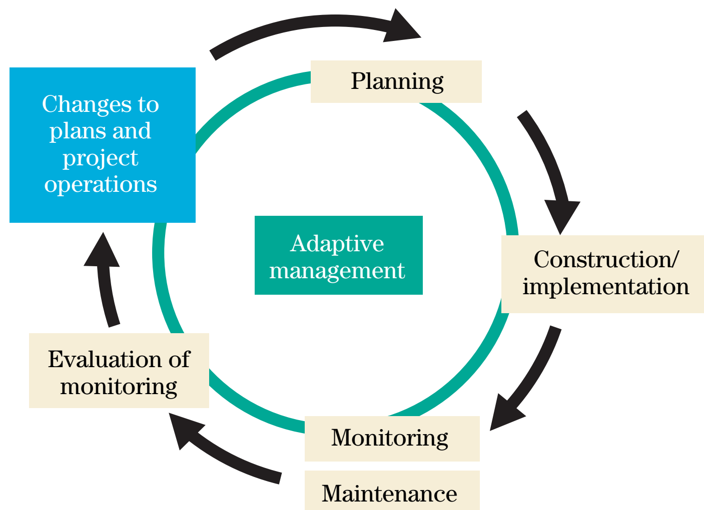
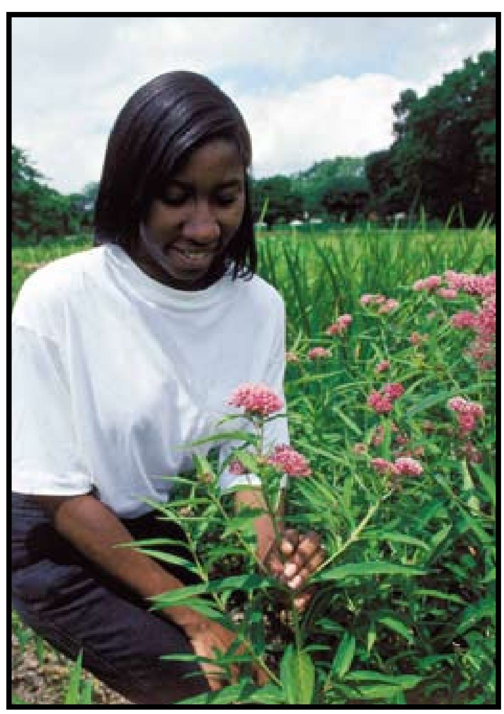
United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 654 Stream Restoration Design National Engineering Handbook

Chapter 16 Maintenance and Monitoring





Issued August 2007

Cover photo: Monitoring during and after implementation enables project managers to determine the level of success achieved and identifies when maintenance is needed.

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.

Chapter 16 Maintenance and Monitoring

Contents

Tables

Figures

Chapter 16 Maintenance and Monitoring

654.1600 Purpose

Any stream restoration project, whether it is designed solely for habitat improvement or strictly to meet some human requirement, is implemented to achieve specific goals or objectives. Continued performance of the project features and health of the biotic resources depend on appropriate maintenance and monitoring of the system. Maintenance and monitoring are actions intended to ensure that the objectives of the stream restoration project are met over time. This chapter provides an overview of key issues in the development of monitoring and maintenance plans. Incorporation of adaptive management as a component of operations is included as a possible approach to maintenance and operation of the project. The user is also directed to the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) National Water Quality Monitoring Handbook for additional detailed information on setting up monitoring plans.

654.1601 Introduction

(a) Relationship of design and implementation to maintenance and monitoring

Maintenance and monitoring are the actions intended to ensure that the objectives of the stream restoration project are attained. Because project objectives, design criteria, and project site conditions determine the specifics of the actual project, maintenance and monitoring plans should follow from the opportunities, constraints, and requirements identified in the planning and design phase. Completion of the construction phase leads to the period of initial project operations when the stream restoration and streambank structures begin to function as designed.

Maintenance is the collection of actions taken to ensure that the stream restoration project performs as designed and to attain project objectives. It ensures the continued functioning of the structures and management measures once they are in place. While projects should be designed so they need a minimal amount of maintenance, some can be required especially in response to extreme flow events.

Monitoring is the process of measuring or assessing specific physical, chemical, and/or biological parameters of a project. Monitoring of any project, whether it is in the channel, streambank, riparian area, and/or adjacent lands, is necessary to ensure that the project is performing as intended. The parameters to be monitored should be directly related to the performance of the project and are linked to the goals and objectives of the project. This is also sometimes referred to as the hypothesis statement, or key questions to be answered.

The monitoring results may identify performance failures and inefficiencies requiring project modifications and changes to structures or operational practices. Performance objectives established for the project allow comparison of monitoring results to identify potential changes that may be needed in response to these performance problems.

(b) Maintenance and monitoring requirements resulting from project objectives

NEH654.02 describes the goals, objectives, and risks of project development. Maintenance and monitoring requirements can be identified initially from examining those actions required to meet the objectives of the project. Table 16–1 compiles different objectives identified in some typical NRCS stream projects. The objectives cited are taken from documentation on various projects. Some of the projects outlined in this table are described in more detail in the case studies of this handbook.

The terms goal and objective are sometimes used interchangeably. However, there are some distinct differences. Project goals are typically defined as the overall desired outcome, such as "restore channel to preflood conditions." Objectives are the more detailed, focused outputs or outcomes that achieve the project goals. The goal of restoring a channel to preflood conditions

Table 16–1 Project goals and objectives

Project	Goal	Objectives
Rose River, VA	Restore channel to preflood condition	Restore the hydrologic function [capacity] of the river by removing large cobble and debris bar that constricts the flood plain
		Stabilize streambanks
		Provide safe access for children to fish, stable cattle and tractor crossings
Little Blue River, KS	Remedy large-scale streambank erosion	Reduce excess stream sediment
		Improve stream channel dimension, pattern, and profile
		Establish a riparian ecosystem
		Improve terrestrial habitat
		Improve water quality
		Reduce nutrients and chemical pollutants
Rapidan River, VA	Restore the hydrologic function of the stream.	Get the water into one channel, not braided and shallow, that matched the preflood geomorphic dimensions
Goode Road/ Cottonwood Creek, Hutchins, TX	Stabilize banks	Reduce peak flows at lower elevation to protect bridge
Chalk Creek, Summit County, UT	Prevent erosion and reduce runoff of sediment	Protect water quality for cutthroat trout and overall health of the watershed
Red River Basin, ND	Restore riparian zones and stabilize stream channel and banks	
Big Bear Creek, PA	Stabilize channel and banks and improve aquatic habitat	Stabilize channel and banks using soil bioengineering and revegetation, stopping scour at a bridge
		Restore 3.7 miles of stream to a high-quality, cold-water fishery dominated by native brook trout

may have objectives such as increase hydraulic capacity by removing flood plain constrictions, stabilizing streambanks, and providing safe access for children to fish, and for stable cattle and tractor crossings (Rose River Restoration NRCS–VA). By attaining the project goal to restore the channel to preflood conditions, these objectives are achieved.

To obtain the goals and objectives of the project, potential maintenance and monitoring actions are suggested in table 16–2. This table lists two example projects showing the requirements that could be deduced from the objectives.

Distinctions between maintenance and monitoring requirements are not made in this section. The important point is to understand what parameters should be accounted for so that objectives are met.

Table 16–2 Project objectives and maintenance and monitoring actions

Project	Objectives	Maintenance or monitoring action or evaluation
Rose River, VA	Improve stream channel dimension, pattern, and profile	Channel profiles
	Stabilize streambanks	Channel planforms comparison to preflood conditions
Chalk Creek, Summit County, UT	Protect water quality for cutthroat trout	Survey of quantity/quality of rearing, spawning, and cover habitat
		Monitor habitat requirements, (stream water temperature, bed-material composition, water depth, and velocity)

654.1602 Development of monitoring plans

Monitoring helps determine whether the project is functioning as intended. Monitoring reveals the need for adjustments to design, construction procedures, and management actions. The information collected from monitoring should be made available to landowners and private interests who can make use of the information. Monitoring parameters are components of a project to be assessed that are evaluated to determine whether project objectives are being met (Washington Departments of Fish and Wildlife, Transportation, and Ecology 2003). Monitoring may be performed for a number of purposes such as (adapted from Federal Interagency Stream Restoration Working Group (FISRWG) 1998; North Carolina Stream Restoration Institute and North Carolina Sea Grant 2003):

- Performance evaluation: determine if the stream project design and management measures are functioning properly.
- Ecological or biological assessment: determine if biological resources are responding to altered conditions.
- Trend assessment: evaluate changing environmental conditions by long-term sampling at various spatial and temporal scales.
- Risk assessment: identify causes and sources of physical, chemical, or biological impairment or uncertainties that will affect operation of the project.

(a) Monitoring parameters

Physical, chemical, biological, and off-project parameters are identified to make up the monitoring plan. These parameters should be linked to the objectives, hypotheses, or key questions being tested with monitoring. Measurements of the selected parameters measure the performance and indicate the ecological functioning of the project.

Physical parameters
Physical parameters are the geomorphic and topographic features that compose the channel bed, streambank, and adjacent riparian areas. Table 16–3, adapted from FISRWG (1998), identifies the physical attributes (cross-sectional profiles and specific parameters for the attribute).

Chemical parameters
Improvements in water quality are a primary objective of many stream restoration projects. Stabilization of channels and streambanks results in reduction of sediment loading and movement. Land use changes in the stream corridor affect nutrient and chemical constituents in the water. Table 16–4 lists potential chemical parameters that could be affected by a project (adapted from FISRWG 1998).

Biological parameters
Aquatic and terrestrial communities change in character and abundance as the channel and streambank are stabilized. Streamside vegetation provides habitat and connectivity to other habitats or adjacent riparian areas. The biological attributes (table 16–5 (adapted from FISRWG 1998)) are the communities, structural components, and processes (primary production) that indicate the biological functioning of the stream system.

Off-project parameters
Project monitoring and maintenance focuses on the processes, systems, and impacts to the specific project and adjacent riparian areas. The watershed, upstream, and downstream processes and impacts were likely examined when formulating designs, accounting for the out-of-study area, or off-project constraints to design and construction. Monitoring and maintenance plans should consider off-project actions such as urbanization and other land use changes, sediment loading, and water control actions (detention structures). This investigation of off-project considerations could identify important parameters such as amount of urbanization or additional water users that should also be monitored.

Table 16–3 Physical parameters for consideration in monitoring

Physical attribute	Parameter
Plan view	Sinuosity, width, bars, riffles, pools, boulders, logs
Cross-sectional profile	Bank repose angle Depth bankfull Width Width-to-depth ratio
Longitudinal profile	Bed particle size distribution Water surface slope Bed slope Pool size/shape/profile Riffle size/shape/profile Bar features
Classification of existing streams	Varies with classification system
Assessment of hydrologic flow regimes through monitoring	2-, 5-, 10-year storm hydrographs Discharge and velocity of baseflow
Channel evolutionary track determination	Decreased or increased runoff, flash flood flows Incisement/degradation Overwidening/aggradation Sinuosity trend-evolutionary state, lateral migration Increasing or decreasing sinuosity Bank erosion patterns
Corresponding riparian conditions	Saturated or ponded riparian terraces Alluvium terraces and fluvial levees Upland/well drained/sloped or terraced geomorphology Riparian vegetation composition, community patterns and successional changes
Corresponding watershed trends—past 20 years and future 20 years	Land use/land cover Land management Soil types Topography Regional climate/weather

Table 16–4 Chemical parameters for consideration in monitoring

Chemical attribute	Parameter
Water clarity	Turbidity
Constituents	Dissolved and suspended solids
	Nutrients
	Toxins—natural and manufactured
Organic loading	Biological oxygen demand
Oxygen capacity	Dissolved oxygen
Water quality measures	Temperature
	pH
	Alkalinity/acidity
	Hardness

Table 16–5 Biological parameters for consideration in monitoring

Biological attribute	Parameter
Primary productivity	Periphyton
	Plankton
	Vascular and nonvascular plants
Zooplankton/diatoms	Species
	Numbers
	Diversity
	Biomass
	Macro/micro-organisms
Fish community	Anadromous and resident species
	Specific populations or life stages
	Number of out-migrating smolts
	Number of returning adults
Riparian wildlife/ terrestrial community	Amphibians
	Reptiles
	Mammals
	Birds
	Plants (invasive species)
Riparian vegetation	Structure
	Composition
	Function
	Changes in time (succession, colonization, extirpation)
Habitat structure	Spawning gravel
	Instream cover
	Shade
	Pool/riffle ratio
	Amount and size distribution of large woody debris

(b) Types of monitoring

The types of monitoring corresponding to the purposes of monitoring are:

- ecological or biological monitoring
- performance monitoring
- trends monitoring
- risk monitoring

For stream restoration projects, performance and ecological or biological monitoring are most important and are included here. While trends and risk monitoring may be very important, a complete discussion is beyond the scope of this chapter. More information is available in FISRWG (1998).

(c) Monitoring strategies

The strategy for collecting and using monitoring data is determined by:

- project type and constituent project structures and nonstructural features (Design documents for the project and restoration (Fischenich and Allen 2000; Johnson, Pittman, et al. 2001) provide information on potential project design features and parameters for monitoring.)
- monitoring parameters identified as important for the project's performance
- type and purpose of monitoring
- resources available (funding) for monitoring

Low effort monitoring
All stream restoration projects require some inspection and monitoring to ensure performance and identify problems and unexpected occurrences. Agency funding for projects often ends with construction, and postimplementation or operations funding is dedicated to maintenance costs. Several low-effort or low-tech monitoring strategies are possible:

- Site visits to future ongoing planning or construction projects can incorporate side trips to the project site. A simple windshield survey and walk-through observation trip can provide valuable monitoring information.
- Local volunteer watershed and conservation organizations are often willing to include monitoring as part their activities. Training of the groups to perform the monitoring and reporting is necessary, but these groups can become valuable eyes and ears for the project (U.S. Environmental Protection Agency (EPA) 1997).

Photographic record
Photographic documentation may provide the information needed for monitoring and is a cost-efficient strategy. For monitoring, repeat photography taken from the same location provides a visual record of changing conditions for soils and vegetation (Hall 2001). However, for a qualitative comparison, it is best to compare photos taken during the same season. This is especially important if vegetation is a major project component. Photographic monitoring is especially suited for documenting success of vegetative plantings, impacts of humans and livestock, and changes in channel gradient and bankline stability (Governor's Watershed Enhancement Board 1993). Monitoring for a project is determined by the objectives and parameters identified in the monitoring plan. Monitoring with photography requires:

- determining specific objectives
- using a repeatable technique
- choosing appropriate camera and media (digital and film)
- developing a filing system (Hall 2001)
- establishing fixed and permanent reference points so that photographs can be compared over time

The frequency for acquiring photography is determined by the parameters monitored. Videography and other remote sensing image acquisition may also be an efficient mode of collecting this information.

Monitoring programs and surveys
A monitoring plan establishes the details of the program for measurement of the selected parameters. The monitoring plan includes (adapted from Washington Departments of Fish and Wildlife, Transportation, and Ecology 2003):

- statement of monitoring objectives
- hypotheses or key questions to be answered

- monitoring parameters
- monitoring protocol
- analysis and use of the information

Statement of monitoring objectives—Identifies the purpose and type of monitoring (project performance) and the project objective (improvement in channel stability, bank stability, and improvement in natural conditions). The direct connection of project objectives to monitoring objectives enables monitoring results to be used for modifying designs and operations to better achieve project goals.

Monitoring parameters—Measurement of the parameters identified as being important for monitoring should be specified in the monitoring plan. Monitoring intensity and evaluation techniques are specified for each of the parameters.

Monitoring intensity—Refers to the level of detail required in the monitoring process; that is, the level of detail required for making decisions on the monitoring objectives (Washington Departments of Fish and Wildlife, Transportation, and Ecology 2003). In some cases, yes/no or good/fair/poor responses provide sufficient information. In other cases, quantitative measurements and modeling are needed to answer monitoring questions. Differences between qualitative and quantitative methods (time, analytic requirements) may determine the level of detail possible within project constraints.

Evaluation techniques—The types of analysis methods used (cross-sectional survey) to monitor the selected parameters. The field sampling methods may differ regionally and for species or habitats. Information for field sampling methods should be identified or developed by NRCS regional engineering and natural resources personnel and project design personnel. This approach ensures that the monitoring will reflect the study area conditions.

Monitoring protocols—For each parameter that has been selected to be monitored, a protocol for implementing the evaluation technique is described. As with evaluation techniques, protocols should be identified or developed by those experienced with local or regional conditions. Protocols normally include (Washington Departments of Fish and Wildlife, Transportation, and Ecology 2003):

- specification of methods and geographic extent of measurements
- identification of monitoring period and frequency
- design of monitoring forms for data collection
- description of data-analysis techniques

654.1603 Developing plans for maintenance

Maintenance of constructed projects ensures that the project operates or performs as intended. Maintenance requirements depend on the project type and level of risk, project goals, and level of effort or resources available for maintenance. The important categories of maintenance are (Martin and Fisher 2002):

- hydrology
- geomorphology
- vegetation
- domestic animals/livestock
- wildlife
- people

Types of maintenance are (FISRWG 1998)

- scheduled maintenance
- remedial maintenance
- emergency maintenance

(a) Project type requirements

Channels and flood plains

Projects establish or restore stability to channels and flood plains. The maintenance of design conditions for hydrology and streambank and flood plain stability often requires scheduled maintenance of project features. Project objectives often include sustainability of the system (FISRWG 1998). Establishment of a dynamic equilibrium requires less extensive maintenance efforts than objectives for maximum hydraulic capacity or other objectives requiring more extensive and frequent maintenance actions. The maintenance requirements specific to the structures, materials, and construction methods can be identified by examining the design documentation and local project conditions for the project. Table 16–6 contains lists of parameters in the stream corridor that could be considered for maintenance.

Protection/enhancement measures

Management measures (structures, vegetation, management actions) that protect streambanks, deflect flows, and improve habitat conditions require periodic maintenance. Failure of the measures after construction should be evaluated to determine if the design or construction method should be altered, rather than just repaired (FISRWG 1998).

Table 16–7 contains a list of possible maintenance actions that may be required for specific protection and enhancement features.

Boulders and other instream features should be maintained to ensure proper functioning. Revetments and heavy or hard protection features require inspection and potential repair and addition of materials. The vegetation of soft protection systems requires inspection to determine survival and level of protection from the vegetation. Hybrid measures, using vegetation in combination with geogrids, geotextiles, and cellular blocks, require maintenance of structural components such as loss of geotextile material and replacement or replanting of vegetation (Fischenich and Allen 2000). The intent of some streambank and channel features is to provide temporary stabilization until riparian vegetation develops and establishes more stable channel bank conditions, so that maintenance of protection/enhancement features will become less important over time (FISRWG 1998).

Vegetation

After construction, monitoring should be frequent enough to evaluate how vegetation establishment progresses (Winward 2000). Many projects that rely on soil bioengineering require that the vegetation become firmly established before experiencing a significant flow event. If a significant event occurs before the vegetation is established, replanting may be necessary. If replanting, protective measures, or irrigation are needed after construction, these actions can be undertaken to ensure that vegetation is established in sufficient abundance and distribution. After establishment of vegetation, project operation requires that it be maintained in a specified abundance and location to achieve project objectives, but not become excessive enough to interfere with water, sediment, or wildlife movement. Maintenance requirements range from mowing of terraces to clearing of excess woody debris, depending on the vegetative component. The

Table 16–6 Maintenance actions for channel and flood plain projects

Project location	Maintenance actions
Channel	Structures—repair of:
	Grade control—rock, concrete,
	Weirs
	Rock vanes
	Island and bar preservation, development
	Bank toe stabilization—rock, vegetation
	Rock barbs
	Removal of:
	Nuisance aquatic vegetation
	Woody debris accumulation
Flood plain	Repair or reformation of bank grading
	Actions to address encroachments
	Maintaining planned boundaries and conditions for rights of way
	Replanting or adding new vegetation due to poor establishment or lack of survival
Buffer strips, setbacks, easements	Establishment of boundaries after encroachments by adjacent land uses
Meander bends	Stabilization of eroding or unstable banks
	Seeding of newly formed areas

Table 16–7 Maintenance actions for different protection/enhancement features

Protection/enhancement features	Maintenance actions
Streambank stability	Repair bank armoring structures (stone filled revetments, soil-covered riprap, cellular blocks, geogrid, gabions, geotextile fabrics, soil cement, bulkheads)
	Terrace zone—seeding, vegetation establishment, mulching
Stream/habitat features	Repair, replacement, expansion of fish cover structures
	Repair, replacement of pool/riffle rocks and structures
Vegetation	Removal of excess woody vegetation
	Repair, maintain irrigation, water availability
	Replanting, replacement of trampled, dead, or impaired vegetation
	Maintain, repair, and replace fencing, signage, and barriers for vegetation protection
	Repair or replacement of brush mattress, matting, or other soil bioengineering materials
	Seeding or reseeding
	Mulching for plant and soil stability
Access and human use structures	Clearing of access pathways for humans and livestock
	Cleaning and repair of recreation structures—picnic tables, boat ramps, parking areas
	Cleaning and repair of restroom facilities

vegetation section of table 16–6 identifies potential actions to consider in vegetation management.

Access and human-use features

Many projects incorporate access points for human uses such as fishing, wildlife access, and agriculture (cattle). Recreation boat ramps, picnic areas, and restroom facilities can be incorporated into projects, increasing public use and the value of the project. These human-use features require a higher level of maintenance to meet public expectations. Exceeding the carrying capacity of the resource by too many visitors or livestock can lead to degradation and erosion of streamside lands and excessive inputs of nutrients and pollutants to the channel. Table 16–6 identifies maintenance activities for the access and human-use features.

(b) Maintenance considerations

Project-specific factors should be considered in planning for maintenance. The necessary maintenance activities for project design features are modified in light of risk, project goals, and level of effort.

Risk

In considering project monitoring and maintenance, risk pertains to the probability of project failure if maintenance is not performed. Numerous circumstances, from budgetary to natural events such as flooding, can prevent maintenance from occurring. Project planners must evaluate how susceptible a project design is to risk of failure if maintenance does not occur, is reduced in scope, or delayed. Projects that rely on structural features may be at less risk than projects dependent on natural or biological components (vegetation maintenance).

Project goals

Project goals and objectives require that maintenance activities be performed to achieve the levels of hydrologic and environmental outputs. Success or performance criteria may be developed for the objectives, specifying the quantities and levels required for project functioning. These criteria help in identifying the maintenance intensity and evaluation techniques required.

Level of effort

The level of effort or available resources (funding, equipment, labor) for maintenance should be considered in design and planning for maintenance. Maintenance plans should reflect the available personnel and other resources.

654.1604 Monitoring and maintenance plan documentation

Preparation of a plan for monitoring is similar to a plan for maintenance. In fact, these two activities are often considered together as part of the plan documentation. Plans for maintenance and monitoring are developed from goals and objectives (NEH654.02). The steps for plan preparation presented here are adapted from Components of a Monitoring Plan, Part 6B of the FISRWG (1998). The guidelines set out three steps for preparing a plan:

- project planning
- implementing and managing the project
- responding to monitoring results

(a) Planning

There are seven steps for planning a monitoring plan.

Step 1 Define the stream restoration project goals and objectives.

Restate the goals and objectives identified as part of project planning (NEH654.03).

Step 2 Develop a conceptual model of the stream, flood plain, and watershed.

A conceptual model serves to communicate relationships of water, geomorphic conditions, and biota (Henderson and O'Neil 2005). The model can be used to identify changes and impacts in the system.

Step 3 Choose performance criteria.

Performance criteria are standards to evaluate to what extent the project is achieving desired or designed outcomes. The performance criteria identify in quantitative terms (defined metrics) or qualitative terms (absence/presence) the results or outcomes of project operation. The Federal Guidelines (FISRWG 1998) provide three components for choosing performance criteria.

Link performance to goals—Goals and objectives for the project should articulate the specific outcomes and results that are expected and intended from the project. The hydrologic, geotechnical, and ecological needs and opportunities identified in planning should have resulted in clear statements for project performance. Performance criteria are meant to assess progress toward the goals. If the goals and objectives are not clear enough for identifying performance criteria, then clarification, interpretation, or explanation of the goals and objectives must be done. The effort to understand or clarify goals will allow establishment of performance criteria that are closely aligned with stated goals.

Develop the criteria—The primary reason for a maintenance and monitoring plan is to assess progress and to indicate the steps required to fix a system or component of the system that is not successful (FISRWG 1998). To that end, the performance criteria and monitoring parameters should be developed as indicators of success. Performance criteria are usually developed through an iterative process that involves listing measures of performance relative to goals and then refining them to develop the most efficient and relevant set of criteria (FISRWG 1998). Criteria are usually specified as levels of outputs (hydraulic capacities, ranges, minimums, maximums, or threshold measurements).

Maintenance performance criteria—Structural, vegetative, and management measures (such as grazing controls) are incorporated into stream restoration project designs because they provide the desired project outputs in terms of necessary hydraulic capacities, levels of protection, and habitat benefits. The necessary maintenance actions are determined by the requirements of the measures. Information from the design phase can be used for maintenance performance of structural components (design sizes, capacities). Maintenance of natural resource and vegetative components is influenced by design requirements, such as level of protection, and by natural conditions. Maintenance of management measures requires identifying the actions, such as repair of fences, needed so that the management measure functions properly (tables 16–6 and 16–7).

Monitoring performance criteria—Performance criteria for the monitoring plan establish the acceptable or desired levels for the parameters being monitored. The performance criteria are based on comparison of the parameter's measurement to the agreed on performance criteria. The monitoring parameters identified (tables 16–3 through 16–5) are measured in the field and compared to performance criteria.

Identify reference sites—Reference sites are channel study areas that are similar to the project channel, but not in need of stabilization. These sites represent the study area if it were undisturbed or stable. Figure 16–1 shows the proximity of the Teton River reference site to the Fox Creek restoration site in Idaho. Conditions (hydrologic, geomorphic, habitat) at the reference site represent the conditions that are the goals of the project. By examining the conditions at the reference site, the study team can ascertain the level of success that is possible from the project. Pre- and postconstruction evaluations can measure the change or impact from the project, but the level of success can be judged only relative to reference systems (FISRWG 1998).

Step 4 Choose maintenance and monitoring parameters and methods.

The purpose of maintenance and monitoring is to ensure the project performs the hydrologic, geomorphic, and habitat functions that are the basis of goals and objectives and project design.

Monitoring parameters—

- Table 16–8 (FISRWG 1998) identifies general project objectives and potential evaluation tools and criteria. As pointed out, the goals and objectives lead to identification of particular parameters for monitoring. Tables 16–3 through 16–5 contain more complete lists of parameters.
- The National Research Council (1992) recommends that parameters include physical, hydrological, and ecological measures. In this way, a holistic assessment of the stream and flood plain is possible. Using reference sites, pub-

Figure 16–1 Fox Creek, ID, case study reference site

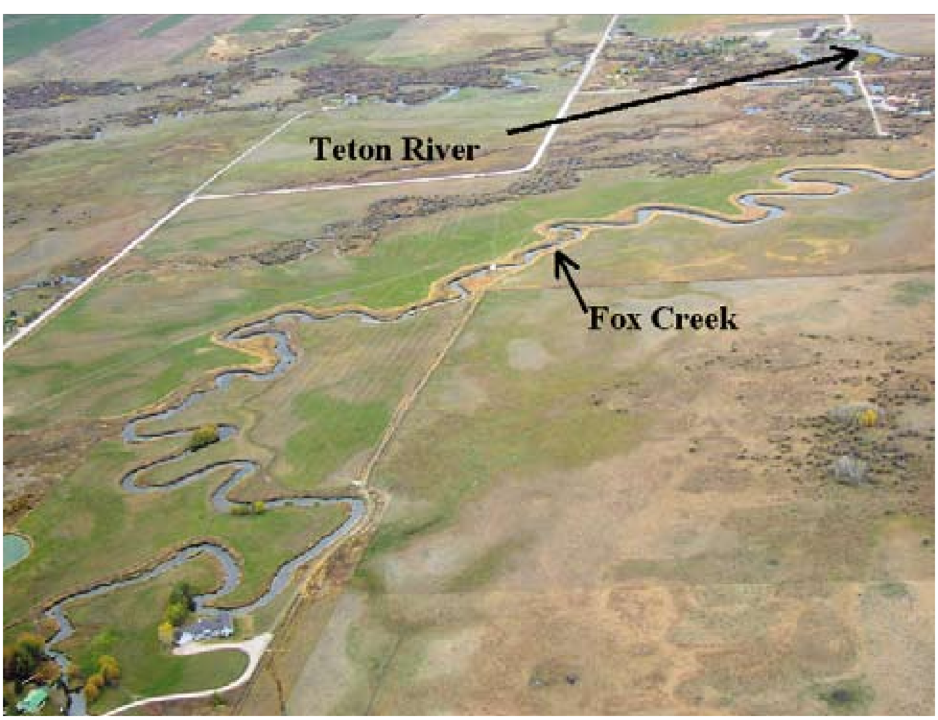


Table 16–8 General project objectives and potential evaluation tools and criteria

General objectives	Potential evaluation tools and criteria
Channel capacity and stability	Channel cross sections
	Flood stage surveys
	Width-to-depth ratio
	Rates of bank of bed erosion
	Longitudinal profile
	Aerial photography interpretation
Improve aquatic habitat	Water depths
	Water velocities
	Percent overhang, cover, shading
	Pool/riffle composition
	Stream temperature
	Bed-material composition
	Population assessments for fish, invertebrates, macrophytes
Improve riparian habitat	Percent vegetative cover
	Species diversity
	Size distribution
	Age class distribution
	Plantings survival
	Reproductive vigor
	Wildlife use
	Aerial photography
Improve water quality	Temperature
	pH
	Dissolved oxygen
	Conductivity
	Nitrogen
	Phosphorous
	Herbicides/pesticides
	Turbidity/opacity
	Suspended/floating matter
	Trash loading
	Odor
Recreation and community involvement	Visual resource improvement based on landscape control point surveys
	Recreational use surveys
	Community participation in management

lished literature, and applicable standards, performance criteria are identified or developed for the physical, hydrological, and ecological monitoring parameters.

- The effects of watershed activities on the project should be considered when identifying parameters. Activities in the watershed can affect the success of the project and cause changes in monitoring parameters not related to the project. Land use changes in urban settings produce changes in water runoff and movement that should be accounted for in monitoring plans. Rural areas similarly undergo land use changes, but the changes are usually slower to take place.
- A holistic view of stream conditions should be pursued using the minimum necessary measurements. While comprehensiveness and redundancy may be desirable, this may be costly and unnecessary.

Monitoring methods—Protocols for monitoring the parameters identified as important are either identified from available sources or developed to meet the channel and regional conditions. Covering sampling and analysis methods for the range of potential monitoring parameters is beyond the scope of this chapter.

Monitoring profiles—Monitoring plans require establishing the physical location from which parameters are measured. Depending on the monitoring parameters needed to determine performance, monitoring is undertaken from a cross-sectional profile, longitudinal profile, or from bankline surveys. However, while it should be noted that other survey techniques and protocols are in use, the ones described herein are the most common.

Channel cross-sectional profile—The channel cross-sectional profile is typically used to monitor bank and channel morphology. The cross section is located across the stream perpendicular to the direction of stream flow. The cross section is used to measure bank and channel elevations, referenced to a benchmark over time. In this way, stability or changes of the bank and channel location can be determined. The channel cross section is used for projects with objectives for stabilizing meandering channels; consolidating multiple, shallow, or braided channels; establishing stable near bank habitat areas; or stabilizing channel slopes.

The cross-sectional survey involves placing endpoints and a benchmark on the stream terrace or stable flood plain, establishing sampling points, taking documentary photographs, and measuring elevations with a surveyor's level (Harrelson, Rawlins, and Potyondy 1994). At least 20 elevation measurements are usually taken at significant breaks of slope that occur across the channel. The active terrace and flood plain may be included in the cross section, dictated by the project and project objectives. Resulting information produces a channel cross section as in figure 16–2 (adapted from Harrelson, Rawlins, and Potyondy 1994). Channel slope can be determined by taking additional elevation measurements upstream and downstream from the cross sections and calculating the changes in slope. In this way, a survey plot of the stream channel and features can be developed (fig. 16–3 (adapted from Harrelson, Rawlins, and Potyondy 1994)).

As elevation measurements are taken, sampling for chemical attributes, sediment, and some biological attributes such as habitat structure (table 16–5) can be obtained at the same time. Harrelson, Rawlins, and Potyondy (1994) provide guidance on basic surveying techniques.

Longitudinal profile—The longitudinal profile establishes how the stream and flood plain change in elevation as the stream flows through the study reach. The slope is determined by successive measurements of water surface, channel bottom, bankfull stage, flood plain, and terraces. Most biological attributes (table 16–5) have distribution, size, or density dimensions requiring measurement over an area, not just a cross section. Establishing longitudinal monitoring sample locations is appropriate for projects that stabilize headcutting, restore riparian vegetation or aquatic habitat, and for some erosion protection projects.

Establishment of a permanent longitudinal profile for monitoring requires identifying a permanent location that has the project features (vegetation) that are important to monitoring. The longitudinal profile should encompass an area 300 to 500 feet along the stream (or approximately 20 times the channel width at bankfull). The survey should be wide enough to measure both banks,

Figure 16–2 Diagram of a cross-sectional survey

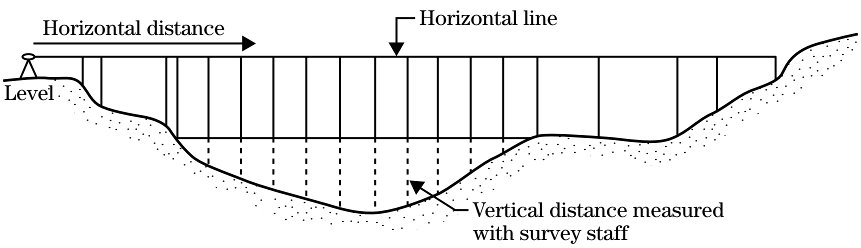
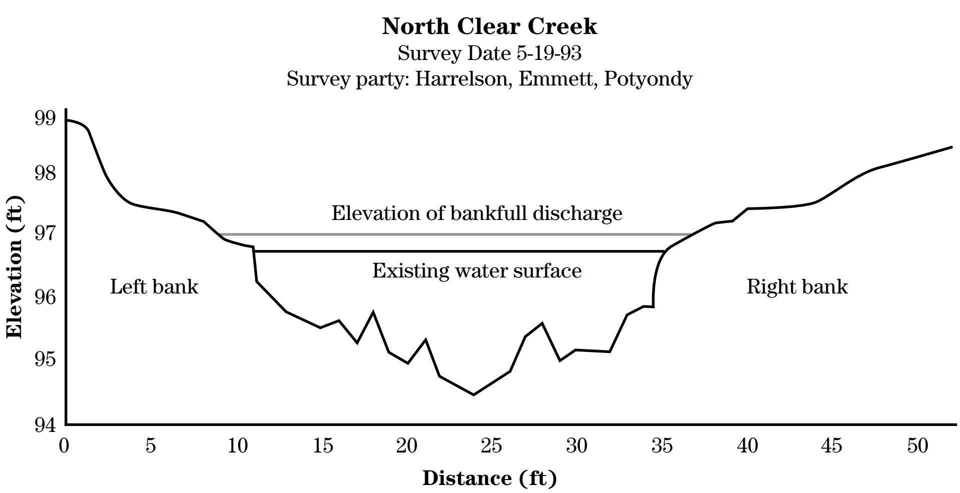


Figure 16–3 Final plot of cross section



the active flood plain, and one or more terraces. A benchmark is established and stations are located at intervals along the longitudinal profile. A surveyor's level is used to measure the elevations of the channel bottom, water surface, terrace, and flood plain. Plotting of the elevation data along the longitudinal profile results in a plot of the slopes (fig. 16–4).

Bankline surveys—The objectives of some projects are to define or stabilize the bankline, provide capacity for a certain bankfull discharge, or maintain a consistent bank width between reaches. For these projects, bankline surveys are used to monitor change in the bank position, determining if the width between the banks is consistent over time and consistent between reaches of the stream. Bankline surveys are implemented by establishing permanent points along the bankline to be measured over time. In low-gradient, meandering systems, the flood plain is well defined and bankfull stage is clearly marked. Where the flood plain is absent or poorly defined, it may be necessary to establish benchmarks or natural indicators as surrogates, such as vegetation, for the top of bank (Harrleson, Rawlins, and Potyondy 1994). The locations of the bankline reference points are documented and physically benchmarked. The bankline's lateral extent into the flood plain and bank-to-bank width are measured and documented over time.

If bank location and width between channel reaches are of concern, a series of reference bankline points are identified. Monitoring the reference points over time will identify changes in location and width of the bankline along the stream. Changes in width between reaches indicate that the cross sections are changing between sections, and the cause or source of these changes should be identified.

Step 5 Estimate costs.

Costs for maintenance and monitoring plans include:

- personnel and management costs to implement plan
- quality assurance
- data management
- field sampling
- data analysis and interpretation
- maintenance and monitoring report preparation
- presentation of results and recommended changes

Figure 16–4 Graphic representation of longitudinal profile

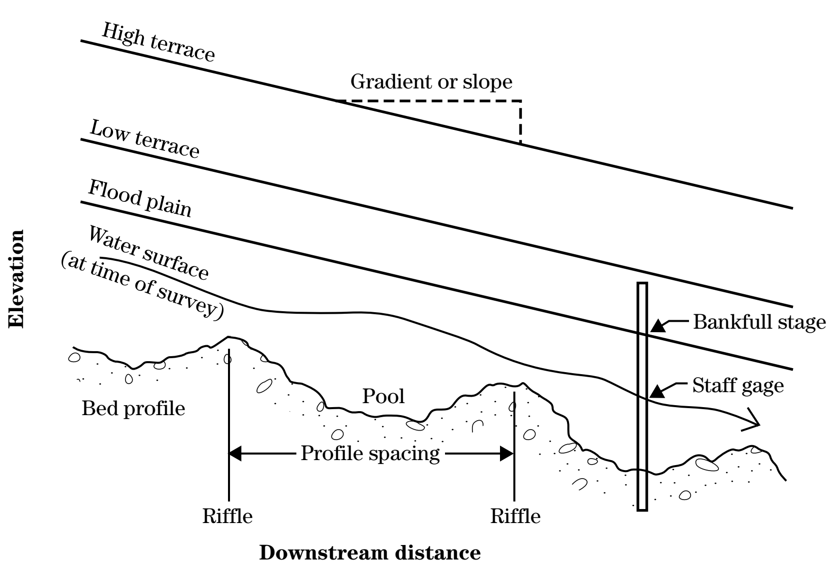


Table 16–9 categorizes the relative costs of monitoring and maintenance as high, medium, and low. Costs vary with region and the intensity and frequency of monitoring and maintenance.

Step 6 Categorize the types and emphasis for data.

The emphasis on data collection changes as the project progresses from planning to implementation to postimplementation.

Planning—

- develop baseline data at the site

Implementation of project—

- monitor construction and management activities
- collect as-built and as-constructed information

Postimplementation—

- collect performance data
- conduct other studies as needed

Step 7 Determine the level of effort and duration.

The level of effort needed for maintenance and monitoring is determined by the goals, objectives, and performance criteria identified in step 3. Maintenance for structures and vegetation is required to meet goals of the project in terms of stabilization, channel capacity, and environmental considerations (FISRWG 1998). The level of effort for monitoring is determined by the goals and objectives and by the end use of the monitoring data. Water quality monitoring to determine whether state water quality standards are met requires a higher level of effort (frequency, data gathered) than monitoring for public access.

Frequency—Frequency of maintenance actions is determined by the type of structure, vegetation, or management measure that is part of the project. Ensuring the proper functioning of the design requires development of maintenance schedules by the responsible agency personnel. For monitoring of physical, chemical, and biological parameters,

Table 16–9 Relative costs of monitoring actions

Type of monitoring and maintenance	Relative costs
Photographic monitoring	Moderate
Windshield survey monitoring	Low
Volunteer monitoring	Low
Cross-sectional profile	High
Longitudinal profile	High
Bankline survey	High
Track watershed trends	Moderate
Chemical parameter monitoring	Low
Biological monitoring	
Primary productivity	Moderate
Fish community	Moderate
Riparian vegetation	High
Habitat structure	High

a sampling plan is developed for the parameter or group of parameters (water quality parameters). Frequency of maintenance and monitoring may decrease as the project and system becomes more established and rates of change decrease. For instance, monitoring of a project may be done annual for the first 3 years, followed by monitoring at 2- to 5-year intervals for the duration of project life.

Duration—Maintenance and monitoring should extend long enough to determine either:

- reasonable assurances of sustainability of the project
- that the system has met performance criteria
- that the system will not likely meet the criteria

Timing—Timing of maintenance activities is important so that structural and vegetative components remain functional. With designs that incorporate soil bioengineering approaches and vegetation, the period after construction is critical to establishment and success of the measures, so higher levels of maintenance and monitoring are required in the immediate postconstruction period. In the winter periods, vegetation and other conditions may not be relevant to the performance criteria and project objectives. Monitoring should be carried out during the time of the year when vegetation and streamflow conditions approximate the conditions used for design.

Sensitivity—The sensitivity of the parameter to change will also determine the level of effort and duration needed to detect a change. In some cases, this may require some statistical analysis. If this is required, it may be appropriate to consult a statistician during the design of the monitoring plan.

(b) Implementing and managing monitoring

Planning for maintenance and monitoring occurs while site design and construction plans are underway and there is normally a great deal of activity. Following construction and beginning of operation of the project, it is important that the monitoring plan is implemented successfully. This takes deliberate effort by the operating agency or authority, with the emphasis then on project operation. Consult the Interagency Guidelines (FISRWG 1998) for suggestions and insights for implementing and managing the monitoring plan.

(c) Responding to monitoring results

Monitoring provides information on performance, biological resources, trends, and risks. The monitoring information serves as the basis for making modifications to the project and operations. The adaptive management section below presents a process for responding to monitoring results. If long-term water quality monitoring shows that the performance criteria are met, then water quality can be considered for deletion from future monitoring. If biological parameters show a lack of nonjuvenile fish, then a fisheries investigation may be indicated. If performance monitoring indicates that performance criteria are not being met, an investigation of the cause should be initiated. This may lead to modification of the project or to the identification of changing conditions within the watershed.

654.1605 Adaptive management

(a) Background for adaptive management

Stream restoration and/or stabilization projects are part of dynamic systems, and over time the project outcomes will likely change (increase or decline) as project life increases. Aquatic habitat, streambank and riparian communities, water flow capacity, and other project conditions may show improvements or deteriorations. Sometimes, there is uncertainty on the point of sustainability (equilibrium), relative to sedimentation, streambank location, or habitat diversity. The prevailing assumptions on which project objectives are based may prove to be erroneous. System relationships and connections may be weak or nonexistent, watershed and local conditions may change, or project design measures may be overkill, and lesser levels of structures, maintenance, or human interference may be called for. The uncertainty in project outcomes and the need for change in project design, operation, and management have given rise to adaptive management. Adaptive management is an approach to natural resource management that incorporates monitoring of project outcomes and uses the monitoring results to make revisions and refinements to ongoing management and operations actions (adapted from National Academy of Science 2002). Figure 16–5 shows the relationship of adaptive management to monitoring, construction, and planning.

(b) Maintenance program and adaptive management

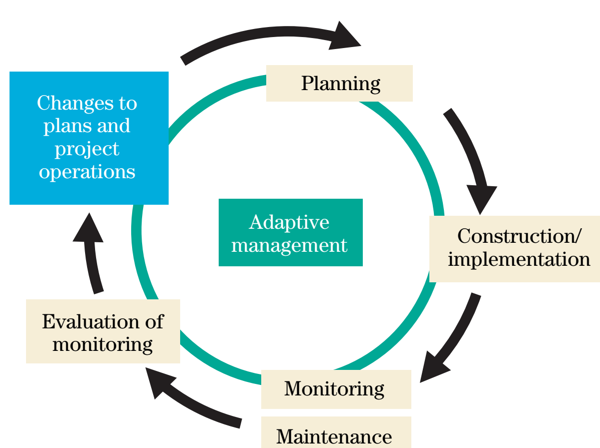
The maintenance and monitoring plans described result in information on project performance (hydrological, geomorphic) and ecological (habitat, water quality) outputs of the projects. In a sense, the system composed of the operating stream restoration project is like an experiment, and the monitoring reports are the findings for the experiment. Assumptions may be proved or disproved, and understandings of relationships may change based on monitoring information. Adaptive management, therefore, incorporates an element of research into conservation projects. Specifically, it is the integration of design, management, and monitoring to systematically test assumptions to adapt and learn (Salafsky, Margoluis, and Redford 2001).

(c) Adaptive management and NRCS projects

The increasing number of projects that incorporate experimental designs and rely on hydrologic, geomorphic, and riparian processes for success has led to application of adaptive management in large and small systems (Save Our Bosque Task Force 2004). Examples of references to adaptive management are (USDA NRCS 1996a):

- Year two process will develop this concept further at the local decisionmaking level. The findings of the interrelationship of ecosystem components will be better understood and promoted for broader planning approaches (ecosystem, whole farm, holistic).
- Steering committee/subcommittee structure with regular meetings and technical input will allow for adjustments to reflect the results of periodic reviews and new scientific information or methodologies. The plan will be revisited regularly and modified as needed.
- Data collected as part of the project monitoring process will be analyzed. Results will be shared to determine if further study is warranted.

Figure 16–5 Adaptive management



(d) Adaptive management in the maintenance and monitoring process

Adaptive management is a part of project operations, most closely related to monitoring. Separate adaptive management programs may be established for larger systems (Raynie and Visser 2002). For most stream restoration projects, reviews of monitoring and inspection information will likely initiate changes in monitoring, maintenance, and operations.

Adaptive management evaluation
Monitoring information is reviewed to answer the following questions (FISRWG 1998):

- Were the project structures, vegetation, and management measures constructed and implemented correctly?
- Did the project measures achieve the desired goals and objectives of the project?
- Are the assumptions used in the project design and cause-effect relationships correct?

Changes resulting from adaptive management evaluations
Revision of project operations, monitoring, and maintenance procedures are identified through adaptive management evaluation. These changes should be incorporated in the project maintenance and monitoring plans and in project operations documentation.

654.1606 Conclusion

Any open channel design work, whether it is a natural stream restoration or a single-purpose design, is done to achieve some specific planned goals or objectives. Maintenance and monitoring plans are often overlooked. However, these are important components of stream design and restoration projects. Monitoring plans ensure that a project is performing as designed and achieving the intended goals. All open channel projects carry some level of inherent risk to life, property and project investment, and monitoring, maintenance, and adaptive management can reduce these risks. Monitoring may also help to avoid catastrophic project failure by identifying problems or performance issues while they can be more cheaply addressed. Finally, the lessons learned from monitoring can be applied to future projects of similar type.

Maintenance is the set of actions taken to ensure that a project's goals or objectives continue to be met. Maintenance may involve the repair of specific project features in response to some damage or the periodic and/or scheduled actions. While projects should be designed to minimize maintenance requirements, the designer should consider what may be required and how it can be linked to the monitoring plan. An ideal maintenance and monitoring plan should provide specific parameters to be assessed to ensure that the project is performing as intended, as well as what maintenance actions should be undertaken.

Adaptive management is an approach to natural resource management that incorporates monitoring of project outcomes and uses the monitoring results to make revisions and refinements to ongoing management and operations actions.