Report

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Prepared for SERDP Program Office
901 N. Stuart St., Suite 303
Arlington, VA 22203

Under Work Unit SI-1114

Abstract: The Army accomplishes its mission, in part, by training forces at military installations to conduct combat operations on land. It also is charged with meeting requirements of the United States Clean Water Act on those lands. To assist the Army, the U.S. Army Engineer Research and Development Center–Construction Engineering Research Laboratory develops tools to: address the priorities the military mission priorities, meet the requirements of environmental legislation, and support the stewardship of land resources. A critical issue is establishing appropriate baseline reference conditions for evaluating activities involving water resources. This study addresses that issue by developing a framework and strategies for determining reference conditions for streams on military installations with legacy sediments (pollutants which were generated by land uses prior to Army occupancy). Subsequently, a weight of evidence approach is recommended for determining the reference condition for streams with legacy sediments. This includes using a variety of strategies to define reference stream water quality and biotic integrity, plus flow and sediment regime. The resulting framework was successfully applied to Fort Benning, Georgia. With additional data, using a weight of evidence approach with these strategies should permit reference conditions to be determined for other streams with legacy sediments.

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Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under SERDP Work Unit SI-1114, “SERDP Ecosystem Management Program (SEMP)” by FTN Associates, Ltd. The USACERL point of contact was Dr. Harold Balbach. The technical monitor at the time was Dr. John A. Hall, Program Manager and the Executive Director of SERDP was Bradley P. Smith.

The work was completed under the direction of the Ecological Process Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator and contract monitor was Dr. Harold Balbach. This report was prepared by Kent Thornton, PhD, and Patrick Downey, FTN Associates, Ltd. (FTN) under contract W9132T-07-P-0074. Editorial review was provided by Christina Laurin, FTN. The authors thank Hugh Westbury, SERDP Ecosystem Management Project (SEMP) Site Coordinator at Fort Benning, GA, for his time, knowledge, and support during our site visit. The authors also thank Mr. Lee Mulkey, SEMP Director for his support and discussions during this project. The associated Technical Director was Dr. William D. Severinghaus. The Deputy Director of CERL is Dr. Kirankumar V. To-pudurti and the Director is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

1.1 Background

The Army's mission is to fight and win our nation's wars by providing prompt, sustained land dominance across the full range of military operations and spectrum of conflict in support of combatant commanders. The Army does this by executing the directives in Title 10 and Title 32 of the United States (U.S.) Code, which include organizing, equipping, and training forces for the conduct of prompt and sustained combat operations on land (www.army.mil/institution/organization). Per 33 US Code Sec. 1251-1387, the Army is also charged with meeting environmental regulations of the U.S. Clean Water Act (CWA) on their installations.

It is this nexus of training military forces on installation lands and meeting environmental regulations on these lands that underlies the following land management research goals of the U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory Installations Division (CERL):

1. Developing and improving planning and management tools and procedures that enable land managers to address the priorities of the military mission
2. Meeting the requirements of environmental legislation, and supporting the stewardship of natural and cultural resources on military lands.

A critical issue for much of the research related to land and water management on military installations is establishing an appropriate reference condition (benchmark or baseline) for management activities. In order to develop realistic performance measures for such activities, there must be a realistic reference against which to compare the effectiveness of management activities and the impacts of military activities.

Establishing this benchmark is particularly difficult for streams impaired by legacy pollutants with natural origins (e.g., sediment, nutrients, and heavy metals) or those arising from historical land use and management. Establishing background and reference conditions is critical not only for establishing appropriate standards for assessing water quality attainment, Total Maximum Daily Load (TMDL)* reductions and subsequent restora-

* Total amount of sediment the stream is allowed to carry without exceeding water quality standards.

tion efforts, but also in determining appropriate land management practices to protect stream ecosystems, particularly for streams affected by legacy sediments.

The goal of this project was to develop a strategic approach for establishing reference conditions for streams on military installations affected by legacy sediments and sedimentation.

1.2 Objectives

Specific objectives for this research project included:

1. Develop a conceptual framework for establishing reference conditions for streams affected by legacy sedimentation and selected other natural pollutants
2. Evaluate current approaches for establishing reference conditions
3. Develop a strategic approach for establishing reference conditions for streams affected by legacy sediments
4. Conduct a preliminary evaluation of the approach, using information from streams on a military installation as a proof of concept.

1.3 Approach

This report provides a strategic approach for establishing reference conditions for streams on military installations affected by legacy sediments and sedimentation. The next chapter presents and discusses the elements of a conceptual framework, and provides a context for determining reference conditions on military installations. These elements include the installation management objectives, existing uses, watershed-stream system, the reference condition for streams with legacy sediments and sedimentation, and attainable uses. The third chapter discusses various strategies for defining or determining a dynamic, stable stream system as the reference for streams with legacy sediments. The fourth chapter evaluates information from the Fort Benning military installation and its stream network, to illustrate how these strategies might be implemented. References cited are included in the final section.

1.4 Scope

1. Environmental reference conditions are those environmental states that describe or are established as the standard for comparison.

2. Legacy sediments are those sediments that remain, and will remain, from previous land use activities that must be considered in future management/restoration practices.
3. This report provides strategic approaches for establishing reference conditions for streams with legacy sediments and sedimentation on military installations.

1.5 Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL: <http://www.cecer.army.mil>

2 Conceptual Framework and Context for Determining Reference Conditions for Streams with Legacy Sediments

2.1 Overview

A conceptual framework that integrates reference conditions for streams with legacy sediments, within the context of environmental management on military installations, is shown as a schematic in Figure 1. The steps in the framework are:

1. Identify management objectives
2. Assess existing uses of the watershed-stream system
3. Understand historical and current conditions within the watershed-stream system; establish the reference condition as a dynamic, stable (resilient) stream system
4. Determine attainable uses for the watershed and its stream

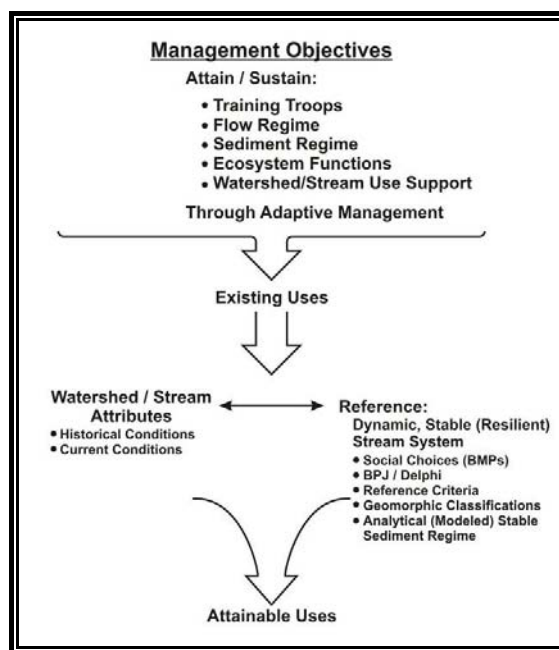


Figure 1. A framework and strategies for determining reference conditions for streams with legacy sediments on military installations.

A more detailed discussion follows for each step in the framework.

2.2 Reference conditions

By definition, a reference describes or establishes a standard. Environmental reference conditions are those environmental states that describe, or are established, as the standard for comparison. Reference conditions have been used for at least a century to determine the acceptable state of engineering and environmental practices and activities. For example, early in the 20th century, upstream sites were selected as a reference for assessing or measuring the effects of anthropogenic activities, primarily point source discharges, on downstream systems. In many cases, biological measurements (macrophytes, periphyton, benthic macroinvertebrates, fish) were included as part of the reference conditions and assessment process in rivers (Butcher 1933; Hynes 1958, 1966; Kolkwitz and Marsson 1908, 1909; Percival and Whitehead 1929).

The passage of the CWA mandated the establishment of Water Quality Standards (WQS), which became the reference for assessing the condition of water bodies throughout the U.S. Each WQS has three components: (1) the designated use(s) to be protected for the water body, (2) water quality criteria that will ensure the use is protected, and (3) an anti-degradation policy, to protect the water body from pollutants. In the early 1970's, these WQS were established primarily for specific physiochemical variables, such as biochemical oxygen demand (BOD), suspended solids, ammonia, total dissolved solids, and organic pesticides.

It became recognized that it was as important to control non-point source contributions to stream systems as point-source discharges for improving stream quality. With this recognition, came a shift in the emphasis for WQS, from individual physiochemical variables to biological criteria. Stream biota integrates the myriad physical, chemical, and biological variables and stressors in ecological systems and specifically relate to that portion of the CWA calling for the restoration and protection of biological integrity in waters of the United States (Cairns 1977; Karr 1981; Karr and Dudley 1981; Karr and Chu 2000). Over the past two decades, the U.S. Environmental Protection Agency (USEPA), individual states, and Native American tribes have been developing biological criteria to assess attainment of designated uses in U.S. waters (Barbour et al. 1999; Davis and Simon 1995; USEPA 1990; USEPA 1996). This has refocused attention on the definition of reference conditions. Various approaches have been proposed and used to establish reference conditions for stream ecosystems, such as upstream or nearby sites (Shields, Knight, and Cooper 1995), regional reference conditions (Hughes, Larsen, and Omernik, 1986), ecore-

gions (Omernik 1987), and percentiles of statistical distributions (USEPA 2000).

Various states and tribes have used different methods to establish biological criteria and associated reference conditions (Davies and Jackson 2006). Reviews of state- and tribal-level definitions and reference conditions have noted disparities and nuances (Freedman et al. 2003; Thornton, Downey, and Freedman 2003). For example, few individuals would think it appropriate to select a natural, cold-water brook trout stream in the mountains as the reference for a slow-moving, warm-water stream in the Piedmont of Georgia. The streams from these two areas naturally have very different characteristics, and could never have the same water quality or biota. Yet, some studies have considered forested stream conditions as the appropriate reference for assessing the condition of agricultural streams (Brooks et al. 2006), which are equally unlikely to have similar water quality or biota. These disparities and nuances over reference conditions led Stoddard et al. (2006) to develop a definition for reference conditions for biotic integrity and subsequent modifiers of this definition (Table 1).

Table 1. Definitions of reference conditions for biotic integrity (Stoddard et al. 2006).

Reference Condition	Definition
Historical conditions (HC)	Condition of streams at some point in their history as pre-human disturbance (pre-industrial)
Minimally disturbed condition (MDC)	Condition of streams in the absence of significant human disturbance
Least disturbed conditions (LDC)	Best available physical, chemical, and biological habitat conditions in today's landscape.
Best attainable conditions (BAC)	Expected conditions of LDC sites with best possible management practices. (Stoddard et al. 2006)

In making the definitions, Stoddard et al. (2006) explicitly reserved the use of the term, “reference condition for biotic integrity” to describe a stream’s condition in the absence of human disturbance. Because there are likely no sites in the United States that are completely free from human disturbance, the authors defined the following additional terms to reflect different levels of human disturbance:

- *historical*– condition of streams at some point in their history, such as pre-intensive agriculture or pre-settlement by European immigrants
- *minimally disturbed* – condition of streams in the absence of significant human disturbance

- *least-disturbed* – condition of streams with the best available, physical, chemical, and biological habitat conditions in the current state of the landscape
- *best-attainable* – condition of streams where best management practices have been fully implemented for some period of time

While these definitions are necessary, they are not sufficient to readily establish reference conditions for many streams. For example, what constitutes “significant” human disturbance? What are the “best attainable” physical, chemical, and biological habitat conditions on the landscape? What does “fully implemented best management practices” mean and how long is “some period of time”? In addition, what if legacy conditions exist in these streams? A legacy is “something resulting from and left behind by an action, event or person” (Lewis et al. 2006). Many sites, particularly on military installations, are affected by legacy pollutants such as sediment.

2.3 Management objectives

Nearly all planning and management activities begin with the vision and mission of the organization; from there, management establishes goals and/or objectives, and then, identifies strategies and associated tactics to achieve these goals and/or objectives (Drucker 1973). Identifying management’s objectives is a critical first step in the planning process (refer to Figure 1).

The first paragraph of this report stated that the Army has two major objectives for its installations: (1) training forces for the conduct of prompt and sustained combat operations on land, and (2) meeting environmental regulations of the U.S. CWA on Army installations.

While these can be competing objectives, they also can be complementary objectives. Military installations can have dynamic, stable (resilient) stream flow and sediment regimes that sustain ecosystem functions and support desired watershed and stream uses, including training troops. To do this, management objectives for the watershed and stream system need to be clearly articulated. SMART (specific, measurable, attainable, realistic, time-based) management objectives can improve the identification and determination of appropriate reference conditions, achieving attainable water uses through adaptive management.

2.4 Existing uses

Existing uses, as defined in 40 CFR 131 for water quality standards regulations, are those uses actually attained in the water body on or after 28 November 1975, whether or not they are included in the WQS.

Assessment of existing uses is necessary because:

1. The CWA requires that all existing uses be protected;
2. Existing uses are part of the historical legacy of the watershed-stream system.

Because many military installations are used for training purposes, one existing stream use is to support training exercises, including troops and equipment. Other, more conventional existing uses that could be applicable to an installation's streams include: aquatic life support, secondary contact recreation, primary contact recreation, drinking water, fish and wildlife support, shellfish support, and similar uses. Existing uses will vary by state and by military installation, but the existing uses need to be identified and documented.

2.5 Understanding historical and current conditions

H.B.N. Hynes (1975a) stated, "The valley rules the stream." The watershed is, and must be considered as, an integral part of the stream ecosystem. Relationships between watershed land use and stream quality, including spatial considerations within the watershed, have been well-documented for soil erosion and sedimentation, loss of riparian* vegetation, and nutrient and contaminant transport, and their effects on stream biota and ecosystems, (Allan, Erickson, and Fay 1997; Allan 2004; Bennett, Carpenter, and Caraco 2001; Berkman and Rabeni 1987; Burcher, Valett, and Benfield 2007; Carpenter et al. 1998; Houser, Mulholland, and Maloney 2005; Hynes 1975b; Hupp 1992; King et al. 2005; Omernik 1976; Rabeni and Smale 1995; Schields, Knight, and Cooper 1995).

Recently, the long-term effects of watershed land use also have been recognized. Stream condition reflects not only the effects of current stressors, but also retains the signature from historical watershed land use activities.

* A **riparian** zone or area is the interface between land and a stream. Plant communities along these margins are called riparian vegetation. Riparian zones occur in many forms including grassland, woodland, wetland, or even non-vegetative.

The legacy of historical watershed land use has been referred to as “the ghost of land use past” (Harding et al. 1998). The authors found that some forested watershed streams with forested riparian zones in North Carolina had benthic* and fish assemblages that reflected agricultural land use. In the 1940’s, these streams were in agricultural watersheds with no forested riparian zones. Fifty years after reforestation, these streams showed little effective recovery of stream fauna to pre-agricultural conditions.

Past land use activity, particularly agriculture, can result in long-term modifications to, and reduction in, stream aquatic diversity, regardless of the current condition (reforestation) of riparian zones. Foster et al. (2003) reviewed the land use history of the National Science Foundation’s Long-Term Ecological Research terrestrial sites and also found that the legacies of land-use activities continued to influence ecosystem structure and function for decades or centuries (or perhaps longer) after those activities had ceased. Data provided by these authors suggested that recovery requires decades, not years.

Other studies also found that conversion of forest to agricultural land use can result in significant loss of soil carbon and nitrogen that can take decades to a century to replenish following abandonment of agriculture use (Knops and Tilman 2000; Murty et al. 2002). These examples indicate that historical land use, in addition to contemporary uses, can influence or dominate stream ecosystem conditions. Whenever this is the case, expectations of stream recovery following implementation of instream, riparian, and watershed management practices might not be realized unless historical influences are considered. In these instances, land use history can both influence the selection of appropriate stream reference condition, and determine the attainable stream condition.

The stream, then, reflects both the historical and the current mosaic of land use/land cover patterns that exist on the landscape. Because a river changes constantly as it moves downstream, it is a continuum of different ecological structure, function, processes, and forms from headwater to the mouth of the watershed (Vannote et al. 1980). In their 1964 work, Leopold et al. first expressed this continuum for a stream’s physical behavior. The authors saw that a river’s width, depth, velocity and temperature changed constantly as water flowed downstream, and that those changes were interrelated and predictable. The Vannote work then added to this concept,

* The **benthic zone** is the ecological region at the lowest level of a body of water, including the sediment surface and some sub-surface layers. Organisms living in this zone are called benthos.

by arguing that a river's biological and chemical processes correspond to its physical attributes, and that the structure of biological communities changes in a downstream direction as the biological communities adapt to the particular conditions of a stretch of stream.

A stream is not a static body of water, but rather a dynamic, evolving system. Any stream attribute (such as stability), at any point along the stream, is influenced by processes occurring both upstream and in the watershed. The continuum, however, is not simply a smooth, gradual change downstream. Watershed and stream disturbances (both natural and anthropogenic), create habitat patches and heterogeneity, discontinuities in space and time (Benda 2004; Montgomery 1999; Perry and Schaeffer 1987; Townsend 1989, 1996). The spatial variability in geomorphic processes influences or controls stream habitat and disturbance regimes that influence stream ecosystem structure and dynamics (Benda 2004; Montgomery 1999; Ward et al. 2002).

Although water flows downhill, recent studies have indicated that downstream conditions can affect upstream conditions. Knickpoints* in streams or other grade instabilities can lead to head cutting, where the instabilities in the sediment transport regime downstream can result in increased scour or aggradation of sediment upstream (Rosgen 1996; Schumm, Harvey, and Watson 1984; Shields, Knight, and Cooper 1995, 2007; Simon 1989). These interconnections along the stream continuum are not just physical, but also biological (Pringle 1997, 2001). It is not just the stream reach, but rather the entire stream system, that needs to be considered in establishing reference conditions.

Both historical and current watershed and stream conditions need to be determined for military installations. Many military installations are located in watersheds that have a long history of disturbance, and not solely from military activities. Forest clear-cutting, agricultural, mining, and other land use practices† created disturbance signatures that can still be seen today, both in the watershed and in the streams. In the buildup of facilities for both World War I and World War II, the least-expensive tracts of land were intentionally selected for purchase, often for only a few cents an acre. Those lands were usually also the ones that had been the most abused previously, and had often been abandoned as worthless prior to

* A knickpoint is a geomorphology term used to describe a location in a channel of water where there is a sharp change in channel slope, such as a waterfall or lake, resulting from differential rates of erosion above and below the knickpoint.

† From 1820 through 1940 in the case of Fort Benning, the southeastern installation of interest here.

their acquisition to support the Army's training needs. Understanding the historical changes that have occurred in the watershed and streams can help shape realistic expectations for stream quality. It is likely there are few minimally disturbed streams on any military installations.

Current upstream disturbance patterns (e.g., agriculture, urbanization) determine the characteristics of streams entering the installation from watershed areas that are not within military control. In addition, downstream activities (e.g., dams, low head weirs, dredging, channelization), can also affect streams on military installations, as the effects of these activities migrate upstream. The context for reference conditions, therefore, is the entire stream system.

2.6 The reference condition – A dynamic stable stream system

The reference condition for streams with legacy sediments is a dynamic, stable or resilient stream system (Figure 1). Resilience, or the ability to return to a desired state following disturbance or perturbation, is described for environmental, social, and economic systems by Gunderson and Holling (2002). This is a total system concept of stability in the sense of practical Lagrange stability (LaSalle and Lefschetz 1961; Thornton and Mulholland 1974). Practical Lagrange stability implies the system is dynamic and moves in space and time, but remains within desired bounds or within an envelope of desired conditions. Because both downstream and upstream reaches can be affected by watershed and in-stream disturbances within any given reach, it is important to consider the entire stream system, not just individual reaches

The geomorphic concept of stable streams was described by Mackin (1948) as a stream whose slope has adjusted over time, with available discharge and the prevailing channel characteristics, to provide the velocity to transport the load from the drainage basin. To Leopold (1994), a stable stream refers to a stream moving toward a statistically probable natural state through the distribution of conservation of energy and energy expenditure. Rosgen (1996) builds upon Leopold's definition, to state that stream stability is morphologically defined as the ability of the stream to maintain (over time) its dimensions, patterns, and profile so that it is neither aggrading nor degrading, and it is able to transport flow and sediment from its watershed.

A stable sediment regime does not mean the stream channel is static. Streams are dynamic and naturally meander within their floodplains. A

stable sediment regime implies the stream does not have net erosion or aggradation within the stream system (Leopold 1994). Because of legacy sediments, many stream systems have altered flow and sediment regimes, which can be stable, but current conditions do not represent historical conditions. The dynamic, stable stream system is the reference for streams with legacy sediments.

Just as the stream continuum (Vannote et al. 1980) is built on the foundation of a stable stream flow and sediment regime (Leopold, Wolman, and Miller 1964), reference conditions for streams with legacy sediments build on the foundation of a stable, resilient, stream system. The next chapter discusses strategies and methods for determining or defining a stable stream system with legacy sediments.

2.7 Attainable uses

The existing uses were identified as one of the first steps in the framework (Figure 1). In addition to existing uses, states and tribes have also designated uses for water bodies. Designated uses are those uses specified in water quality standards for each body or segment, whether or not those uses are being attained (40 CFR 131). These designated uses are not standardized across the United States, nor do all streams necessarily have the same designated uses within a state, so each military installation will need to determine the designated uses for the streams on their installation.

Designated uses might include drinking water, primary contact recreation, warm-water or cold-water fishery, extraordinary resource waters, or scenic waters. The water quality criteria applicable to water bodies vary, depending on the designated use of the water bodies. For example, the dissolved oxygen (DO) criterion for use as a cold-water fishery might be 7 mg/L while the DO criterion for a warm-water fishery might be 4 mg/L.

In some instances, the designated uses cannot reasonably be attained, or cannot be attained for decades or more. They may represent an ultimate goal rather than anything foreseeable by the present generation. The analyses used to establish the reference conditions for streams with legacy sediments can provide insight into attainable uses for the streams. The CWA has provisions for changing a designated use that cannot be attained. This procedure is called a “use attainability analysis,” which is defined as a structured scientific assessment of the factors affecting the attainment of the use, which may include physical (i.e., sediment), chemical, biological, and economic factors as described in Sec. 131.10(g) (40 CFR 131).

2.8 Summary

A conceptual framework is proposed that provides context for determining reference conditions for streams with legacy sediments. This framework includes:

- identifying management objectives
- assessing existing uses of the watershed stream system
- understanding the historical and current conditions within the watershed-stream system
- establishing the reference condition as a dynamic, stable (resilient) stream system
- evaluating reference conditions in the context of designated use category
- determining the reasonably attainable uses for the watershed and its streams

3 Strategies for Determining Reference Conditions

A crucial aspect of the framework presented in Chapter 2 is determining what constitutes a stable stream system. There are a number of strategies for identifying reference conditions that might be useful for determining characteristics of a stable stream system influenced by legacy sediments on military installations (Table 2).

Table 2. Strategies for determining reference conditions.

Reference Condition Approach	Description
Best Professional Judgment (BPJ)	Reference sites are selected by knowledgeable individuals to represent least/minimally disturbed or best attainable conditions based on professional judgment and experience.
Historical Reconstruction	Reference conditions are reconstructed based on historical records, paleodendrochronology or paleolimnological analyses, or similar methods.
Statistical Distributions	Reference conditions represent a specific percentile threshold from cumulative frequency distributions of biogeochemical metrics, indices, or constituent values.
Reference Criteria	The <i>a priori</i> criteria or standards are specified to represent reference conditions. These standards can represent either a goal to attain or departure from existing conditions.
Social Choice Context	Land use patterns are used to reflect the cumulative social choices made for land management with the reference condition reflects these social choices.
Delphi (Expert) Elicitation	Similar to BPJ, but the reference condition reflects the cumulative knowledge and consensus from multiple experts.
Geomorphic Stream Classification	Reference conditions based on an underlying conceptual model(s), are determined through analyses of the geomorphic stream system.
Analytical (Modeled) Reference Condition	Reference conditions, are based on the use of empirical or dynamic models to represent attainable conditions under various management regimes.

Some of these strategies are appropriate for determining reference hydrologic and geomorphic characteristics of stable stream systems, while others are appropriate for determining reference water quality or biotic characteristics of stable stream systems. It is necessary to identify reference conditions for physical, chemical, and biological aspects of the stream system to effectively manage streams with legacy sediments on military installations.

The strategies listed in Table 2 are described in greater detail in the following sections. Not all of these strategies are appropriate for determining reference conditions for streams with legacy sediments. The discussions of the strategies include information on the appropriateness of the strategies for determining reference conditions for streams affected by legacy sediment or sedimentation.

3.1 Best professional judgment

Best professional judgment (BPJ) has been used historically and extensively to establish reference conditions, and is an acknowledged and accepted approach (USEPA 1996, 2000). In this approach, individuals who have spent their careers studying and understanding stream ecosystems select those streams that, in their BPJ, represent minimally or least disturbed streams in the watershed or region, or that represent the best attainable stream conditions as a function of implementing a suite of watershed management practices.

These individuals also can use BPJ to identify the criteria for characterizing minimally/least disturbed streams or best attainable stream conditions. In this approach, the reference streams are those streams satisfying these criteria (Klemm et al. 2003). To further support the use of BPJ, Waite et al. (2000) found that results of BPJ-based assessments were comparable to those using *a priori* screening criteria.

Because BPJ is based on the experience of the investigator, BPJ may not always identify the complete set of reference streams that are minimally or least disturbed, or exhibit best attainable conditions. For example, the use of a probabilistic monitoring frame to select and sample streams within the Mid-Atlantic region identified streams of higher quality than those selected through BPJ (Herlihy et al. 2000). Typically this disparity occurs when streams are in remote locations of the region that are not easily accessible for sampling, and, therefore, outside the range of experience for most investigators.

BPJ is a strategy that should be considered in determining reference conditions for streams with legacy sediments.

3.2 Historical reconstruction

One of the categories used in Tiered Aquatic Life Uses (TALU) classification is historical condition. Stoddard et al. (2006) provides a definition for

historical condition as a reference, but with this caveat — that almost every ecosystem has experienced some disturbance, and that a return to historical condition is unlikely. However, paleo-reconstructions of stream condition have been conducted to determine natural flow (St. George and Nielsen 2002; Scott, Friedman, and Auble 1996), sedimentation (O'Connor, Jones, and Haluska 2003), temperature regimes (Joynt and Wolfe 2001), and similar historical conditions. Anecdotal information also is available for some stream systems, which can help to provide insight into historical stream conditions.

Historical conditions for the TALU classification have been used, and are being used, by some states to provide a frame of reference for the extent of change that has occurred in stream condition (Davies and Jackson 2006). Historical reconstructions can be used to better characterize the range of conditions that previously existed within a stream system, and possibly, to understand functional relationships and interconnections that existed within and between the watershed and the stream systems. Some states have incorporated historical conditions for this purpose (State of Maine 2003). Reviewing historical information to identify possible causes of legacy sediments, as discussed above, is useful.

However, establishing historical reference conditions for streams with legacy sediments is not recommended, for these reasons:

1. Historical conditions no longer exist to be identified and utilized.
2. The watershed-stream system has shifted to an alternate condition.
3. It is not economically or ecologically feasible to restore ecosystems to pre-industrial or pre-European settlement conditions.

3.3 Statistical distributions

Statistical distributions of biogeochemical indices, metrics, or constituent values can be constructed, and used to provide a reference for least disturbed conditions (LDC) (Figure 2, Stoddard et al. 2006). In its guidance for establishing nutrient criteria for water bodies (including streams), USEPA (2000) suggested using the 5th or 25th percentile value of existing nutrient concentrations (in a regional population) as the criterion for determining those water bodies that have acceptable versus unacceptable nutrient concentrations. As Stoddard et al. (2006) noted, “Obvious limitations of this approach are that: (1) It requires an *a priori* decision about what proportion of the regional population is considered to be in LDC (Are 5 percent of streams in acceptable condition [leading to use of the 5th per-

centile value] or is 25 percent a more reasonable value?); (2) It assumes that higher index scores represent better conditions, rather than just different environments (e.g., smaller vs. larger streams); and (3) It is dependent on the distribution of sites sampled relative to the range of the indicator. ”

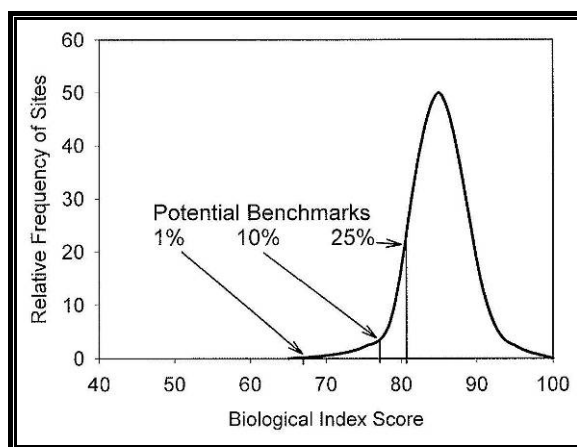


Figure 2. Using statistical distribution to define reference conditions (Stoddard et al. 2006).

A similar approach has been used to establish a criterion for a population of reference sites, where the threshold represents either the 75th or 95th percentile of the distribution. The same concerns raised by Stoddard et al. (2006) apply.

This method is not recommended for establishing reference conditions for streams with legacy sediments, because of the concerns raised by Stoddard et al. (2006)

3.4 Reference criteria

Palmer et al. (2005) proposed a reference for assessing successful river restoration projects in the form of five general restoration standards or criteria. This approach of establishing criteria was reviewed and supported by Gillian et al. (2005) and Jansson et al. (2005), although Jansson added a sixth criterion: a conceptual model of the underlying mechanisms by which the target would be achieved. Palmer also indicated these criteria can be used either to establish a desired target or goal, or to indicate desired improvement over the existing condition. These criteria, therefore, might be corollaries either for least disturbed reference (desired target) or best attainable reference (improvement over existing conditions).

Reference criteria can be established, once the historical and current watershed and stream conditions are known and understood, to provide targets for watershed management and stream restoration. One or more numeric criteria for each of the Palmer group's general criteria can be developed for specific military installations and watersheds. These criteria can represent either an upper bound to be attained or an acceptable improvement over existing or current conditions. Best professional judgment (see section 3.1) and a Delphi Approach (section 3.1) can be used to develop these numeric criteria. The Delphi approach is a formal, structured, multiple-expert extension of BPJ that can also provide estimates of the consensus or disagreement among experts on an appropriate stream system reference frame and criteria (see Section 3.6).

This strategy is recommended for streams with legacy sediments.

3.5 Social choice context

As part of a study to integrate ecological and socioeconomic indicators for estuaries and watersheds of the Atlantic slope, Brooks et al. (2006) developed a concept for reference condition based on a social choice context. One of the premises guiding the project was that humans are part of, not apart from, aquatic ecosystems and their watersheds. Individuals make choices concerning the use of their private property based on socioeconomic factors as well as environmental factors. In any given area (e.g., community, watershed, ecoregion, region), these collective decisions result in characteristic patterns of land use. These patterns also vary across space and time. Brooks et al. (2006) found that there was no single, optimal management solution with universal applicability throughout the Mid-Atlantic region. While there was no "best" landscape pattern for any given watershed, there were identifiable landscape patterns that were associated with non-attainment of designated uses for aquatic ecosystems (Wardop et al. 2007).

To define and determine realistic reference conditions for streams and their watersheds requires insight into not just environmental, but also socioeconomic and cultural factors in the watershed (Thornton and Laurin 2005). In many studies, reference conditions have been defined as systems without human intervention, but this disregards the fact that humans are part of the ecosystem. The socioeconomic context is part of defining reference conditions, particularly on military installations where training is an integral part of watershed activities. A social choice context does not mean that disturbance regimes cannot be reduced. It does mean that un-

derstanding the underlying socioeconomic factors and rationale can provide dual insight into approaches for identifying acceptable management practices and into attainable uses for the watershed-stream system.

3.6 Delphi technique and expert elicitation

Expert elicitation, structured around a panel of experts, represents a collective approach to BPJ. When developing the Biological Condition Gradient Model, Davies and Jackson (2006) used 10 ecological attributes to characterize the change in response of aquatic ecosystems to increasing levels of human disturbance. Their gradient of biological change was divided into six tiers that ranged from natural and native condition in Tier 1 and minimal changes in Tier 2, to severe changes in the biotic community structure in Tier 6. To evaluate the consistency with which different macroinvertebrate or fish sample metrics were assigned to these tiers, a regionally diverse group of biologists was asked to assign a set of sample metrics to the six tiers. The 33 macroinvertebrate biologists and 11 fishery biologists concurred in 81 percent and 75 percent of 54 tier assignments, respectively. The top tier corresponded to historical conditions, while the second tier corresponded with minimally disturbed conditions. Each of these tiers, then, combined with the 10 ecological attributes, served as a reference for the condition of aquatic ecosystems. Expert elicitation also was used by Reckhow et al. (2005) to develop and quantify designated use attainment nutrient criteria for several aquatic ecosystems (see further discussion under section 3.8).

The Delphi technique is a structured, systematic method for moving toward consensus among a panel of experts. The experts are asked to answer questionnaires in two or more rounds, based on a particular topic, such as criteria for stream reference conditions. Following each round of elicitation, an anonymous summary is prepared with the experts' answers for each question and the rationales behind the answers. The experts are offered the opportunity to revise their answers, based on the summarized replies and rationales. The group typically converges toward a set of criteria or responses within a few rounds. Delphi approaches have not been used extensively in water resources, but were used by Taylor and Ryder (2003) to address fisheries, water, and lake-level requirements for 25 reservoirs, as part of the dispute between Alabama, Florida, and Georgia on the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint (ACT/ACF) systems. Delphi approaches have also been used to address forest management issues, including watershed management (Angus et al.

2003; Geneletti 2005; Kangas et al. 1998; Kangas and Leskinen 2005; Morgan, Pitelka, and Shevliakova 2001).

Delphi and expert elicitation approaches are recommended to define reference conditions for watershed-stream systems with legacy sediments.

3.7 Geomorphic stream classification

Geomorphic stream classification approaches have been developed by Rosgen (1996, 1997), Simon (1989), and Schumm, Harvey, and Watson (1984). These classification approaches consider the stream reach within the context of the stream system (Figure 3).

The Watershed Assessment of River Stability & Sediment Supply (WARSSS) (www.epa.gov/warsss) was developed by Rosgen, based on his applied river morphology procedures for stream assessment (see Figure 4). This geomorphic classification system has four levels of assessment. Level I assessment provides a perspective of the entire watershed and stream network. In many instances, potentially stable and unstable stream reaches can be identified for further analysis during Level II and III assessments. Level IV assessment is verification of river stability and sediment supply assessments. In addition to WARSSS, Fischenich (2000) also provides guidance for preliminary watershed assessments.

Figure 4 shows that Level I geomorphic characterization considers basin relief, landforms, and valley morphology of the watershed. Analyses are conducted for valley and channel slope, channel shape (narrow, wide, deep, shallow, entrenchment ratio [width of flood prone-area/width of bankful channel]), and channel patterns (sinuosity, meander width ratio, single versus braided channels), to characterize both the stream system and stream types within the system (see Figure 5).

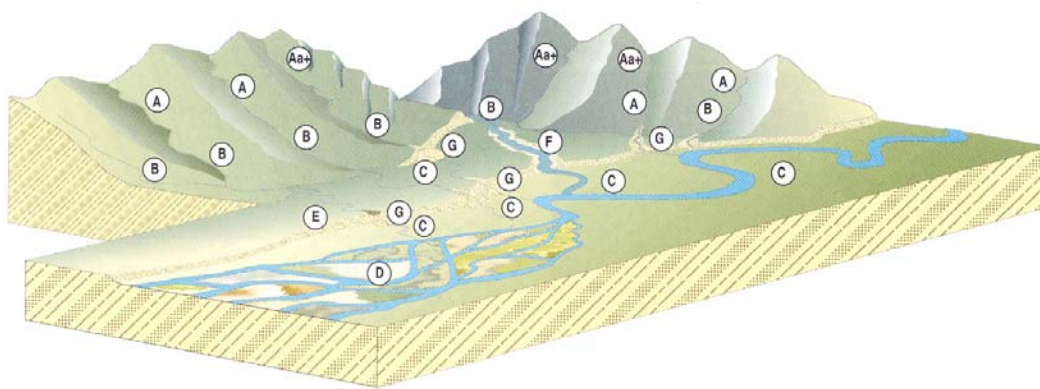


Figure 3. Geomorphic classification of the stream system (Source: USEPA)*

* Reproduced from Fig. 68, available at <http://www.epa.gov/warsss/rla/box09.htm>).

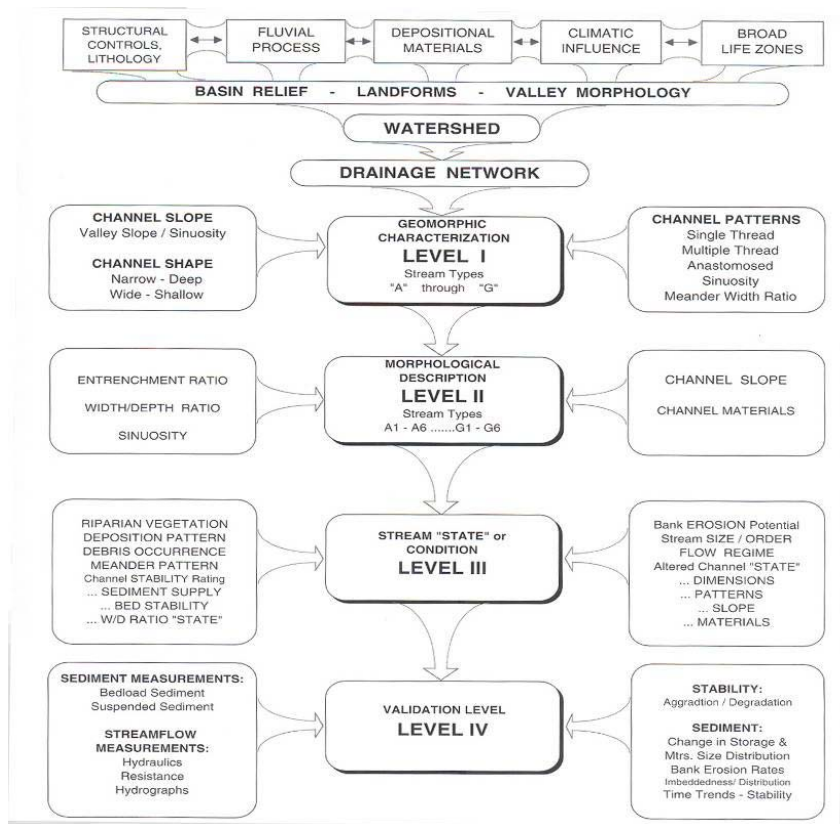


Figure 4. Framework for Rosgen stream classification and assessment of river stability and departure (Rosgen 1996).

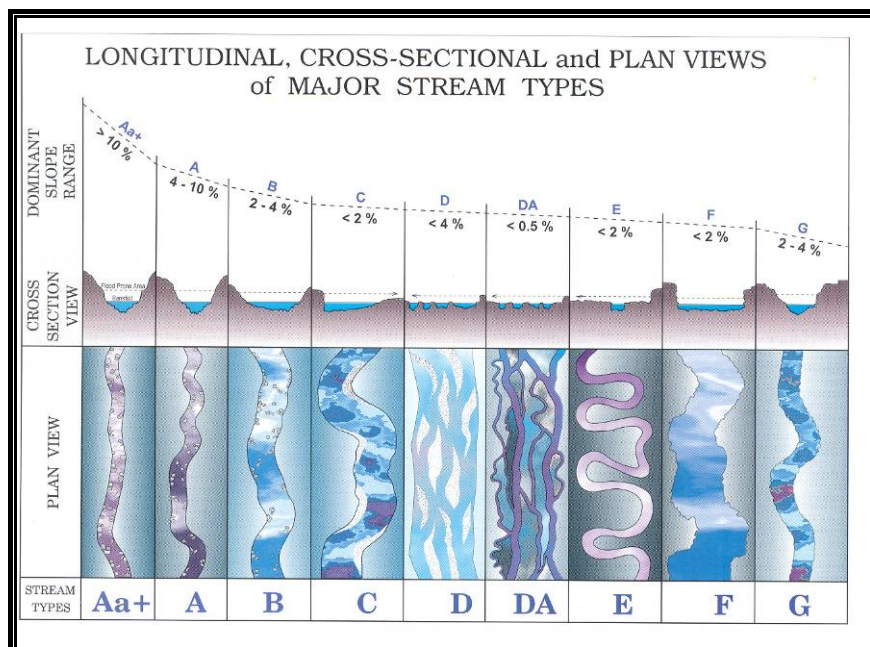


Figure 5. Level I classification of stream type (Source: USEPA*).
(See Appendix B for explanation of classification types.)

The Level II assessment focuses on a morphological description of the stream types within the watershed (Figure 4). The Level II assessment provides a more detailed analysis, based on field-collected data. Stream types are further delineated by channel cross-section, longitudinal profiles, and planform features. These features include parameters such as entrenchment ratio, width/depth ratios, dominant channel bed materials, water surface slope, bed features (e.g., riffle/pool ratios, step/pools, cascades), sinuosity, and meander width ratio. Such Level II analyses provide insight into “reference reaches” as well as unstable reaches.

The Level III assessment represents stream condition and stream departure analysis (Figure 4). Level III assessments provide information on stream stability, potential, and function. These analyses focus on riparian vegetation, flow regime, stream size and order, stream bank erosion potential, channel stability, deposition patterns, aggradation/degradation trends, altered channel features, and meander patterns. In addition, companion inventories can consider sediment budgets, nonpoint sources, cumulative watershed effects, hydraulic studies, aquatic/terrestrial habitat analysis, and fish viability evaluation. Level III analyses included analytical (modeled) evaluations of the sediment transport regime. These analyses consider sediment processes, sediment regime, and stability analyses, using a variety of approaches, including: suspended sediment transport rating (Glysson 1987; Simon 1998), unit stream power (Brookes 1990), sediment input (Thomas et al. 1995), hydrologic and channel stability analyses (Kondolf, Vorster, and Williams 1990), and sediment input/output analyses and potential impacts on downstream reaches (Shields et al. 2003). The importance of considering riparian vegetation and watershed characteristics, in addition to stream channel attributes, was illustrated in a restoration study conducted by Shields, Knight, and Cooper (2007). Level IV analyses are verification of river stability and sediment supply assessments. Kondolf (1995) provides a discussion of uses and limitations of geomorphic stream channel classification.

Following the Level III analyses, including stream stability analyses, those reaches that are stable and those that are unstable can be identified. “Reference reaches” may be based on stream reaches within the watershed or on first principle, conceptual models of stable reaches. Similar models are provided by Schumm, Harvey, and Watson (1984) and Simon (1989) (see Figure 6). A conceptual model of warm-water fish response to unstable and stable channels was developed by Schlosser (1987, Figure 7).

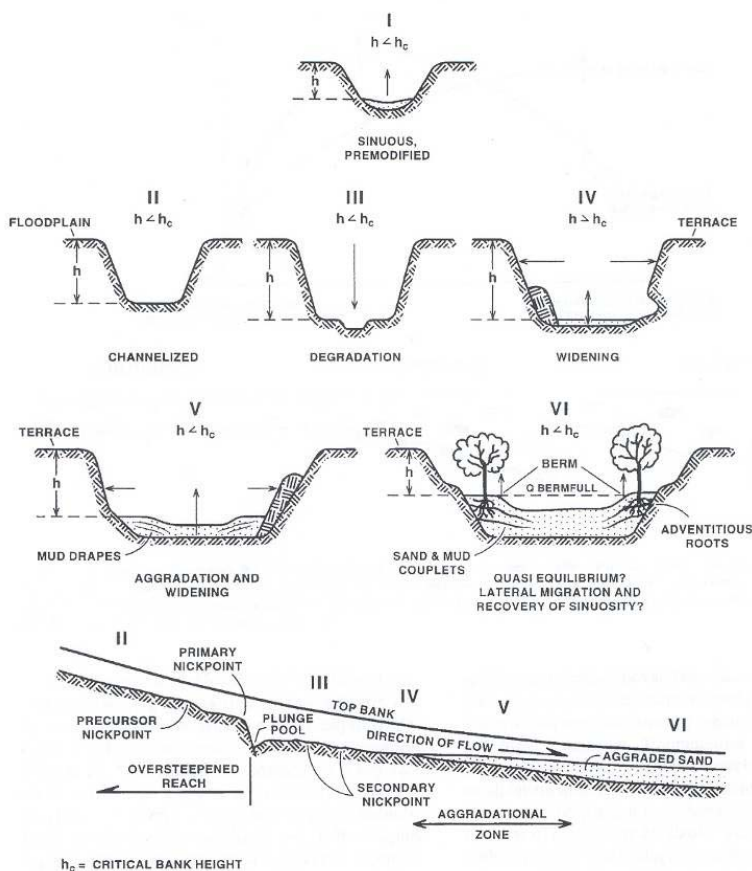


Figure 6. Incised channel evolution modeled after Schumm, Harvey, and Watson (1984) and Simon (1989).

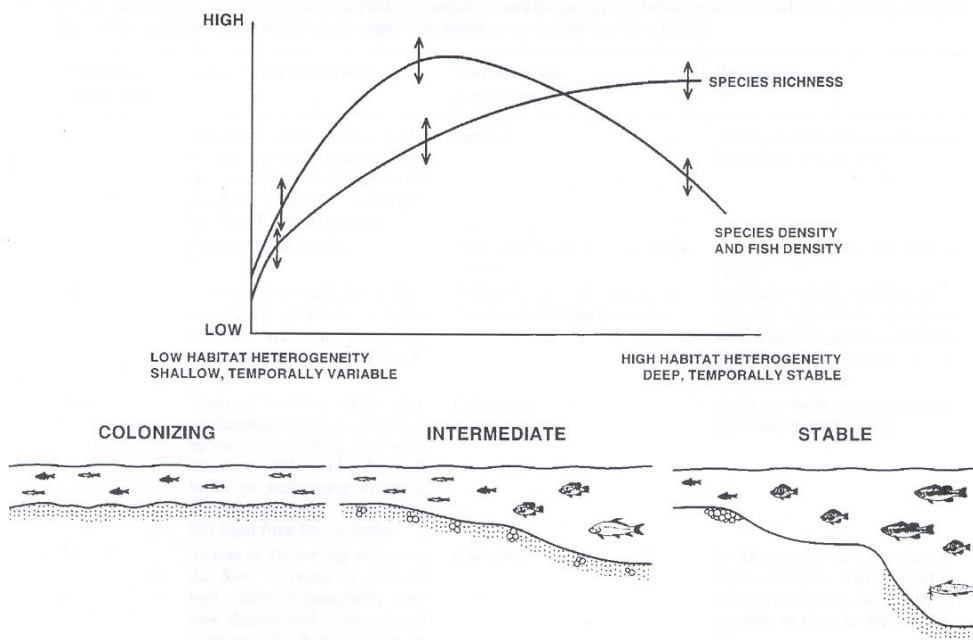


Figure 7. Conceptual model for warm-water fisheries, after Schlosser, 1987 (Shields et al. 1998).

This strategy is recommended for defining reference conditions for streams with legacy sediments.

3.8 Analytical (modeled) reference condition

A number of empirical and dynamic sediment regime and sediment transport models have been used to determine reference conditions and reference reaches (Brookes 1990; Rhoads 1995; Shields et al. 2003; Simon 1998; Thorne 1999; Van den Berg 1995). The use of sediment regime and sediment transport approaches for reference condition estimates are usually conducted in conjunction with stream restoration or improvement projects.

As noted earlier, the reference condition for streams with legacy sediments is based on a stable stream flow and sediment regime, but also considers the chemical and biotic factors and interactions associated with a healthy stream ecosystem. Numerous empirical, steady-state, and dynamic models have been developed for relating watershed activities with stream chemistry and biology and will not be discussed here. However, one method (structural equation models) is discussed, because it permits a consideration of the socioeconomic factors in determining reference conditions and attainable uses.

Structural equation models (SEM) have been used to provide a multivariate approach for determining the probability of attaining designated uses (Reckhow et al. 2005; Stober et al. 2001). Reckhow et al. (2005) used SEM with expert elicitation, to determine which water quality variables were good predictors of designated use attainment for nutrients. For freshwater systems, Secchi depth, total phosphorus, chlorophyll a and *Daphnia sp* population resurgence were identified as good predictors for designated use attainment. Meanwhile, for estuarine systems, the vertical salinity gradient, dissolved inorganic nitrogen, DO, and chlorophyll a were identified as predictors of designated use attainment. Stober et al. (2001) used SEM to determine relationships among habitat alteration, nutrient enrichment, hydroperiod modification, and fish tissue mercury contamination in the South Florida Everglades Ecosystem. In both studies, the probabilities of attainment of the desired condition can be estimated. These models permit incorporation of societal as well as environmental variables in predicting or determining reference conditions.

3.9 Weight of evidence approach

Each strategy described above has potential advantages and disadvantages for use in determining reference conditions for streams with legacy sediments. Watershed and stream attributes vary in both time and space, so it is unlikely that any single strategy or method will be adequate for determining reference conditions for a stream system. This is particularly important for geomorphic processes and sediment regimes, because of potential upstream and downstream effects from management practices and channel processes. Therefore, multiple approaches should be considered, and a weight of evidence approach used, to determine appropriate reference conditions for streams with legacy sediments on military installations. The reference condition is strengthened and corroborated when multiple methods are used and the results support each other.

Strategies recommended for a weight of evidence approach to determining reference conditions for streams with legacy sediments include:

1. Geomorphic stream classification
2. Analytical (modeled) reference condition
3. Social choice context
4. Best professional judgment
5. Reference criteria
6. Delphi approach.

These strategies are recommended for establishing and determining reference conditions for streams with legacy sediments, in moving toward a stable stream system. The first two strategies contribute to determining the stable flow and sediment regime. The remaining strategies confirm this physical base, and add ecological and socioeconomic factors to determine reference conditions for streams with legacy sediments.

3.10 Summary

1. There are multiple strategies for determining reference conditions; not all are appropriate for streams affected by legacy sediments.
2. Reference conditions for physical, chemical, and biological stream attributes need to be determined, and require using different strategies.
3. A weight of evidence approach, using several strategies, is recommended for determining reference conditions for streams on military installations impacted by legacy sediments.

4 Proof of Concept: Fort Benning, Georgia

4.1 An application of reference condition strategies for streams with legacy sediments

Fort Benning is a U.S. Army Training and Doctrine Command installation, located in Muscogee and Chattahoochee counties of west central Georgia and extending into Russell County in east-central Alabama. The installation spreads over about 182,000 acres, with about 93 percent of the acreage in Georgia and 7 percent in Alabama. The Chattahoochee River runs through Fort Benning, separating the Georgia and Alabama portions of the installation.

Fort Benning was first established in October 1918, and substantially expanded during 1940-42. Its first mission was basic training for the infantry. Its Infantry School currently provides basic and advanced infantry training including airborne, air assault, and ranger. The 3rd Brigade of the Third Infantry Division (Mechanized) is also stationed at Fort Benning and conducts field training with tanks, armored personnel carriers, and other heavy equipment. Recent base realignment actions have proposed that the armored vehicle training load be substantially increased within the next 5 years.

The framework and strategies proposed for identifying reference conditions for streams with legacy sediments (See Section 4.5) are described below, using Fort Benning as the proof of concept. This project was to develop strategies for establishing reference conditions, not actually to conduct the analyses. Not all the information needed to implement the strategies is available at Fort Benning, or likely in any other watershed or military installation that is not actively engaged in stream restoration. However, with some additional information, this report's authors think reference conditions can be established for stream systems with legacy sediments on military installations using these strategies.

4.2 Management objectives

The management objectives proposed for the Fort Benning framework include attaining and sustaining:

- military mission
- stable flow and sediment regime for the stream network

- terrestrial, wetland, and aquatic ecosystem functions
- watershed and stream use support for: military training, longleaf pine and red-cockaded woodpecker habitat restoration, gopher tortoise habitat, forest harvest, and aquatic life use.

4.3 Existing uses

As classified by the Georgia Environmental Protection Division, existing uses for the streams located on Fort Benning, as of 28 November 1975, included military training, aquatic life, secondary recreation, and fish and wildlife propagation.

4.4 Watershed and stream conditions

Fort Benning is located primarily within the Sand Hills and Southern Hilly Gulf Coastal Plain Level IV ecoregions of the southeastern United States (Griffith et al. 2001). Most of the installation consists of undeveloped areas that are used for military training, weapons ranges, drop zones, and landing zones. The land use is as follows: forest represents about 57 percent, mixed forest and grasslands about 22 percent, wetlands about 8 percent, and residential/commercial or development about 8 percent of the land use (see Table 3 and Figure 8). The remaining, approximately 5 percent of land is barren, open water, or mixed vegetation types.

The watershed in which Fort Benning is located is about 436,000 acres. Fort Benning occupies about 42 percent of the watershed area, leaving 58 percent of the watershed outside the installation boundaries. Land use in the remainder of the watershed is similar, although not identical, to that found on Fort Benning, with forest comprising about 54 percent, mixed forest and grasslands comprising about 20 percent, wetlands about 4 percent, and residential/commercial or development about 13 percent of the land use (Table 3 and Figure 8).

The topography of the installation and the watershed is rolling, with steep slopes in some areas (Figure 9). Upland forested areas contain primarily mixed longleaf, loblolly, and shortleaf pine, with some areas having mixed hardwoods dominated by oak (Elliot et al. 1995). Floodplain vegetation is primarily mesic hardwoods, dominated by water oak, sweet gum, and swamp tupelo (Cavalcanti 2004). Stream slope gradients range from almost 10 percent to less than 1 percent. Streams generally have sandy bottoms, with fine silts and woody debris in some areas. The proportion of watershed streams on Fort Benning, both by percentage of stream miles

(42 percent) and stream number (42 percent), reflect the proportion of land area in Fort Benning compared with the entire watershed.

Most of the streams on Fort Benning have their origin outside the installation. Sandy or sandy clay loam soils cover much of the fort. (Figure 10, Elliot et al. 1995). Soils within the watershed, in general, are highly erodible (Figure 8). Unpaved roads and disturbance from military training activities are major sources of sediment on the installation. Rates of sedimentation over the past 25 years vary from less than a few mm/yr to 4.0 cm/yr (Lockaby et al. 2005).

Table 3. Land use percentages. (U.S. Geological Survey)

New Type	Zone On Base Acres	Data % Area	Outside Base Acres	Percent Area	Total Sum of Acres	Total Sum of Percent Area
Bare Rock/Sand/Clay	1443.5384	0.79	2208.270921	0.87	3651.81	1.66
Commercial/Industrial/Transportation	1310.572822	0.72	2942.691232	1.16	4253.26	1.88
Deciduous Forest and Evergreen Forest	103865.0141	56.91	137793.8318	54.31	241658.85	111.22
Developed	12851.70444	7.04	30601.67062	12.06	43453.38	19.10
Grasslands/Herbaceous/Pasture/Hay	16193.27257	8.87	35833.16651	14.12	52026.44	23.00
Mixed Forest	24195.23075	13.26	14143.82459	5.57	38339.06	18.83
Open Water	1860.77099	1.02	2002.098714	0.79	3862.87	1.81
Row Crops	2147.314209	1.18	8709.985657	3.43	10857.30	4.61
Shrub/Scrub	4719.160289	2.59	8253.203427	3.25	12972.36	5.84
Wetlands	13907.10712	7.62	11241.16461	4.43	25148.27	12.05
Grand Total	182493.6857	100.00	253729.908	100.00	436223.59	200.00

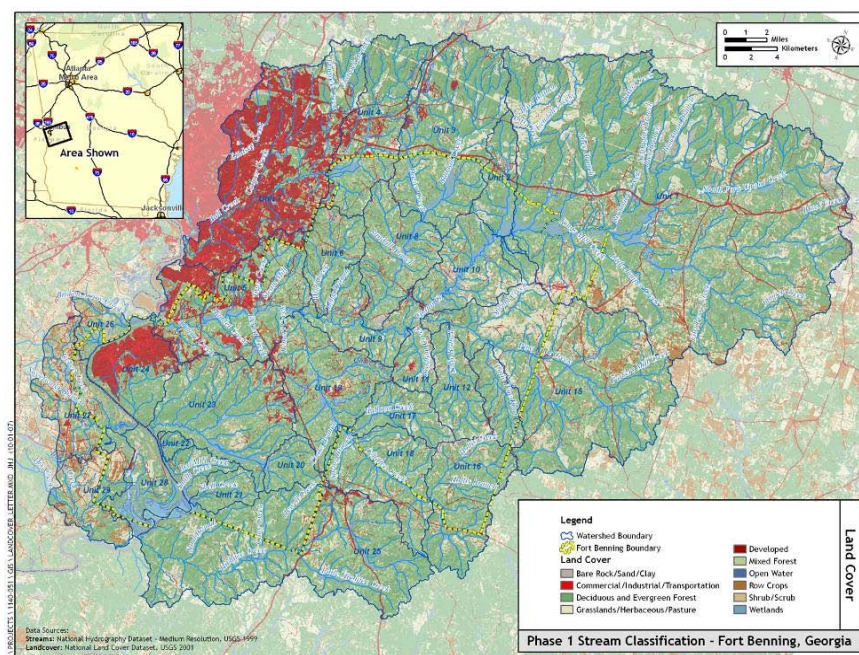


Figure 8. Land use within the Fort Benning watershed. (Elliot et al. 1995, NPS)

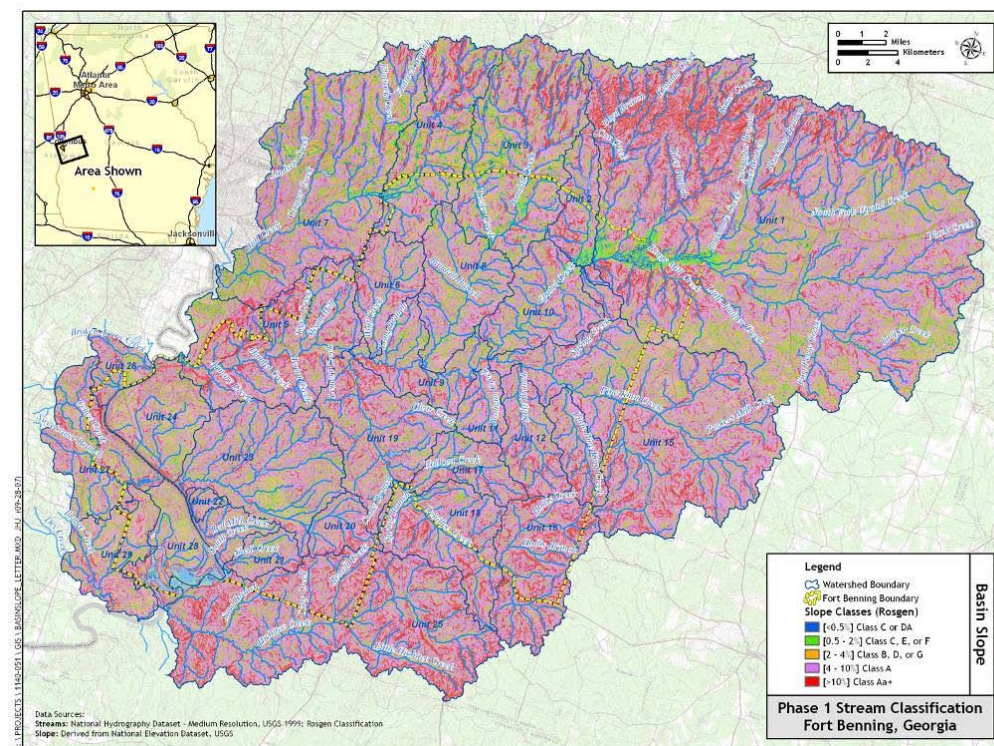


Figure 9. NHD valley slope estimates for Fort Benning watershed. (Elliot et al. 1995, NPS)

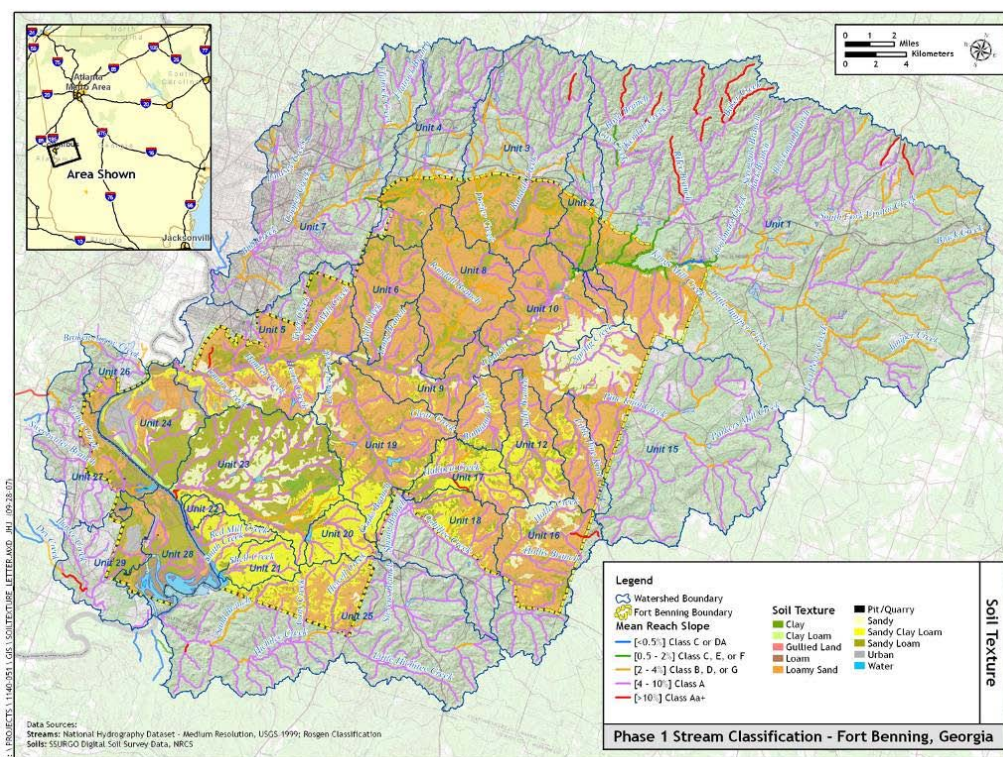


Figure 10. Soil types on Fort Benning installation. (Elliot et al. 1995, NPS)

For comparison, sedimentation rates in floodplain forests in South Carolina ranged from 0.02 to 0.20 cm/yr and from 0.20 to 0.36 cm/yr in Arkansas (Hupp 2000). A reconnaissance survey of the watershed outside the Fort Benning installation revealed similar stream and sediment conditions to those on the installation (personal observation of authors). Portions of the watershed outside Fort Benning are undergoing residential and commercial development. Cattle are grazed in pastures throughout the watershed. Areas that have been disturbed are also eroded.

Historical land use also has had an effect on existing watershed and stream conditions. Prior to military acquisition, row crop agriculture, principally corn and cotton, and pasture were the dominant land use activities (Kane and Keeton 1998). There was evidence of extensive soil erosion during the agricultural period (U.S. Army Infantry Center [USAIC] 2001). About half of the current installation was purchased by the military in 1918, with the remainder purchased in 1941 and 1942 (Maloney, Mulholland, and Feminella 2005). It has been used for military training, with varying degrees of intensity, for almost 90 years. The streams, their floodplains, and channels reflect these legacy conditions.

4.5 Reference conditions

4.5.1 Social choice context

The current land use activities within the watershed reflect the cumulative social choices made by individual property owners. These include military training, suburban development, forest management, and agriculture. It is likely that some form of better management practice (BMP) can be implemented for any of these land use activities, but the current land use provides the initial socioeconomic context for reference conditions within the watershed. Understanding the socioeconomic and ecological context is critical in moving toward the implementation of BMPs. Some of these activities have an impact on streams that originate outside the installation and flow onto Fort Benning (Figure 8). In addition, there is a soil/sediment legacy from previous agricultural and training land use activities that has left its signature on streams within the watershed.

4.5.2 Best professional judgment

Reference sites have been selected for individual stream reaches for specific study objectives by most of the Strategic Environmental Research and Development Program (SERDP) investigators (e.g., Cavalcanti and Lock-

aby 2005; Maloney, Mulholland, and Feminella 2005; Mulholland, Houser, and Maloney 2005; Roberts, Mulholland, and Houser 2007). While the selection of reference sites was not explicitly to assess streams with legacy sediments, BPJ was used to identify least disturbed sites, relative to disturbed sites. Access problems, however, affected the choice of reference sites. Some sites were not available due to heavy training use and/or firing range danger. Other sites were difficult or impossible to access because of terrain and/or lack of convenient usable roads relatively near the stream site. While these factors did restrict reference site selection, BPJ still should be included with the methods used to determine reference stream systems for legacy sediments at Fort Benning, with site selection based on field measurements and observation.

4.5.3 Reference criteria/Delphi criteria

Selection of *a priori* reference criteria for Fort Benning streams should be considered both for a desired target of a stable stream flow and sediment regime and for improvement from existing conditions. Desired targets can be used to assist in identifying reference conditions for the stable stream system or stream network. These reference criteria might initially be established only for those streams originating on Fort Benning. Reference criteria for improvement from existing conditions should be established for those streams flowing through Fort Benning that originate off the installation, as well as for streams targeted for restoration on Fort Benning. Even though the Army has no control over watershed management and the stream regime outside the installation, Fort Benning personnel could work in partnership with upstream and downstream property owners to develop reference conditions for these streams, as an improvement over current conditions, and move toward attaining that reference condition.

Feminella and Mitchell (2007) noted that an understanding of system-specific flow regimes and sediment movement dynamics are likely to be required to restore woody debris to streams experiencing the disturbance regime on Fort Benning. Determining the criteria and attributes of a stream network or system with a stable flow and sediment regime will assist in developing site-specific reference criteria that are compatible with attaining and sustaining the desired stream system condition.

There were at least four stream research teams that were conducting research/monitoring activities at Fort Benning as a part of SEMP. A Delphi approach and questionnaire could be used to develop reference criteria for the watershed-stream system at Fort Benning. A two- or three-round Del-

phi approach could be used to reach consensus on reference criteria for the watershed-stream system on Fort Benning.

4.5.4 Geomorphological classification and stability analysis

A preliminary Level I Rosgen classification was initiated for streams within the watershed. Level I geomorphic classification requires information on stream and valley slope, sinuosity, width/depth ratio, and entrenchment ratio (Rosgen 1996). Stream and valley slopes were mapped and estimated using the National Hydrography Dataset (NHD) (Figure 9, Figure 11). Fort Benning has a rolling topography with some watershed and stream slopes approaching 10 percent. Upland disturbances tend to result in increased sediment transport in these upland streams (Bhat et al. 2006; Maloney, Mulholland, and Feminella 2005). Watershed catchments and stream reaches were classified by slope. Sinuosity was determined by analyzing selected stream reaches from GoogleEarth Scenes. A preliminary classification of stream type, based on only these two metrics, for selected stream reaches is shown in Table 4. Width to depth ratios (bank full width/bank full average depth) and entrenchment ratio (width of flood prone area/bank full channel width) are based on field measurements, which were not available. With width to depth and entrenchment ratios, a preliminary or Level I assessment of stream stability could be made.

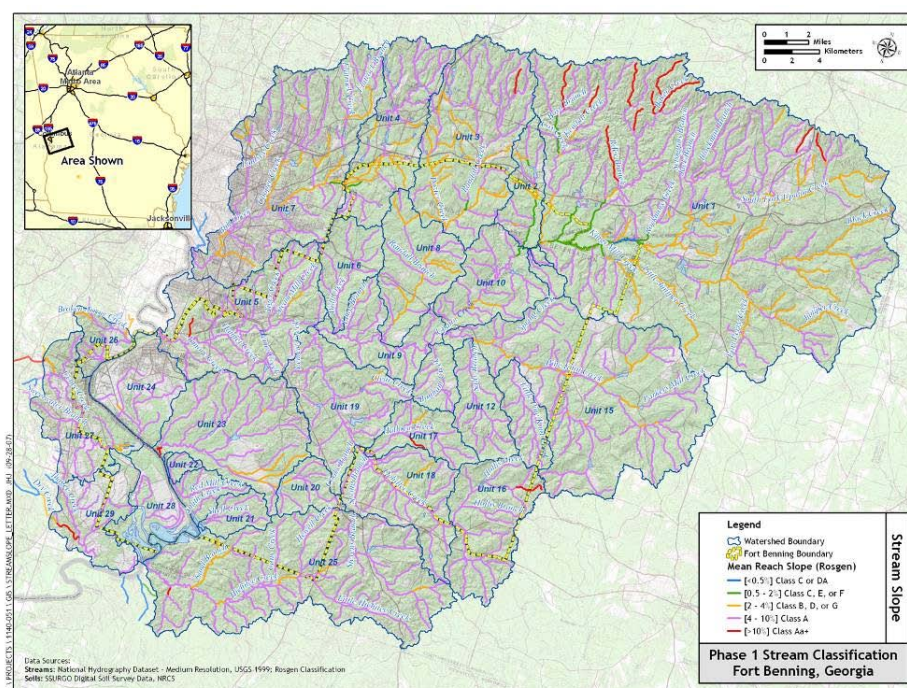


Figure 11. NHD stream slope estimates for Fort Benning watershed.

Table 4. Preliminary Level I classification of selected stream reaches.

Stream Reach	Slope	Sinuosity	W/D Ratio	Entrenchment Ratio	Stream Type
Upper Upatoi	0.5-2%	1.4	?	?	F
Lower Upatoi	4-10%	1.6	?	?	A
Randall Creek	2-4%	1.2	?	?	G
Oswichee Creek	4-10%	1.9	?	?	A

Shields, Knight, and Cooper (2007) demonstrated the importance of the riparian zone integrity in restoring and maintaining a stable stream regime in a watershed in northern Mississippi, with erodible soils and incised channels similar to those found on Fort Benning. Two sets of incised stream channels were restored; one set with standard watershed erosion controls and the other set with watershed erosion controls and riparian habitat restoration. Conventional erosion control without riparian habitat restoration was found to be ineffective for ecosystem restoration in incised, warm water streams (Shields, Knight, and Cooper 2007). Riparian zone vegetation analyses could be conducted on Fort Benning to determine the integrity of the riparian zone, and identify areas where the riparian zone has been disturbed.

4.5.5 Analytical (modeled) reference conditions

Level III Assessment specifically addresses stream stability and departure using analytical procedures. Additional analytical procedures might include unit stream power, sediment impact, and hydrologic and channel stability analyses. Additional information will be required to conduct these analyses on the Fort Benning stream system. While this discussion is limited to the hydrologic and geomorphic characteristics of Fort Benning streams, reference conditions for stream chemistry and biotic integrity will also need to be determined. Analytical procedures can also be used to determine these reference conditions.

4.6 Attainable uses

The designated uses for streams in this watershed are fishing; propagation of fish, shellfish, game and other aquatic life; secondary contact recreation in and on the water; or, for any other use requiring water of a lower quality (Water Use Classifications for Interstate and Intrastate Waters Chapter ADEM Administrative Code 335-6-11, Environmental Rule 391-3-6 Water Quality Control www.gaepd.org/Documents/rules_exist.html). Water quality information can be obtained to determine if these designated uses are being attained, for the assessment units used by Georgia and Alabama to assess

WQS for these streams. If these designated uses are not being attained, a use attainability analysis can be implemented, to change the designated uses. Use attainability analysis is a structured scientific assessment of the factors affecting the attainment of the use. These factors can include the physical, chemical, biological and economic factors as described in Section 131.10(g) (40 CFR 131).

4.7 Next steps

The proof of concept in determining reference conditions for streams with legacy sediments on Fort Benning could be completed, if additional information were collected for a subset of streams on the installation. Field measurements would be required to complete Levels I and II Rosgen stream classification assessments (Figure 12) for the streams on Fort Benning. A worksheet for stream classification and a field form for preliminary channel stability analysis (included in Appendix A) describe the required field measurements. The worksheet is for Rosgen stream classification, while the field form is for a rapid geomorphic assessment (RGA) (Simon et al. 2007). These approaches provide preliminary estimates of stream reach stability using similar stream reach morphometric data.

One approach for selecting a subset of Fort Benning streams for data collection would be to partition Fort Benning streams into two categories: those originating on the installation and those originating off the installation. The preliminary emphasis could be on the set of streams originating on Fort Benning. For some of the streams that fall within this category, physical, chemical, and/or biotic information previously has been collected for other studies. It is proposed that this subset of Fort Benning streams (originating on the installation, with previously collected data) be selected to provide the proof of concept. This subset might be further reduced by excluding streams that flow through restricted or limited access areas.

Once a subset of streams has been selected, preliminary estimates of valley and stream slope characteristics for the stream reaches within these stream systems can be determined from Figure 9, Figure 11. Additional information needed for a Rosgen Level I classification can be found in Table 4. At a minimum, information needed for a Rosgen Level I classification (W/D and entrenchment ratios, sinuosity) could be collected for these stream systems. However, it requires little additional time, once a field crew has been deployed, to also collect the information on sediment type, and bank and channel characteristics needed for a Level II Rosgen stream

classification and RGA. With this additional information (see field forms in Appendix A), a preliminary estimate of stream stability can be made for these stream systems.

A stable stream flow and sediment regime is the foundation for a reference for streams with legacy sediments. While the final determination of stream stability can not be made without additional information [Rosgen Level III classification, Tier 2 analysis (Simon et al. 2007), channel evolution modeling], the preliminary estimates of stream stability are still useful in determining where stable reaches might exist and what factors might be contributing to unstable reaches. This is adequate to provide a proof of concept for the determination of reference conditions for streams with legacy sediments.

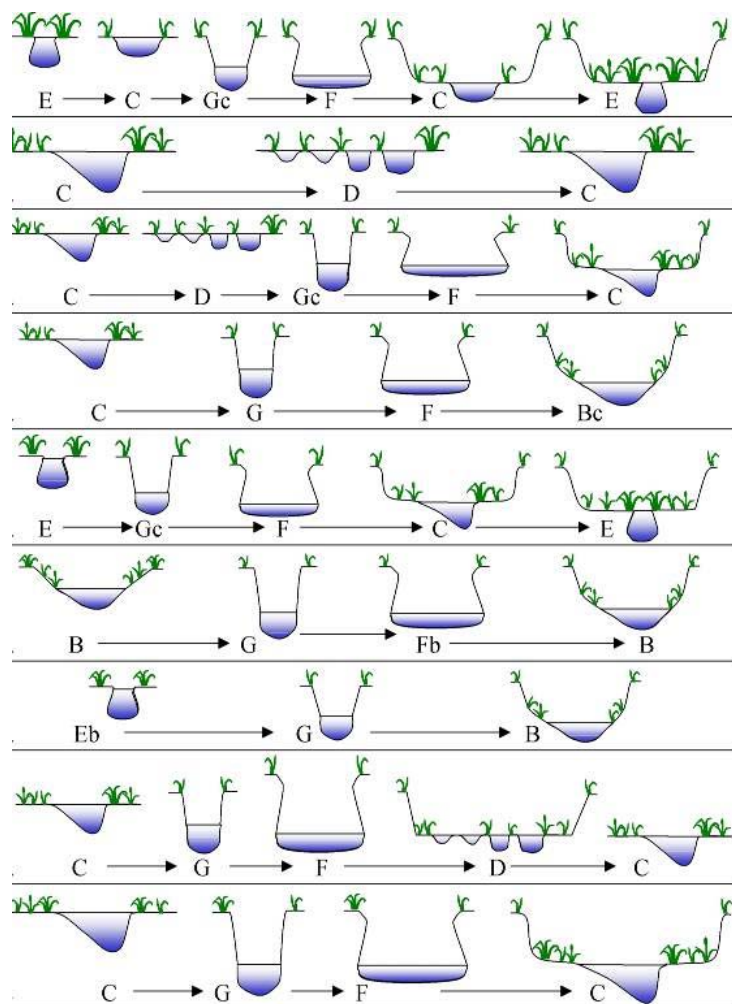


Figure 12. Rosgen stream classification type evolution or succession scenarios.

5 Summary and Recommendations

5.1 Summary

The framework and strategies proposed for determining reference conditions for streams with legacy sediments on military installations is applicable to Fort Benning, Georgia. A complete analysis, however, would require additional information not collected as part of this project. Some of these additional data needs, and their use in determining reference conditions, were discussed.

5.2 Recommendations

The following research topics are suggested for streams with legacy sediments on military installations to extend the ecological usefulness of the approach:

1. **Determining Reference Conditions** – While this report has provided an approach both for determining reference conditions for streams with legacy sediments and for the proof of concept, this approach needs to be applied and evaluated. Additional field data are required for Level III Rosen assessments and Tier 2 analytical assessments (Simon et al. 2007) for the full evaluation of the reference condition approach. Fort Benning is a logical test site, but its applicability should also be extended to other military installations. Quist et al. (2003) studied the effects of military training on terrestrial-aquatic systems at Fort Riley, Kansas, which also might be considered for evaluating the approach.
2. **Assessing Inaccessible Sites** – Many streams on military installations are not readily accessible for investigation because of prohibitions, restrictions or limitations on use. However, streams in these areas can be altered by watershed or channel disturbances that affect both upstream and downstream segments. Having approaches or procedures for assessing or indexing these inaccessible streams would contribute to determining the stability of these stream reaches. Being able to obtain stream geomorphological measurements (e.g., bankfull depth, width, floodprone width, knick points) with centimeter vertical resolution using remote sensing imagery might permit preliminary estimates of stream stability. The development and ground-truthing of remote sensing methods would contribute to a better characterization of stream conditions on military installations.

3. **Coupled Watershed-Stream Channel Sediment Transport Models** – Watershed erosion models and stream channel sediment transport models are available, but coupled watershed-stream models with moveable, rather than fixed, dimensions are needed to predict the stream flow and sediment regime. Two models that have previously been coupled are Annualized Agricultural Nonpoint Source Pollution Model (AnnAGNPS) (Bosch et al. 1998), and Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) (Langendoen 2000; Simon et al. 2007). The applicability of these and similar models outside of agricultural applications is unknown. Coupled models that could provide dynamic predictions of channel evolution would contribute both to the establishment of reference conditions and the development of restoration strategies for streams with legacy sediments.
4. **Sediment-Biotic Response Models** – Biotic response models for benthic macroinvertebrates (RIVPACS – RIVER Prediction And Classification System) have been developed based on biogeography and stream size for streams in Europe (Wright 2000), Australia (Davies 2000), and the U.S. (Hawkins et al. 2000; Carlisle and Meador 2007). Developing similar biotic response models for benthic macroinvertebrates or fish in incised warmwater streams typically found on military installations could provide a benchmark for the types of benthic responses to be expected in stable streams with legacy sediments.
5. **Reference Criteria for Streams with Legacy Sediments** – Reference criteria have been proposed for restored streams to provide a benchmark for assessing the success or performance of stream restoration practices (Palmer et al. 2005). Reference criteria for stable stream systems with legacy sediments have not been developed. Having these reference criteria could contribute not only to defining reference conditions for streams with legacy sediments, but also to a dialog among stream ecologists on appropriate criteria for this unique category and class of streams. A Delphi approach might be considered to initiate this discussion.
6. **Stream System Dynamics** – Streams on military installations have experienced, and will continue to experience, disturbances. In many respects, however, these streams are no different from streams receiving disturbances from natural (tornados, landslides, forest fires) and anthropogenic (agriculture, urbanization, mining) sources. Characterizing the effects, recurrence interval, magnitude, and duration of disturbance regimes on stream systems could contribute to a better understanding of stream dynamics and disturbance responses and expected condition. A more realistic reference frame and understanding of stream dynamics

could emerge from a synthesis of information on stream disturbance regimes.

7. **Watershed-Stream System Management** – The watershed and its stream form the adaptive management unit. Given the disturbance regime and its attributes, as identified through the research discussed in the bullet above, different ecosystem types could be proposed for management that offer desired ecosystem goods and services that are sustained through disturbance and that might not be attained from less disturbed systems in the region. In many regions of the country, exotic, invasive species move into disturbed areas. It might be possible to create reservoirs or islands of native, disturbance tolerant species that could move into these disturbed areas and compete with non-native species. Further studies are recommended to investigate the success potential for this approach.

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Acronyms and Abbreviations

Term	Spellout
ACF	Apalachicola-Chattahoochee-Flint reservoir system
ACT	Alabama-Coosa-Tallapoosa reservoir system
ADEM	Alabama Department of Environmental Management
AnnAGNPS	Annualized AGricultural Nonpoint Source Pollution Model
ANSI	American National Standards Institute
AUSRIVAS	Australia River Assessment System
BAC	best attainable condition
BMP	best management practice
BOD	biochemical oxygen demand
BPJ	best professional judgment
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
CN	Installations Division of CERL
CN-N	Installations Division, Ecological Branch of CERL
CO	carbon monoxide
CONCEPTS	CONservational Channel Evolution and Pollutant Transport System
COS	Centers of Standardization
CWA	Clean Water Act
DO	dissolved oxygen
EMAP	Environmental Monitoring and Assessment Program
EMRRP	Ecosystem Management and Restoration Research Program
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
GAEPD	Georgia Environmental Protection Division
HC	historical conditions
LDC	least disturbed condition
MBII	macroinvertebrate integrity index
MDC	minimally disturbed condition
NHD	National Hydrology Dataset
NSN	national supply number
OMB	Office of Management and Budget
PNAS	Proceedings of the National Academy of Science
PO	purchase order
RGA	rapid geomorphic assessment
RIVPACS	RIVer Prediction and Classification System
SEM	structural equation models
SEMP	SERDP Ecosystem Management Project
SERDP	Strategic Environmental Research and Development Program

Term	Spellout
SMART	specific, measurable, attainable, realistic, time-based
SR	Special Report
STAR	Science to Achieve Results program
TALU	Tiered Aquatic Life Uses
TMDL	Total Maximum Daily Load
TN	Technical Note
TR	Technical Report
URL	Universal Resource Locator
U.S.	United States
USA	United States of America
USAIC	United States Army Infantry Center
USEPA	U.S. Environmental Protection Agency
WARSSS	Watershed Assessment of River Stability & Sediment Supply
WERF	Water Environmental Research Foundation
WQS	water quality standards
WWW	World Wide Web

Appendix A: Field Data Forms

Worksheet 12. Worksheet form for stream classification (from WARSSS website)

Stream Name: _____	
Basin Name: _____	Drainage Area: _____ Ac. mi²
Location: _____	
Twp. & Rge: _____	Sec. & Qtr.: _____ Lat./Long.: _____
Cross-Section Monuments (Lat./Long.): _____	
Observers: _____	Date: _____

Bankfull WIDTH (W_{bkr}) _____ Ft.
WIDTH of the stream channel at bankfull stage elevation, in a riffle section.

Bankfull DEPTH (d_{bkr}) _____ Ft.
Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section. ($d_{bkr} = A/W_{bkr}$)

Bankfull X-Section AREA (A_{bkr}) _____ Ft. ²
AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.

Width/Depth Ratio (W_{bkr}/d_{bkr}) _____ Ft./Ft.
Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.

Maximum DEPTH (d_{mbkr}) _____ Ft.
Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and thalweg elevations, in a riffle section.

WIDTH of Flood-Prone Area (W_{fpa}) _____ Ft.
Twice maximum DEPTH, or ($2 \times d_{mbkr}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.

Entrenchment Ratio (ER) _____ Ft./Ft.
The ratio of flood-prone area W_{fpa} divided by bankfull channel WIDTH (W_{fpa}/W_{bkr}) (riffle section)

Channel Materials (Particle Size Index) D50 _____ mm.
The D_{50} particle size index represent the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and thalweg elevations.

Water Surface SLOPE (S) _____ Ft./Ft.
Channel slope = "rise over run" for a reach approximately 20 - 30 bankfull channel widths in length, with the "riffle to riffle" water surface slope representing the gradient at bankfull stage.

Channel SINUOSITY (K) _____
Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL/VL); or estimated from a ratio of valley slope divided by channel slope (VS/S).

Stream Type		For reference, note: p184, Stream Type Chart; P. 185, Classification Key
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Channel stability ranking scheme (from Simon et al. 2007)

Channel-stability ranking scheme

Station # _____ Station Description _____

Date _____ Crew _____ Samples Taken _____

Pictures (circle) U/S D/S X-section Slope _____ Pattern: Meandering
Straight
Braided

1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay
0	1	2	3	4

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks
0	1		2	3

3. Degree of incision (Relative ele. Of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%
4	3	2	1	0

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%
0	1	2	3	4

5. Streambank erosion (Each bank)

	None	fluvial	mass wasting (failures)
Left	0	1	2
Right	0	1	2

6. Streambank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

7. Established riparian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

9. Stage of channel evolution

	I	II	III	IV	V	VI
	0	1	2	4	3	1.5

10. Composition of adjacent side slope (circle)

	N/A	Bedrock	Boulders	Gravel-SP	Fines
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

11. Percent of slope (length) contributing sediment

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

12. Severity of side-slope erosion

	None	Low	Moderate	High
Left	0	0.5	1.5	2
Right	0	0.5	1.5	2

Appendix B: Key to stream classifications*

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/ Soils/Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams.	<1.4	<12	1.0 to 1.1	≥10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition, and/or structural. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate w/scour pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.4	<.02	Broad valleys w/terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment, w/abundance of sediment supply. Convergence/divergence bed features, aggradational processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuities and width/depth ratios. Very stable streambanks.	>2.2	Highly variable	Highly variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosing (multiple channel) geologic control creating fine deposition w/well-vegetated bars that are laterally stable with broad wetland floodplains. Very low bedload, high wash load sediment.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.4	<.02	Entrenched in highly weathered material. Gentle gradients, with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	.02 to .039	Gullies, step/pool morphology w/moderate slopes and low width/depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials, i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

* As outlined by USEPA, Watershed Assessment of River Stability and Sediment Supply (WARSSS); available at: www.epa.gov/warss/sedsource/pdf/tab02.pdf

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1. REPORT DATE (DD-MM-YYYY) 06-03-2009		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE A Framework and Strategies for Determining Reference Conditions for Streams with Legacy Sediments on Military Installations			5a. CONTRACT NUMBER w9132T-07-P-0074		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT SERDP Ecosystem Mgt. Program (SEMP)		
6. AUTHOR(S) Kent Thornton, Patrick Downey, Harold E. Balbach, and Elizabeth L. Keane			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER SI-1114		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005, Champaign, IL 61826-9005			8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CERL TR-09-08		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Strategic Environmental Research and Development Program (SERDP) 901 N. Stuart St., Suite 303 Arlington, VA 22203			10. SPONSOR/MONITOR'S ACRONYM(S) SERDP		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The Army accomplishes its mission, in part, by training forces at military installations to conduct combat operations on land. It also is charged with meeting requirements of the United States Clean Water Act on those lands. To assist the Army, the U.S. Army Engineer Research and Development Center–Construction Engineering Research Laboratory develops tools to: address the priorities the military mission priorities, meet the requirements of environmental legislation, and support the stewardship of land resources. A critical issue is establishing appropriate baseline reference conditions for evaluating activities involving water resources. This study addresses that issue by developing a framework and strategies for determining reference conditions for streams on military installations with legacy sediments (pollutants which were generated by land uses prior to Army occupancy). Subsequently, a weight of evidence approach is recommended for determining the reference condition for streams with legacy sediments. This includes using a variety of strategies to define reference stream water quality and biotic integrity, plus flow and sediment regime. The resulting framework was successfully applied to Fort Benning, Georgia. With additional data, using a weight of evidence approach with these strategies should permit reference conditions to be determined for other streams with legacy sediments.					
15. SUBJECT TERMS surface water quality, Fort Benning GA, legacy sediments, water quality modeling					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Harold E. Balbach
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) 217 373 6785