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Chapter 14 Treatment Technique Design

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Cover photos: *Top*—Treatment techniques for streambank stabilization and stream restoration require specific design tools. Management and removal of disturbance factors should be balanced with structural approaches.

Bottom—Treatments range from simple to complex. Design tools assist the user in properly installing a treatment.

Advisory Note

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

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654.1400 Purpose

Stream design and restoration often include specific treatments in the riparian area, on the bank, and in the bed of a stream. Treatments can include techniques that provide ecological enhancement, as well as protection of these areas. This chapter provides an overview of some of the frequently used treatment techniques for bank protection, grade protection, and habitat enhancement using a wide range of plant materials, earth materials, and other inert materials. In addition, analysis techniques that are needed for successful designs are provided. This chapter contains a brief overview of each analysis approach or treatment technique. Refer to the section in the listing of technical supplements for performance criteria, specific analysis, and design guidelines for each technique. Where information is available, the benefits, flexibility, risk, and cost of each technique are presented from a physical, as well as an ecological perspective.

The reader should not interpret the listed techniques as an endorsement of any particular product mentioned and should not infer that one treatment or approach is superior to another. The list of approaches is not exhaustive. There are other techniques, as well as variants of each of those described, that may be appropriate and applicable. Finally, while this chapter provides techniques that focus on the treatment of local problems, the use of several of these techniques, as well as other design elements, often can provide a more holistic approach to complex restoration projects.

654.1401 Introduction

A wide variety of analysis techniques can be applied to channel design and stream restoration. The selection and design of the different techniques depends upon the project goals, watershed conditions, and consequences of failure. All techniques contain some inherent flexibility and inherent risk. The tolerance for risk by the landowner and the public must be considered as the designer selects not only the technique to use but also the level of design analysis to apply. Finally, a selection of an appropriate treatment technique and level of analysis must consider cost. Cost effectiveness includes both the initial project costs, as well as operation, maintenance, and replacement costs. Much of the information presented in NEH654.02 and NEH654.04 should be reviewed and be included in these important decisions.

The design and restoration of a stream often requires the application of a combination of technologies. Techniques that are part of a traditional engineering approach can be altered or enhanced to provide habitat benefits. Many of the treatment techniques described herein are used in conjunction with other techniques to achieve project goals. For example, systems composed of living plant materials are often used in association with inert materials such as wood or rock, as well as manufactured products. In addition, the use of several design analysis techniques may be required for the successful application of a single treatment technique. Information on the reach and watershed that was assessed and calculated, as described in earlier chapters, may provide the required input for the designs and assessments.

Many of the treatment techniques described have been implemented by themselves to address small, local issues. This approach has sometimes been unjustly referred to as applying a band-aid solution. However, the band-aid approach may be completely justifiable in a scenario where there is only localized instability. It only becomes a band-aid when there is an attempt to address systemwide instability with a localized solution.

Some of the techniques described are sequential. For example, the installation of habitat features on an unstable stream must be done after the stream has been stabilized. Techniques such as the channel evolution model, addressed in NEH654.03 and NEH654.13, may be useful in making this assessment.

Some of the treatments described in this chapter should be implemented concurrently. For example, while it is often simpler to plant vegetation into a conventional bank protection project after construction, better results are achieved if the vegetation is incorporated directly into the treatment during construction. To adequately do so, provisions for vegetating should be addressed during the planning and design stages of the project.

654.1402 Design analysis

Design analysis, using sound physical principles and well-established engineering formulae, are used in the implementation of both soft and hard treatments. This section contains some of the techniques that have broad applicability to many treatment approaches described in this chapter.

The level of design analysis needed to employ these treatment techniques depends on both the treatment technique employed, as well as site conditions. The level of analysis should also match the cost of the project under consideration and level of risk associated with the project.

(a) Do Nothing option

The Do Nothing option is also sometimes referred to as the No Action alternative. This option is placed as the first entry under the design analysis section of this chapter to emphasize the importance of this consideration. It is covered briefly, but it is an important analysis. While it may seem self-evident that the planners and designers have discarded the Do Nothing approach if treatment options are being investigated, it is strongly suggested that this decision be continually revisited. This is also known as the Future, Without-action alternative, since the primary objective is to describe not only the problems as they exist today but also to predict a direction or magnitude of change in conditions. Natural stabilization may be occurring, but not quick enough to satisfy goals and objectives. Conversely, problems may be accelerating or affecting more area in the future, which brings the need for development of other restoration alternatives into focus.

Any treatment approach carries with it some level of both known and potential impact. These impacts can be both ecological and physical. Impacts that should be considered include:

- how the treatment interacts with the local environment
- how the treatment may alter, accelerate, or limit natural processes on a reach or watershed scale

- how the treatment may affect the social dynamics on a local or watershed scale
- alteration to the natural environment that is required for the construction of the treatment
- aesthetics—how the treatment interacts with the visual scene
- scale of impact on a temporal basis—is the cost of treatment justified based on sustainability of impact over time

These potential impacts should be weighed against the intended benefits of the treatment. These assessments often require a strong and well-coordinated interdisciplinary approach.

The Do Nothing option should constantly remain as a possibility. The resources, both physical and ecological, that may be lost by not implementing the project must be weighed against the impacts and costs of the project. By continually assessing this option, the designer can gain confidence that the selected design is appropriate and needed.

(b) Soil properties and special geotechnical problems related to stream stabilization projects

Many channel bank stability problems have a sizable geotechnical component. Although streambanks may be protected from erosive forces of flowing water, forces acting on soils in the bank can induce slope failures. Problems that are geotechnical in nature require a solution that is geotechnically based.

Analyzing bank slopes for geotechnical stability requires an understanding of a complex system of forces. The forces involved in bank instability problems include:

- gravity acting on the soils in the slope
- internal resistance of soils in the slope
- seepage forces in the soils in the slope
- tractive stresses imposed on the soils by flowing water

Knowledge of the site-specific soil characteristics and strength properties is required to understand, predict performance, and design stream restorations and stabilization. Soil characteristics and shear strength parameters are required for various stream stabilization techniques such as bank sloping, retaining wall design, sheet pile design, and pile foundation design.

NEH654 TS14A contains a descriptions of soil characteristics and special geotechnical problems, with a particular focus on bank protection. Guidance on recognizing these problems in the field is presented, along with a description of typical measures for solving them. A particular focus of NEH654 TS14A includes:

- stabilizing very steep slopes caused by erosion at the toe of the slope
- piping/sapping of streambanks, together with sloughing of saturated zones of sands and silts with low clay content
- shallow slope failures in blocky-structured, highly plastic clays
- severe erosion on dispersive clays

(c) Scour calculation

Scour is one of the major causes of failure for stream and river projects. It is important to adequately assess and predict scour in the course of any stream or river design. Designers of treatments such as barbs, revetments, or weirs that are placed on or adjacent to streambeds must estimate the probable maximum scour during the design life of the structure to ensure that the structure will either adjust to or account for this potential change. NEH654 TS14B provides guidance useful in performing scour depth computations.

Although the term scour includes both bed and bank erosion, the emphasis in NEH654 TS14B is on erosion that acts mainly downward or vertically such as bed erosion at the toe of a revetment or adjacent to a bank barb. Scour can be classified as one of three types, as shown in table 14–1.

A treatment may experience one or combinations of these scour types.

Many Federal and state agencies, as well as academic institutions, have developed methods and approaches for estimating these types of scour, and several of those techniques are briefly described in

NEH654 TS14B. Each of these techniques is developed for different types of conditions. The successful use of these techniques requires an understanding of both their inherent limitations, as well as their advantages.

(d) Stone sizing criteria

Many channel protection techniques involve rock or stone as a stand-alone treatment or as a component of an integrated system. Rock is often used where long-term durability is needed, velocities are high, periods of inundation are long, and there is a significant threat to life and property. NEH654 TS14C contains information useful in determining the required particle size to resist fluvial forces, regardless of the application of the stone.

The design of stone or riprap requires engineering analysis. Stone sizing should be approached with care because rock treatments can be expensive and can give a false sense of security if not applied appropriately. Since stone sizing methods are normally developed for a specific application, care should be exercised matching the selected method with the intended use. For example, a design technique developed for conventional riprap revetment may contain inherent assumptions that limit its applicability to a stone barb. The forces that are acting on the barb may be outside the range that were considered for the revetment and may lead to the barb being damaged during less than design flows.

Table 14–1 Scour types

Type of scour	Definition
General	Commonly affects the entire channel cross section, but general scour may affect one side or reach more than another
Bedform	Usually found in sand-bed streams, this is the troughs between crests of bedforms
Local	Commonly affects the streambed immediately adjacent to some obstruction to flow

Many Federal and state agencies have developed methods and approaches for sizing riprap, and several of those techniques are briefly described in NEH654 TS14C. NEH654 TS14C also describes some of the typical applications of both integrated systems and stand alone riprap treatments.

(e) Use of geosynthetics in stream restoration and stabilization projects

A variety of geosynthetic materials may be used for various function and applications in stream restoration and stabilization projects. A geosynthetic is defined as a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as part of a manmade project structure or system (American Society for Testing and Materials International (ASTM D4439). Geosynthetics used in stream restoration and stabilization include geotextiles, geogrids, geonets, geocells, and rolled erosion control products. NEH654 TS14D addresses the design of these products.

(f) Use and design of soil anchors

Many treatments do not rely solely on their weight or positioning for their stability. Some external anchoring is needed to resist the fluvial forces of the stream or river. If the treatment relies on an anchor for stability, proper design and installation is essential for project success. NEH654 TS14E covers three of the more common anchoring methods that are in use.

- driven soil anchors
- screw-in soil anchors
- cabling to boulders

These approaches have been used on structures such as rootwads, large woody debris structures, and brush barbs. Depending on the site conditions and design of the treatment, these methods may provide either temporary or permanent anchoring.

The focus of NEH654 TS14E is primarily on driven soil anchors. It provides guidance for estimating the pull-out capacity required of the anchor, given expected streamflows, soil characteristics, and the nature of the object that is to be anchored. Installation guidance is also provided.

(g) Pile foundations

Piles are also used to transfer foundation forces through relatively weak soil to stronger strata to minimize settlement and provide strength. The most likely applications for pile foundations in stream restoration and stabilization projects are as support for bank stabilization (retaining wall) structures and as anchors for large woody material. Piles may be used to support ancillary structures such as culverts, structural channels, bridges, and pumping station structures. NEH654 TS14F addresses the design and analysis required for pile foundation design. Installation issues are also addressed.

654.1403 Treatment techniques

Treatment techniques address a variety of stream stabilization and habitat enhancement techniques. While these treatments are addressed in separate sections, environmentally sensitive stream design will often require combining techniques. There are well-established techniques that are not listed here, including variants of some of the ones that are addressed. Depending on site conditions and project goals, these other treatments may be appropriate, as well.

(a) Grade stabilization

One of the most challenging problems facing river engineers today is the stabilization of degrading channels. Channel degradation leads to damage of both riparian infrastructure, as well as the environment. Bank protection is generally ineffective over the long term if the channel continues to degrade. When systemwide channel degradation exists, a comprehensive treatment plan is usually required. This usually involves the implementation of one or more grade control structures to arrest the degradation process. Another more involved approach would be to change the channel gradient through a reconstruction of the channel, incorporating suitable meander bend geometry.

While grade control can be applied to any alteration in the watershed that provides stability to the streambed, the most common method for establishing grade control is the construction of inchannel structures. A wide variety of structures have been employed to provide grade control in channel systems. These range from simple loose rock structures to reinforced concrete weirs and vary in scale from small streams to large rivers. NEH654 TS14G provides a description of some of the more common types of grade control structures and describes the various design factors that should be considered when selecting and siting grade control structures.

(b) Flow changing techniques

Flow changing devices are a broad category of treatments that can be used to divert flows away from eroding banks. These include devices known as deflectors, bendway weirs, vanes, spurs, kickers, and barbs. While there are variants in their design and behavior and names, they are basically structures that:

- project from a streambank
- are oriented upstream
- redirect streamflow away from an eroding bank
- alter secondary currents
- promote deposition at the toe of the bank

These treatments are typically constructed of large boulders and stone, but timber and brush have also been successfully used as part of stream design and restoration. NEH654 TS14H describes the attributes and design criteria for many flow-changing techniques. However, the primary focus of NEH654 TS14H is on the analysis, design, and installation of stream barbs. NEH654 TS14H draws on recent field evaluations that focus on areas where these structures have performed well, as well as areas where their performance has been less than satisfactory. A design description includes cautions and warnings related to specific design features. A step-by-step design procedure is also provided.

(c) Soil bioengineering

Stabilizing streambanks with natural vegetation has many advantages over hard armor linings. Compared to streams without vegetated banks, streams with well-stabilized vegetation on their banks have better water quality and fish and wildlife habitats. Vegetation is an extremely important component of biological and chemical health, as well as the stability of the system.

Streambank soil bioengineering is defined as the use of live and dead plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment (Allen and Leech 1997). Streambank soil bioengineering uses plants as primary structural components to stabilize and reduce erosion on streambanks, rather than just for aesthetics. As a result of increased public appreciation of the environment, many Federal, state, and local governments, as well as grass roots organizations, are actively engaged in implementing soil bioengineering treatments to stabilize streambanks.

NEH654 TS14I provides guidance for the analysis, design, and installation of many commonly used soil bioengineering techniques. Integrated approaches are addressed, as well as techniques that solely use plants to provide stabilization. Installation guidelines and materials requirements are described in detail. NEH654 TS14I addresses many of the regional concerns and issues that should be considered for the successful application of these techniques.

(d) Large woody material for habitat and bank protection

Large woody materials (LWM) structures are intended to provide habitat and stabilization, until woody riparian vegetation and stable bank slopes can be established. LWM normally decays within a few years, unless it is continuously submerged, but this decay depends on climatic conditions, wood type, and density. Therefore, structures made entirely or partially of woody materials are not suited for long-term stabilization, unless wood is preserved by continuous wetting or chemicals. Woody structures are best applied to channels that are at least moderately stable, have gravel or finer bed material, and that have a deficit of habitats created by wood. NEH654 TS14J addresses the analysis, design and installation of LWM structures.

(e) Streambank armor protection with riprap structures

Structural measures for streambank protection, particularly rock riprap, have been used extensively and with great success for many years. Many situations still require rock riprap to some degree. It is one of the most effective protection measures at the toe of an eroding or unstable slope. Rock is a fairly common commodity in most areas of the country and readily available to most sites. Rock riprap measures have a great attraction as a material of choice for emergency type programs, where quick response and immediate effectiveness are critical.

NEH654 TS14K describes some of the basic principles and techniques used to treat streambank erosion with the more traditional structural measures such as rock riprap and rock-filled gabions. These design basics are applicable to any structure that involves the use of stone. This section also describes the challenges inherent in integrating more vegetatively oriented solutions into these techniques without materially increasing the exposure time and risks involved with failures. This combined approach is desirable to produce a better long-term solution that will be complementary to the natural environment and more self-sustaining. NEH654 TS14K also addresses where stone can be used to provide habitat enhancement, either as part of a traditional bank stabilization structure or as instream habitat boulders.

(f) Articulating concrete block revetment systems for stream restoration and stabilization projects

A variety of natural and constructed materials are available to provide erosion protection in stream restoration and stabilization projects. One of these products is an articulating concrete block (ACB) revetment system. An ACB revetment system is a matrix of interconnected concrete block units installed to provide an erosion resistant revetment with specific hydraulic characteristics. The individual units are connected by geometric interlock, cables, ropes, geotextiles, geogrids, or a combination thereof and typically overlay a geotextile for subsoil retention. An ACB revetment system may be used to provide permanent erosion protection where vegetation and other soil bioengineering practices are not stable for the design event. Typical applications may include entire channel cross-sectional protection, toe and lower side slope protection, stream crossings, grade stabilization structures, and other high energy environments.

NEH654 TS14L describes the ACBs currently available and some of the benefits of their use. A summary of hydraulic performance testing is presented along with design procedure for open channel flow. Critical features are described for typical installations, including subgrade preparation, ancillary components (such as drainage layers), filter placement, ACB placement, system termination, and anchors and penetrations.

(g) Vegetated rock walls

A vegetated rock wall is a mixed-construction biotechnical slope protection. They are primarily used in urban and suburban applications where limited area is available and where there is a need for static bank stabilization. They may be considered to be an alternative to a conventional concrete channel. While vegetated rock walls are expensive, they provide more habitat benefits and are generally considered to be more aesthetically pleasing.

NEH654 TS14M describes the analysis, design, and installation requirements for these structures. Both structural, mechanical and vegetative elements work together to prevent surface erosion and shallow mass movement by stabilizing and protecting the toe of steep slopes. These walls differ from conventional retaining structures because they are placed against relatively undisturbed earth and are not designed to resist large earth pressures.

(h) Fish passage and screening design

Fish passage and screen design is often an important component in stream restoration and water resource management. A wide variety of design issues depend on the project region and species of interest. NEH654 TS14N provides an overview of fish passage and screen design including biological considerations. This section includes a generalized assessment and design approach. Additional references for more information regarding design of fish passage and screen structures are provided.

(i) Stream habitat enhancement using LUNKERS

Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids (LUNKERS) are structures that are designed to provide both stability and edge cover for aquatic habitat. While their use has primarily focused on providing trout habitat, they are applicable to other species, as well. LUNKERS have also been used in many projects to enhance the integrity of stream channel geomorphology and bank stability. Where flood volumes and velocities are to be mitigated, LUNKERS can contribute to bank stability and establishment of a secure riparian corridor.

NEH654 TS14O provides step-by-step guidance for the analysis, design, and installation of these structures. A particular focus is on the placement, anchoring, and finished grading for LUNKER structures to result in stream channels that function efficiently without lateral scour.

(j) Gully stabilization

Gullies develop in response to concentrated flow. Basically, the forces created by flowing water exceed the resisting soil forces. Unchecked, the gullies erode and deliver sediment through a variety of processes that cause loss in soil productivity, channel entrenchment and headward advance, and expansion into the landscape. The processes increase the channel network, bank slope, bank height, and streambank instability resulting from the headward migration of nickpoints. NEH654 TS14P describes the major elements involved with gully formation processes and problem assessment. Alternate approaches to treatment may be considered, depending on gully specifics and landowner desire for effectiveness, cost, and reliability. The information and examples provided in NEH654 TS14P should help in the determination of the approach that may be most suitable for the circumstances.

(k) Abutment design for small bridges

Bridges are installed in a variety of NRCS applications including farm and rural access roads, livestock crossings, emergency watershed protection work, and recreation facilities. They may also be used to replace existing culverts that act as barriers to fish passage. NEH654 TS14Q presents a procedure for determining the ultimate and allowable bearing capacity for shallow strip footings adjacent to slopes. The procedure is appropriate for the design of abutments for the relatively small bridges typically involved in NRCS work.

(l) Design and use of sheet pile walls in stream restoration and stabilization

Sheet pile may be used in a variety of applications for stream restoration and stabilization. It is typically used to provide stability to a stream, stream slopes, or other manmade structures in high-risk situations. Typical applications of sheet pile include toe walls, flanking and undermining protection, grade stabilization, slope stabilization, and earth retaining walls. While sheet pile can be combined with soil bioengineering techniques, it does have some ecologic and geomorphic disadvantages.

NEH654 TS14R describes typical applications for cantilever sheet pile walls in stream restoration and stabilization projects. It also describes the types of sheet pile material, loads applied to the sheet pile, failure modes, design for cantilever wall stability, structural design of the piles, and some construction considerations.

(m) Sizing stream setbacks to help maintain stream stability

Many local communities, watershed groups, counties, and states are developing setback ordinances to help protect stream systems. NEH654 TS14S briefly outlines several guidelines and presents an empirically based equation that predicts the streamway width required to allow a stream to self-adjust its meander pattern. NEH654 TS14S does not cover stream setbacks that are required due to local or state laws or cost-sharing program rules.

654.1404 Conclusion

Treatment technique design contains an overview of some of the frequently used treatment techniques for bank protection, grade protection, and habitat enhancement, as well as analysis techniques for their design. Specifics related to each of the presented treatment and analysis approaches are included in the technical supplements of this handbook.

Many of these treatment techniques have been used and are applicable for small, local issues. While they have been considered to be band-aid solutions, in many cases, a band-aid is all that is needed or justified. In addition, many of the techniques described in this chapter have been used as components of larger, more extensive restoration and design projects.

The reader should not interpret descriptions herein as an endorsement of any product that is mentioned, nor should one treatment or approach be inferred as superior to another. The choice of a particular treatment or combination of treatments should be based on the stakeholders' goals and objectives, watershed conditions, and site condition.