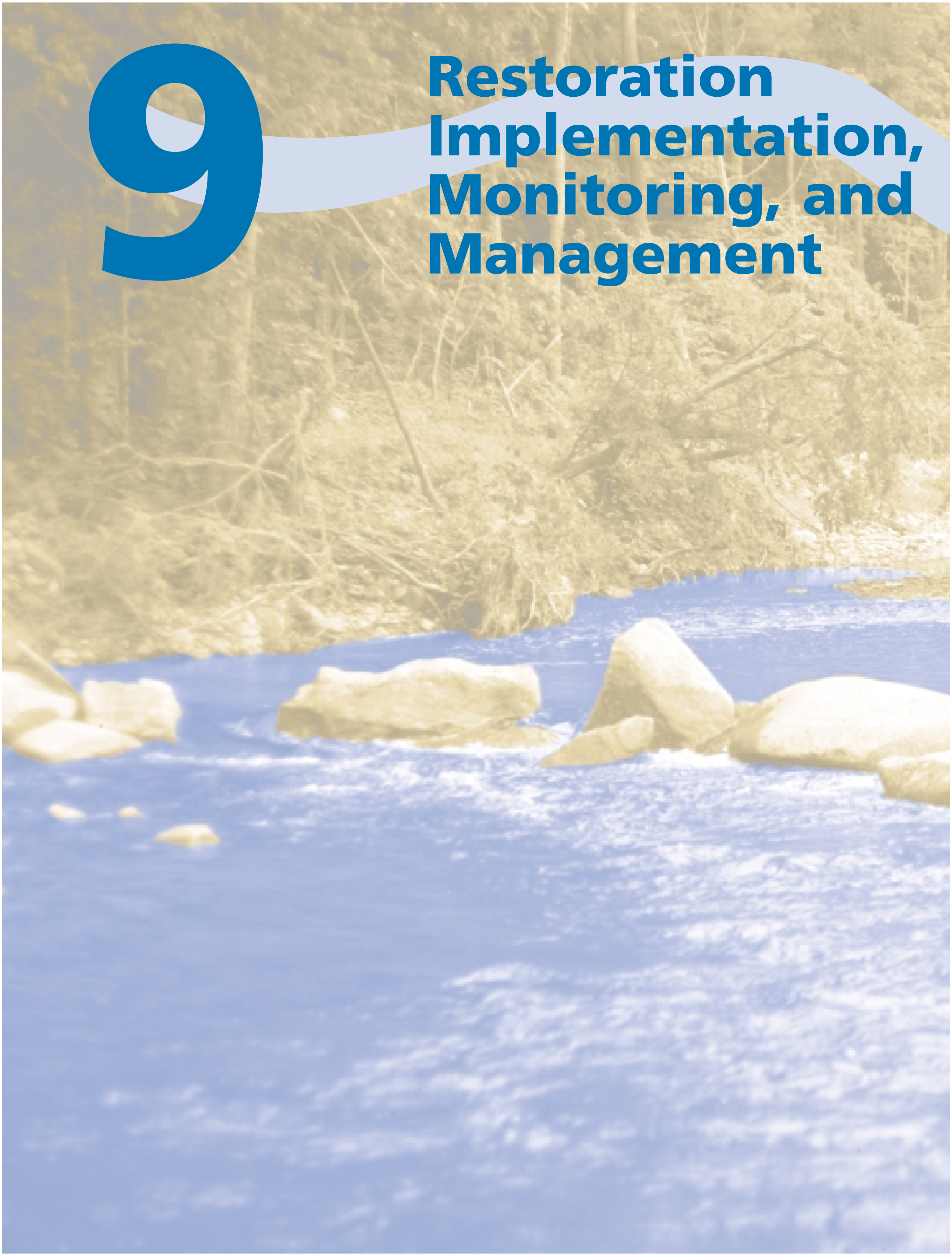
9 Restoration Implementation, Monitoring, and Management



9.A Restoration Implementation

- *What are passive forms of restoration and how are they "implemented"?*
- *What happens after the decision is made to proceed with an active rather than a passive restoration approach?*
- *What type of activities are involved when installing restoration measures?*
- *How can impact on the stream channel and corridor be minimized when installing restoration measures (e.g, water quality, air quality, cultural resources, noise)?*
- *What types of equipment are needed for installing restoration measures?*
- *What are some important considerations regarding construction activities in the stream corridor?*
- *How do you inspect and evaluate the quality and impact of construction activities in the stream corridor?*
- *What types of maintenance measures are necessary to ensure the ongoing success of a restoration?*

9.B Monitoring Techniques Appropriate for Evaluating Restoration

- *What methods are available for monitoring biological attributes of streams?*
- *What can assessment of biological attributes tell you about the status of the stream restoration?*
- *What physical parameters should be included in a monitoring management plan?*
- *How are the physical aspects of the stream corridor evaluated?*
- *How is a restoration monitoring plan developed, and what issues should be addressed in the plan?*
- *What are the sampling plan design issues that must be addressed to adequately detect trends in stream corridor conditions?*
- *How do you ensure that the monitoring information is properly collected, analyzed, and assessed (i.e., quality assurance plans)?*

9.C Restoration Management

- *What are important management priorities with ongoing activities and resource uses within the stream corridor?*
- *What are some management decisions that can be made to support stream restoration?*
- *What are some example impacts and management options with various types of resource use within the stream corridor (e.g., forest management, grazing, mining, fish and wildlife, urbanization)?*
- *When is restoration complete?*

9 Restoration Implementation, Monitoring, and Management

9.A Restoration Implementation
9.B Monitoring Techniques Appropriate for Evaluating Restoration
9.C Restoration Management

*Completion of the restoration design marks the beginning of several important tasks for the stream restoration practitioner. Emphasis must now be placed on prescribing or implementing restoration measures, monitoring and assessing the effectiveness of the restoration, and managing the design to achieve the desired stream corridor conditions (**Figure 9.1**).*

Implementation, management, and monitoring/evaluation may proceed as part of a larger setting, or they may be considered components of a corridor-specific restoration effort. In either case, they require full planning and commitment before the restoration plan is implemented. The technical complexity of a project must be determined by the restoration practitioner based on available resources, technology, and what is necessary to achieve restoration goals. There must be reasonable assurance that there will be continuing access for ongoing inspection, mainte-

Figure 9.1: A restored stream. *Stream corridor restoration measures must be properly installed, monitored, and managed to be successful.*

nance, emergency repairs, management, and monitoring activities as well. All cooperators should be aware that implementation, monitoring, and management might require unanticipated work, and that plans and objectives might change over time as knowledge improves or as changes occur.

This chapter builds on the discussion of restoration implementation, monitoring, evaluation, and adaptive management presented in Chapter 6. Specifically, it moves beyond the planning components associated with these key restoration activities and discusses some of the technical issues and elements that restoration practitioners must consider when installing, monitoring, and managing stream corridor restoration measures.

The discussion that follows is divided into three major sections.

Section 9.A: Restoration Implementation

This first section describes the implementation of restoration measures beyond just removing disturbance factors and taking other passive approaches that allow the stream corridor to restore itself over time.

Technical considerations relating to site preparation, site clearing, construction, inspection, and maintenance are discussed in this section.

Section 9.B: Monitoring Techniques Appropriate for Evaluating Restoration

The purpose of restoration monitoring is to gather data that will help to determine the success of the restoration effort. This section presents some of the monitoring techniques appropriate for evaluating restoration.

Section 9.C: Restoration Management

Management of the restoration begins with the implementation of the plan. The "adaptive management" approach was presented in Chapter 6 as an important part of the planning process. It provides the flexibility to detect when changes are needed to achieve success and to be able to make the necessary midcourse, short-term corrections.

Ideally, the long-term management of a successful restoration will involve only periodic monitoring to check that the system is sustaining itself through natural processes. However, this is rarely the case for stream corridors in human-inhabited landscapes.

New crops, markets, and government programs can rapidly and significantly alter the physical, chemical, and biological characteristics of stream corridors and their watersheds, destroying restoration efforts. Conversion of rural lands *and wildlands to urban uses and exploitation of natural resources can change the landscape and cause natural processes to become unbalanced, leaving the stream corridor with no way to sustain itself.*

Additionally, natural imbalances can occur due to local and regional climatic changes, predation, disease, fire, genetic changes, and catastrophes like earthquakes, hurricanes, tornadoes, volcanic eruptions, landslides, and floods. Long-term management of the restored stream corridor will therefore require vigilance, anticipation, and reaction to future changes.

9.A Restoration Implementation

Implementation of stream corridor restoration must be preceded by careful planning. Such planning should include the following (at a minimum):

- Determining a schedule.
- Obtaining necessary permits.
- Conducting preimplementation meetings.
- Informing and involving property owners.
- Securing site access and easements.
- Locating existing utilities.
- Confirming sources of materials and ensuring standards of materials.

The careful execution of each planning step will help ensure the success of the restoration implementation. Full restoration implementation, however, involves several actions that require careful execution as well as the cooperation of several participants. See Chapters 4 and 5 for specific guidance on planning a stream corridor initiative.

Site Preparation

Site preparation is the first step in the implementation of restoration measures. Preparing the site requires that the following actions be taken.

Delineating Work Zones

The area in which restoration occurs is defined by many disparate factors. This area is determined most fundamentally by the features of the landscape that must be affected to achieve restoration goals. Boundaries of property ownership, restrictions imposed by permit requirements, and natural or cultural features that might have special significance can also determine the *work zone*. A heavy-equipment operator or crew supervisor cannot be expected to be aware of the multiple requirements that govern where work can occur. Thus, delineation of those zones in the field

Major Elements of Restoration Implementation

- *Review of Plans*
- *Site Preparation*
- *Site Clearing*
- *Installation and Construction*
- *Site Reclamation/Cleanup*
- *Inspection*
- *Maintenance*

should be the first activity conducted on the site. The zones should be marked by visible stakes and more preferably by temporary fencing (usually a bright-colored sturdy plastic netting). This delineation should conform to any special restrictions noted or temporary stakes placed during the preconstruction meeting between the project manager and field inspector.

Preparing Access and Staging Areas

A site is often accessed from a public road in an upland portion of the site. Ideally, for convenience, a staging area for crew, equipment, and materials can be located near an access road close to the restoration site but out of the stream corridor and away from wetlands or areas with highly erodible soils. The staging area should also be out of view from public thoroughfares, if possible, to increase security.

Although property ownership, topography, and preexisting roads make access to every site unique, several principles should guide design, placement, and construction of site access:

- Avoid any sensitive wildlife habitat or plant areas or threatened and endangered species and their designated critical habitat.
- Avoid crossing the stream if at all possible; where crossing is unavoidable, a bridge is almost mandatory.
- Minimize slope disturbance since effective erosion control is difficult on a sloped roadway that will be heavily used.
- Construct roadways with low gradients; ensure that storm water runoff drains to outlets; install an adequate roadbed; and, if possible, set up a truck-washing station at the entrance of the construction site to reduce off-site transport of mud and sediment by vehicles.
- In the event of damage to any private or public access roads used to transport equipment or heavy materials to and from the site, those responsible should be identified and appropriate repairs should be made.

Taking Precautions to Minimize Disturbance

Every effort should be made to minimize and, where possible, avoid site disturbance. Emphasis should be placed on addressing protection of existing vegetation and sensitive habitat, erosion and sediment control, protecting air and water quality, protecting cultural resources, minimizing noise, and providing for solid waste disposal and worksite sanitation.

Protection of Existing Vegetation and Sensitive Habitat

Fencing can be an effective way to ensure protection of areas within the construction site that are to remain undisturbed (e.g., vegetation designated to be preserved, sensitive terrestrial habitat, or sensitive wetland habitat).

As in delineating work zones, fencing should be placed around all protected areas during initial site preparation, even before the access road is fully constructed, if possible, but certainly before wholesale earthmoving begins. Fencing material should be easy to see, and areas should be labeled as protection areas. Caution should always be exercised when grading is planned adjacent to a protected area.

Erosion

Many well-established principles of effective erosion and sediment control can be readily applied to stream corridor restoration (Goldman et al. 1986). Every effort should be made to prevent erosion because prevention is always more effective than having to trap already-eroded sediment particles in runoff. Erosion and sediment controls should be installed during initial site preparation.

The most basic method of control is physical screening of areas to remain undisturbed. Properly chosen, installed, and maintained sediment control measures can provide a significant degree of filtration for sediment-bearing runoff (**Figure 9.2**).

Where undisturbed areas lie downslope of implementation activities, one method of controlling sediment is the use of a silt fence, which is normally made of filter fabric. Silt fences can provide a significant degree of filtration for sediment-bearing runoff, but only if correctly chosen, installed, and maintained. Design guidelines for silt fences include the following:

- Drainage area of 1 acre or less.
- Maximum contributing slope gradient of 2 horizontal to 1 vertical.
- Maximum upslope distance of 100 ft.
- Maximum flow velocity of 1 ft./sec.

Installation is even more critical than material type; most fabric fences fail because either runoff carves a channel beneath them or sediment accumulates against them, causing them to collapse. To help prevent failure, the lower edge of the fabric should be placed in a 4- to 12-inch-deep trench, which is then backfilled with native soil or gravel, and wire fencing should be used to support the fabric.

Figure 9.3 presents example silt fence installation guidelines. Properly installed silt fences commonly fail due to lack of maintenance. One rainfall event can deposit enough sediment that failure will occur during the next rainfall event if the sediment against the fence is not removed.

Figure 9.2: Silt fence at a construction site. *Properly chosen and installed silt fences can provide a significant degree of off-site sediment control.*

Erosion and sediment controls should be installed during initial site preparation.

Straw bales are also common sediment control measures. Bales should be placed in trenches about 4 inches deep, staked into the ground, and placed with their ends (not just corners) abutting each other. **Figure 9.4** presents example straw bale installation guidelines. The limitations on siting are the same as for silt fences, but straw bales are typically less durable and might need to be replaced.

Where the scope of a project is so small that no official erosion control plans have been prepared, control measures should be appropriate to the site, installed promptly, and maintained appropriately.

Proper restoration implementation requires managers to prepare for "unexpected" failure of erosion control measures. By the time moderate to heavy rains can be expected, the follow-

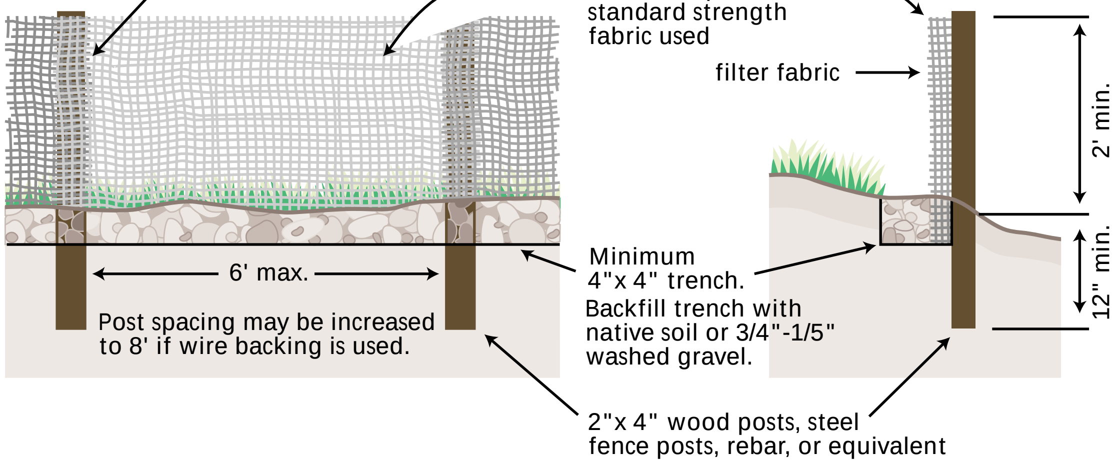


Figure 9.3: Silt fence installation guidelines. *Erosion control measures must be installed properly.*
Source: King County, Washington.

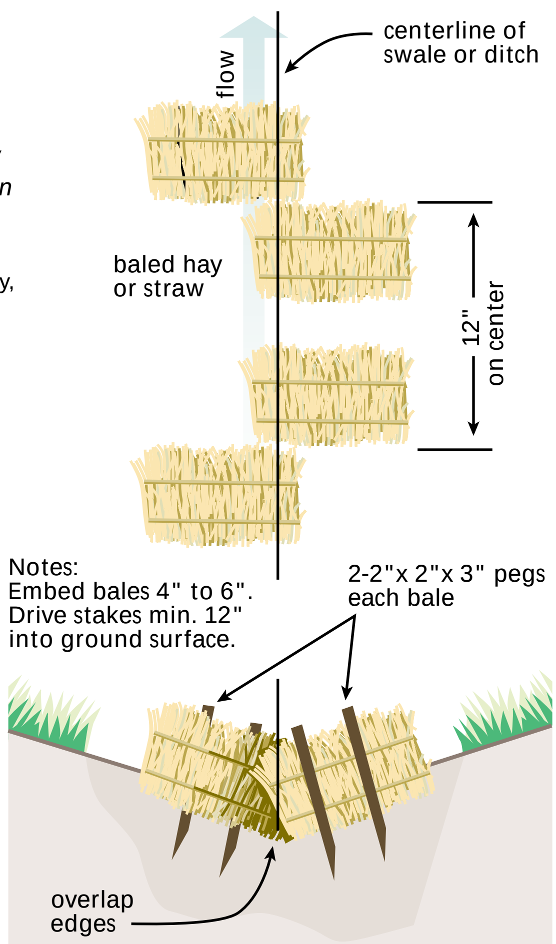


Figure 9.4: Straw bale installation guidelines. *Straw bales are common sediment control measures.*
Source: King County, Washington.

ing preparations should have been made:

- Additional erosion control materials should be stockpiled on site, including straw bales, filter fabric and wire backing, posts, sand and burlap bags, and channel lining materials (rock, geotextile fabric or grids, jute netting, coconut fabric material, etc.).
- Inspection of the construction site should occur during or immediately after a rain storm or other significant runoff event to determine the effectiveness of sediment control measures.
- A telephone number for the site superintendent or project manager should be made available to neighboring residents if they witness any problems on or coming from the site. Residents should be educated on what to watch for, such as sediment-laden runoff or failed structures.

Water Quality

Although sediment is the major source of water quality impairment on construction sites, it is not the only source. Motorized vehicles and equipment or improperly stored containers can leak petroleum products. Vehicles should be steam-cleaned off site on a regular basis and checked for antifreeze leaks and repaired. (Wildlife can be attracted to the sweet taste of most antifreeze and poisoned.) Various other chemicals such as fertilizers and pesticides can be washed off by rain. Most of these problems can be minimized or avoided entirely by thoughtful siting storage areas for chemicals and equipment and staging areas. Gradients should not favor rapid overland flow from these areas into adjacent streams and wetlands. Distances should be as great as possible and the intervening vegetation as dense as site traffic will allow.

Occasionally, implementation activities will require the entry or crossing of heavy equipment into the stream channel (**Figure 9.5**). Construction site planning and layout should always seek to avoid these intrusions. When these intrusions are absolutely necessary, they should be infrequent. Gravelly streambeds are best able to receive traffic; finer substrates should be reinforced with a geoweb network backfilled with gravel. In addition, any equipment used in these activities should be thoroughly steam-cleaned prior to stream entry.

Application of fertilizers and pesticides can also be a source of pollution into water bodies, and their use may be closely regulated in restoration settings. Where their use is permitted, the site manager should closely monitor the quantity applied, the local wind conditions, and the likelihood of rainfall. Potential water quality impacts are a function of the characteristics of the selected pesticide, its form, mode of application, and soil conditions. Pesticides and fertilizers must be stored in a locked and protected storage unit that provides adequate protection from leaks and spills. Pesticides must be prepared or mixed far from streams and, where possible, off site. All containers should be rinsed and disposed of properly.

Figure 9.5: Heavy equipment. *Avoid heavy equipment in stream channels unless absolutely necessary.*

Air Quality

Air quality in the vicinity of a restoration site can be affected by vehicle emissions and dust. Rarely, however, will either be a major concern during implementation activities. Vehicle emissions are regulated at the source (the vehicle), and dust is usually associated primarily with haul roads or major earthmoving during dry periods. The need for dust control should be evaluated during initial restoration implementation and road planning (if not previously determined during the planning phase of the restoration initiative). Site conditions, duration of construction activities, prevailing winds, and proximity to neighbors should be considered when making decisions on dust control. Temporary road surfaces or periodic water spraying of the road surface are both effective in controlling dust. Covered loads and speed limits on all temporary roads will also reduce the potential for construction-related dust and debris leaving the site (Hunt 1993). Where appropriate, use of volunteer labor in lieu of diesel-powered equipment will help to protect air quality in and surrounding the site. Due to safety concerns, it is recommended that volunteers not be used on a site where heavy equipment will also be used.

Cultural Resources

Since stream corridors have been a powerful magnet for human settlement throughout history, it is not uncommon for historic and prehistoric resources to be buried by sediment or obscured by vegetation along stream corridors. It is quite possible to discover cultural resources during restoration implementation (particularly during restoration that requires earth-disturbing activities). (See **Figure 9.6.**)

Prior to implementation, any potential cultural resources should be identified in compliance with section 106 of the National Historic Preservation Act. An archaeological record search should be conducted during the planning process in accordance with the State Historic Preservation Officer (SHPO). If a site is uncovered unexpectedly, all activity that might adversely affect the historic property must cease, and the responsible agency official must notify the U.S. Department of the Interior (USDI) National Park Service and the SHPO. Upon notification, the SHPO determines whether the activity will cause an irreparable loss or degradation of significant data. This might require on-site consultation with a 48-hour response time for determining significance and appropriate mitigation actions so as not to delay implementation activities inordinately.

If the property is determined not to be significant or the action will not be adverse, implementation activities may continue after documenting consultation findings. If the resource is significant and the on-site activity is determined to be an adverse action that cannot be avoided, implementation activities are delayed until appropriate actions can be taken (i.e., detailed survey, recovery, protection, or preservation of the cultural resources). Under the Historical and Archaeological Data Preservation Act of 1974, USDI may assume liability for delays in implementation.

Figure 9.6: Archaeological site. *Cultural resources, such as those at this site in South Dakota, are commonly found near streams.*

Noise

Noise from restoration sites is regulated at the state or local level. Although criteria can vary widely, most establish reasonable and fairly consistent standards.

The U.S. Housing and Urban Development (HUD) agency has set a maximum acceptable construction noise emission of 65 A-weighted decibels (dBA) at the property line. Numerous studies conducted since the late 1960s suggest that community complaints rise dramatically above 55 dBA (Thumann and Miller 1986). Meeting the HUD standard (65 dBA) requires that typical construction equipment be over 300 feet away from the listener; avoiding the chance of any significant complaints requires about 500 feet of separation or more. The project manager should contact surrounding neighbors prior to restoration implementation. Public awareness of and appreciation for the project goals help improve tolerance for off-site noise impacts. (Impacts from noise on equipment operators is usually not significant since most construction equipment meets the noise standards imposed by the U.S. General Services Administration of 75 dBA at 50 feet.)

High noise levels might be a concern to wildlife as well, particularly during the breeding season. Any sensitive species that inhabit the project vicinity should be identified and appropriate actions taken to reduce noise levels that could adversely affect these species.

Solid Waste Disposal

Debris is an inevitable by-product of implementation activities. The management of debris is a matter of job site safety, function, and aesthetics. From the first day, the locations of equipment storage, vehicle unloading, stockpiled materials, and waste should be identified. At the end of each workday, all scattered construction debris, plant materials, soil, and tools should be gathered up and brought to their respective holding areas. The site should be left as neat and well organized as possible at the end of each day. Even during the workday, sites in close proximity to business or residential districts should be kept as well organized and "sightly" as possible to avoid complaints and delays initiated by unhappy neighbors.

The importance of these measures to the safety and efficiency of the restoration effort as a whole is sometimes evident only to the project manager. Under such conditions, achieving adequate job site cleanliness is almost impossible because the manager alone does not have time to tidy up trash and debris. Meetings with work crews to emphasize this element of the work should occur early in the construction process and be repeated as often as required. People working on site, whether contractors, volunteers, or government personnel, need to be reminded of these needs as an unavoidable part of doing their jobs.

Worksite Sanitation

Sanitation facilities for work crews should be identified before construction begins. Particularly in remote areas, the temptation to allow ad hoc arrangements will be high. In urban areas, the existing facilities of a neighboring business might be offered. In most settings, however, one or more portable toilets should be provided and might be required by local building or grading permits. Although normally self-contained, any facilities should be located to minimize the risk of contamination of surface water bodies by leakage or overflow.

Obtaining Appropriate Equipment

Standard earthmoving and planting equipment is appropriate for most restoration work. Small channels or wetland pool areas can be excavated with backhoes or track-mounted excavators or trackhoes. Trackhoes are mobile over rough or steep terrain (**Figure 9.7**). They have adequate reach and power to work at a distance from the stream channel; with an opposing "thumb" on the bucket, they can maneuver individual rocks and logs with remarkable precision. Logs can also be

Figure 9.7: Backhoe in operation at a restoration site. _Backhoes are mobile in rough terrain and can move rocks and logs with remarkable precision._ Source: M. Landin.

placed by a helicopter's cable. Although the hourly rate is about that of the daily cost of ground-based equipment, the ability to reach a stream channel without use of an access road is sometimes indispensable.

Where access is good but the riparian corridor is intact, instream modifications can be made with a telescoping crane. This equipment comes in a variety of sizes. A fairly large, fully mobile unit can extend across a riparian zone 100 feet wide to deliver construction materials to a waiting crew without disturbing the intervening ground or vegetation. Where operational constraints permit their use, bulldozers and scrapers can be very useful, particularly for earthmoving activities that are absolutely necessary to get the job done. In addition, loaders are excellent tools for transporting rocks, transplanting large plants, and digging and placing sod.

For planting, standard farm equipment, such as tractors with mounted disks or harrows, are generally suitable unless the ground is extremely wet and soft. Under these circumstances, light-tracking equipment with low-pressure tires or rubber tracks might work. Seeds planted on restoration sites are commonly broadcast by hydroseeding, requiring a special tank truck with a pump and nozzle for spraying the mixture of seeds, fertilizer, binder, and water (**Figure 9.8**). A wider range of seed species can be planted more effectively with a seed drill towed behind a tractor (e.g., Haferkamp et al. 1985). Where access is limited, hand planting or aerial spreading of seeds might be feasible.

Site Clearing

Once the appropriate construction equipment has been acquired and site preparation has been completed, any necessary site clearing can begin. Site clearing involves setting the geographic limits, removing undesirable plant species, addressing site drainage issues, and protecting and managing desirable existing vegetation.

Geographic Limits

Site clearing should not proceed unless the limits of activity have been clearly marked in the field. Where large trees are present, each should be marked with colored and labeled flagging to ensure that the field crew understands what is to be cut and what is to remain and be protected from damage.

Removal of Undesirable Plant Species

Undesirable plant species include nonnative and invasive species that might threaten the survival of native species. Undesirable plants are normally removed by mechanical means, but the specific method should be tailored to the species of concern if possible. For example, simply cutting the top growth

Figure 9.8: Hydroseeding of a streambank. *Special tank trucks carrying seed, water, and fertilizer can be used in revegetation efforts.*

might be adequate management for some plants, but others might resprout rapidly. Where herbicides are selected (and permitted), their use might need to precede clearing of the top growth by up to 2 weeks to allow full absorption of certain chemicals used for this purpose.

For initial brush removal, a variety of track-mounted and towed equipment is available. Bulldozers are most commonly used because of their ready availability, but other equipment can often work more rapidly or more effectively with minimal site disturbance.

Hand clearing with portable tools might be the only appropriate method in some sensitive or difficult areas.

Drainage

Sites that are very wet and poorly drained might require extra preparation. However, many of the traditional efforts to improve drainage are in partial or direct conflict with wetland-protection regulations and might conflict with the restoration goals of the project as a whole. Standard engineering approaches should be reviewed for appropriateness, as well as the timing and schedule of the restoration activities.

Specific techniques for improving the workability of a wet construction site depend on the particular access, storage needs, and site characteristics. Load-bearing mats can provide stable areas for equipment and the unloading of plant materials. Surface water may be intercepted above the working area by a shallow ditch and temporarily routed around the construction area. Subsurface water can sometimes be intercepted by a perforated pipe set in a shallow trench, such as a French drain, but the topography must be favorable to allow positive drainage of the pipe to a surface outlet.

Protection and Management of Existing Vegetation

Protecting existing vegetation on a restoration site requires a certain degree of attention and advanced planning. An area on a site plan that is far from all earthmoving activity might appear to the site foreman as the ideal location for parking idle equipment or stockpiling excess soil. Only a careless minute with heavy equipment, however, can reduce a vegetated area to churned earth (**Figure 9.9**). Vegetation designed for a protection zone should be clearly marked in the field.

Existing vegetation might also require temporary protection if it occupies a part of the site that will be worked, but only late in the implementation sequence. Before that time, it is best left undisturbed to improve the level of overall erosion control. To save mobilization costs, most earthmoving contractors normally begin construction by clearing every part of the site that will eventually require it. If clearing is to be phased instead, this requirement must be specified in the contract documents and discussed at a preimplementation meeting.

Figure 9.9: ***Lessons to be learned.*** *Heavy equipment can quickly reduce a vegetated area to churned earth.*

When identifying and marking vegetation protection zones, the rooting extent of the vegetation should be respected. Fencing and flagging of protected vegetation should be sturdy and maintained. Despite the cool shade and fencing, vegetation protection zones are neither a picnic area nor a storage/staging area. They are zones of no disturbance.

When working in riparian corridors with mature conifers, it is especially important to protect them from mechanical operations which can cause severe damage.

Installation and Construction

Following site preparation and clearing, restoration installation activities such as earthmoving, diversion of flow, and the installation of plant materials can proceed.

Earthmoving

Fill Placement and Disposal

How and where fill is placed on a site should be determined by the final placement of restoration measures. Fills adjacent to retaining walls or similar structures need to meet the criteria for structural fill.

Where plants will be the final treatment of a fill slope, the requirements for soil materials and compaction are not as severe. Loose soil on a steep slope is still prone to erosion or landsliding, however. Where fill is to be placed on slopes steeper than about 2:1, a soils engineer should determine whether any special measures are appropriate (**Figure 9.10**). Even on gentler slopes, surface runoff from above should not be allowed to saturate the new material

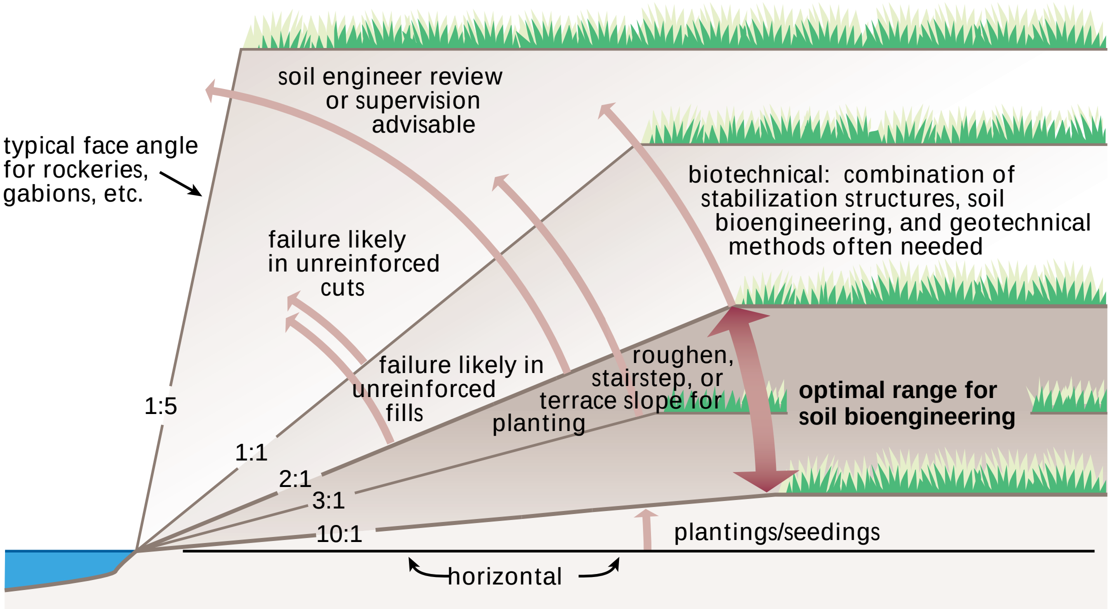


Figure 9.10: Treatment of cuts and fills. *Slope gradient is an important factor in determining appropriate restoration measures.*

since the stability of noncompacted fills is generally quite low.

To reduce grading expenses, the cut and fill should be balanced so no material needs to be transported to or from the site. If the volume of material resulting from cuts exceeds that from fills, some of the soil must be disposed of off-site. Disposal sites can be difficult to locate and might require an additional grading permit from the local jurisdiction. These possibilities should be planned for far enough in advance to avoid unanticipated delays during implementation.

As a general rule, topsoil removed from the site should be properly stockpiled for reuse during the final stages of implementation. Even if undesirable species are present, the topsoil will provide a growth medium suitable for the plant community appropriate to the site. It will also be a source of native species that can reestablish the desired diversity most rapidly (Liebrand and Sykora 1992). Stockpiled soil also can be vegetated with species that will be used at the restoration site to protect the soil from erosion and noxious weeds.

Contouring

The erosive power of water flowing down a slope should be recognized during earthmoving. The steepest direction down a hillside is also the direction of greatest erosion by overland or channelized flow. The overall topography of the graded surface should be designed to minimize the uncontrolled flow of runoff in this direction. Channelized flow should be diverted to ditches cut into the soil that more closely follow the level contours of the land. Dispersed sheet flow should be broken up by terraces or benches along the slope that also follow topographic contours. On a fine scale, the ground surface can be roughened by the tracks of a bulldozer driven up and down the slope, or by a rake or harrow pulled perpendicularly to the slope. In either case, the result is a set of parallel ridges, spaced only a few inches apart, that follow the contours of the land surface and greatly reduce on-site erosion.

Earthmoving should result in a slope that is stable, minimizes surface erosion by virtue of length and gradient, and provides a favorable environment for plant growth.

Final Grading

Earthmoving should result in a slope that is stable, minimizes surface erosion by virtue of length and gradient, and provides a favorable environment for plant growth. The first two criteria are generally determined by plans and can be modified only minimally by variations in grading techniques. Where plans specify a final slope gradient steeper than about 1:1, however, vegetation reestablishment will be very difficult, and a combination of stabilization structures, soil bioengineering, and geotechnical methods will probably be necessary. The shape at the top of the slope is also important: if it forms a straight abrupt edge, plant regrowth will be nearly impossible. A rounded edge that forms a gradual transition between upland and slope will be much more suitable for growth (Animoto 1978).

Providing a favorable environment for plant growth requires attention to the small-scale features of the slope. Rough-textured slopes, resulting from vehicle tracks or serrated blades, provide a much better environment for seedlings than do smooth-packed surfaces (**Figure 9.11**). Small terraces should be cut into slopes steeper than about 3:1 to create sites of moisture accumulation

igure 9.11: Track-oughened area. *Rough-textured lopes provide a much better environment for seedlings han do smooth-packed surfaces.*

and enhanced plant growth. Compaction by excessive reworking from earthmoving equipment can result in a lower rate of rainfall infiltrating the soil and, consequently, a higher rate of erosive surface runoff. The result is a loss of the topsoil needed to support plant growth and less moisture available for the plants that remain.

Diversion of Flow

Channelized flow (from stream channels, ditches, ravines, or swales) might need to be diverted, impounded, or otherwise controlled during implementation of restoration measures. In some cases, this need might be temporary, until final grading is complete or plantings have become established. In other cases, the diversion is a permanent part of the restoration. Permanent facilities frequently replace temporary measures at the same location but are often constructed of different materials.

Temporary dikes, lined or grassed waterways, or pipes can be used to divert channelized flow. Runoff can also be impounded in ponds or sediment basins to allow sediment to settle out.

Most temporary measures are not engineered and are constructed from materials at hand. Dikes (ridges of soil up to a few feet high) are compacted to achieve some stability and are sometimes armored to resist erosion. They are used to keep water from washing over a newly graded or planted slope where erosion is otherwise likely, and to divert runoff into a natural or artificial channel. The loosened soil from swales can be readily compacted into an adjacent dike, improving the efficiency and capacity of the runoff diversion. Pipes or rock-lined ditches can carry channelized water down a slope that is steep enough to otherwise suffer erosion; they can also be used to halt erosion that has already occurred from uncontrolled discharges. Flexible plastic pipe is most commonly used in these situations, although the outlet must be carefully located or well armored with rocks or sandbags to avoid merely shifting the point of erosion farther downslope.

Sediment ponds and traps are basins either dug into the soil with a rock-armored overflow or impounded by an embankment with an outlet. A fraction of the sediment carried by the site runoff will settle out in the trap, depending on the ratio of surface area or storage volume to inflow rate. The utility of sediment ponds may be limited depending on the sediment-trapping efficiency. A sediment pond can also release nearly as much sediment as is ultimately trapped if the pond is not built to handle maximum surface water flows or is not maintained properly.

Several techniques are available where the active streamflow must be temporarily isolated from installation activities. Most common are temporary dams, constructed of sandbags, geotextile fences, water control structures, or sheet piles. All may be suitable in certain situations, but have drawbacks. Sandbags are inexpensive, but submerged burlap sacks rot quickly and the sand used to fill them might not be appropriate for the stream. Fabric fences can be used in conjunction with sandbags, but they will not withstand high flows. Water control structures, such as long water-filled tubes available commercially, can be very effective, but need ample lateral space and carry a high initial cost. They also can be swept away by high flows. Sheet piles are effective if heavy equipment is already on site, but their installation and removal can mobilize much fine sediment.

Alternatively, water can be diverted into a bypass pipe, normally made of large flexible plastic (unless anticipated discharges are very great), and the construction area can be kept totally and reliably dry. A dam must be constructed at the pipe inlet to shunt the water, and an adequate apron of nonerosive material must be provided at the discharge. Both of these structures can themselves lead to instream damage, but with care the problems are only temporary. Since fish passage and migration are generally precluded with such a diversion, its applicability is limited.

In some situations unexpectedly erosive conditions will demand better outlet or channel protection than that originally specified in the plans. Erosion control in these settings might require a thick blanket of angular rocks and geotextiles (cloth, plastic grids, or netting) used with plantings. New types of geotextiles are becoming widely available and can serve a wide range of flow conditions. Where possible, channels and spillways should be stabilized using soil bioengineering or other appropriate techniques.

Installation of Plant Materials

Plant establishment is an important part of most restoration initiatives that require active restoration. Detailed local standards and specifications that describe planting techniques and establishment procedures should be developed. Native species should be used where possible to achieve the restoration goals. Vegetation can be installed by seeding; planting vegetative cuttings; or using nursery-grown bare-rooted, potted, and burlap-wrapped specimens. If natural colonization and succession is appropriate, techniques may include controlling exotic species and establishing an initial plant community to hasten succession.

Plant establishment is an important part of most restoration initiatives that require active restoration.

Timing

The optimum conditions for successful plant installations are broad and vary from region to region. As a general rule, temperature, moisture, and sunlight must be adequate for germination and establishment. In the eastern and midwestern United States, these conditions are met beginning in late winter or early spring, after ground thawing, and continuing through mid-autumn. In the West, the typical summertime dryness normally limits successful seedings to late summer or early autumn. Where arid conditions persist through most of the year, plants and seedings must take advantage of whatever rainfall occurs, typically in late autumn or winter, or supplemental irrigation must be provided. Because the requirements can vary so much for different species, the local supplier or a comprehensive reference text (e.g., Schopmeyer 1974, Fordham and Spraker 1977, Hartmann and Kester 1983, Dirr and Heuser 1987) should be consulted early in the restoration design phase. If rooted stock is to be propagated from seed before it is planted at the restoration site, 1 to 2 years (including seed-collection time) should be allowed.

Plants should be installed when dormant for the highest rate of survival. Survival is further influenced by species used and how well they are matched to site conditions, available moisture, and time of installation. In mild climates, the growth of roots occurs throughout the winter, improving survival of fall plantings. Where high wintertime flows are anticipated, however, first-season cuttings might not survive unless given some physical protection from scour. Alternatively, planting can occur in the spring before dormancy ends, but supplemental irrigation might be needed even in areas of abundant summertime rainfall. Irrigation might be necessary in some regions of the country to ensure successful establishment of vegetation.

Acquisition

Native plant species are preferred over exotic ones, which might result in unforeseen problems. Some plant materials can be obtained from commercial sources, but many will need to be collected. When attempting to restore native plant communities, it is desirable to use appropriate genotypes. This requires the collection of seeds and plants from local sources. Early contact with selected sources of rooted stock and seed can ensure that appropriate species in adequate quantities will be available when needed.

The site itself might also be a good source of salvageable plants. Live cuttings can be collected from healthy native vegetation at the donor site. Sharp, clean equipment must be used to harvest the plant material. Vegetation is normally cut at a 40 to 50 degree angle using loppers, pruners, or saws. If the whole plant is being used, the cut is made about 10 inches above the ground, which encourages rapid regeneration in most species. Cuttings typically range from 0.4 to 2 inches in diameter and 2 to 7 feet long.

After harvesting, the donor site should be left in a clean condition. This will avoid the potential for landowner complaints and facilitate potential reuse of the site at some time in the future. Large unused material can be cut for firewood, piled for wildlife cover, or scattered to hasten decomposition. Any diseased material should be burned, per local ordinances.

Transportation and Storage

The requirements for the transport and storage of plant materials vary, depending on the type of material being used. Depending on species, seeds may require a minimum period of dormancy of several weeks or months, with specific temperature requirements during that time. Some seeds may also require scarifying or other special treatment. Nurseries that specialize in native plants are recommended because they should be cognizant of any special requirements. Although the necessary information for any chosen species should be readily available from local seed sources or agricultural extension offices, this interval must be recognized and accounted for in the overall implementation schedule.

Live cuttings present rather severe limitations on holding time. In most cases, they should be installed on the day they are harvested, unless refrigerated storage areas are secured. Thus, donor sites must be close to the restoration site, and access and transportation must be orchestrated to coincide with the correct stage of construction. Live cuttings should be tied in manageable bundles, with the cut ends all lying in the same direction. Since drying is the major threat to survival at this stage, cuttings should be covered with damp burlap during transport and storage (**Figure 9.12**). They should always be shaded from direct sun. On days with low humidity and temperatures above 60 degrees Fahrenheit, the need for care and speed is particularly great. Where temperatures are below this level, "day-after" installation is acceptable, although not optimal. Any greater delay in installation will require refrigeration, reliably cold weather on site, or storage in water.

Figure 9.12: Live cuttings covered with damp burlap to prevent drying during transport. *Drying is a major threat to survival of live cuttings during transport and storage.*

Rooted stock is also prone to drying, particularly if pots or burlap-wrapped roots are exposed to direct sun. Submergence of the roots in water is not recommended for long periods, but 1 to 2 hours of immersion immediately prior to planting is a common practice to ensure the plant begins its in-place growth without a moisture deficit. On-site storage areas should be chosen with ample shade for pots. Bare-rooted or burlap-wrapped stock should be heeled into damp ground or mulch while awaiting final installation.

Planting Principles

The specific types of plants and plant installations are generally specified in the construction plans and therefore will have been determined long before implementation. A project manager or site foreman should also know the basic installation principles and techniques for the area.

The type of soil used should be determined by the types of plants to be supported. Ideally, the plants have been chosen to match existing site conditions, so stockpiled topsoil can be used to cover the plant material following layout. However, part of the rehabilitation of a severely disturbed site might require the removal of unsuitable topsoil or the import of new topsoil. In these situations, the requirements of the chosen plant species should be determined carefully and the soil procured from suitable commercial or field sites that have no residual chemicals and undesirable plant species.

When using seeds, planting should be preceded by elimination of competing plants and by preparation of the seedbed (McGinnies 1984). The most common methods of seeding in a restoration setting are hand broadcasting and hydroseeding. Hydroseeding and other methods of mechanical seeding might be limited by vehicular access to the restoration site.

When using either cuttings or rooted stock, the soil and the roots must make good contact. This requires compaction of the soil, either by foot or by equipment, to avoid air pockets. It also requires that the soil be at the right moisture content. If it is too dry (a rare condition), the soil particles cannot "slip" past each other to fill in voids. If it is too wet (far more common, especially in wetland or riparian environments), the water cannot squeeze out of the soil rapidly enough to allow compaction to occur.

Another aspect to consider is that quite frequently after planting, the resulting soil is too rough and loose to support vigorous seed growth. The roughness promotes rapid drying, and the looseness yields poor seed-to-soil contact and also erratic planting depths where mechanical seed drills are used. As a result, some means of compaction should be employed to return the soil to an acceptable state for planting.

Special problems may be encountered in arid or semiarid areas (Anderson et al. 1984). The salt content of the soil in these settings is critical and should be tested before planting. Deep tillage is advisable, with holes augured for saplings extended to the water table if at all possible. First-year irrigation is mandatory; ongoing fertilization and weeding will also improve survival.

Competing Plants

Although a well-chosen and established plant community should require no human assistance to maintain vigor and function, competition from other plants during establishment might be a problem. Competing plants commonly do not provide the same long-term benefits for stability, erosion control, wildlife habitat, or food supply. The restoration plan therefore must include some means to suppress or eliminate them during the first year or two after construction.

Competing plants may be controlled adequately by mechanical means. Cutting the top growth of competing plants can slow their development long enough for the desired plants to become established. Hand weeding is also very effective, although it is usually feasible only for small sites or those with an ongoing source of volunteer labor.

Unfortunately, some species can survive even the most extreme mechanical treatment. They will continue to reemerge until heavily shaded or crowded out by dense competing stands. In such cases the alternatives are limited. The soil containing the roots of the undesired vegetation can be excavated and screened or removed from the site, relatively mature trees can be planted to achieve near-instantaneous shading, or chemical fertilizers or herbicides can be applied.

Use of Chemicals

In situations where mechanical controls are not enough, the application of fertilizers and the use of herbicides to suppress undesirable competing species may be necessary.

Herbicides can eliminate undesirable species more reliably, but they may eliminate desirable species. Their use near watercourses may also be severely curtailed by local, state, and federal permit requirements. Several herbicides are approved for near-stream use and degrade quickly, but their use should be considered a last resort and the effects of excessive spray or overspray carefully controlled.

If herbicide use is both advisable and permitted, the specific choice is based first on whether the herbicide is absorbed by the leaves or by the roots (e.g., Jacoby 1987). The most common foliar-absorbed herbicide is 2,4-D, manufactured by numerous companies and particularly effective on broadleaf weeds and some shrubs. Other foliar herbicides have become available more recently and are commonly mixed with 2,4-D for broad-spectrum control. Root-absorbed herbicides are either sprayed (commonly mixed with dye to show the area of application) or spread in granular form. They persist longer than most foliar herbicides, and some are formulated to kill newly sprouted weeds for some time after application.

Since herbicides and fertilizers may be problematic near surface water, they should be used only if other alternatives are not available.

Mulches

Mulching limits surface erosion, suppresses weeds, retains soil moisture, and can add some organic material to the soil following decomposition. A variety of mulches are available with different benefits and limitations, as shown in **Table 9.1**.

Organic mulches, particularly those based on wood (chips or sawdust), have a high nitrogen demand because of the chemical reactions of decomposition. If nitrogen is not supplied by fertilizers, it will be extracted from the soil, which can have detrimental effects on the vegetation that is mulched. Certain species of wood, such as redwood and cedar, are toxic to certain species of seedlings and should not be used for mulch.

Straw is a common mulch applied on construction and revegetation sites because it is inexpensive, available, and effective for erosion control. Appropriate application rates range from about 3,000 to 8,000 lb/acre. Straw can be spread by hand or broadcast by machine, although uniform application is difficult in windy conditions. Straw must be anchored for the same reason: it is easily transported by wind. It can be punched or crimped into the soil mechanically, which is rapid and inexpensive, but requires high application rates. It can be covered with jute or plastic netting, or it can be covered with a sprayed tackifier (usually asphalt emulsion at rates of about 400 gal/acre). Straw or hay can also be a source of un-

Since herbicides and fertilizers may be problematic near surface-water, they should be used only if other alternatives are not available.

Mulch	Benefits	Limitations
Chipped wood	Readily available; inexpensive; judged attractive by most	High nitrogen demand; may inhibit seedlings; may float offsite in surface runoff
Rock	May be locally available and inexpensive	Can inhibit plant growth; adds no nutrients; suppresses diverse plant community; high cost where locally unsuitable or unavailable
Straw or hay	Available and inexpensive; may add undesirable seeds	May need anchoring; may include undesirable seeds
Hydraulic mulches	Blankets soil rapidly and inexpensively	Provides only shallow-rooted grasses, but may out compete woody vegetation
Fabric mats	Relatively (organic) or very (inorganic) durable; works on steep slopes	High costs; suppresses most plant growth; inorganic materials harmful to wildlife
Commercial compost	Excellent soil amendment at moderate cost	Limited erosion-control effectiveness; expensive over large areas

Table 9.1: Types of mulches.

desirable weed seed and should be inspected prior to application.

Wood fibers provide the primary mechanical protection in hydraulic mulches (usually applied during hydroseeding). Rates of 1 to 1.5 tons/acre are most effective. They can also be applied as the tackifier over straw at about one-third the above rate. Hydraulic mulches are adequate, but not as effective as straw, for controlling erosion in most settings. However, they can be applied on slopes steeper than 2:1, at distances of 100 feet or more, and in the wind. On typical earthmoving and construction projects, they are favored because of the speed at which they can be applied and the appearance of the resulting slope—tidy, smooth, and faintly green. The potential drawbacks—introducing fertilizers and foreign grasses that are frequently mixed into hydraulic mulches—should be carefully evaluated.

An appropriate mulch in many restoration settings is a combination of straw and organic netting, such as jute or coconut fibers (**Figure 9.13**). It is the most costly of the commonly used systems, but erosion control and moisture retention are highly effective, and the problems with undesirable seeds and excess fertilizers are reduced. The value of an effective mulch to the final success of an initiative is generally well in excess of its cost, even when the most expensive treatment is used.

The value of an effective mulch to the final success of an initiative is generally well in excess of its cost, even when the most expensive treatment is used.

Irrigation

In any restoration that involves replanting, the need for irrigation should be carefully evaluated. Irrigation might not be needed in wetland and near-stream riparian sites or where rainfall is well distributed throughout the year. Irrigation may be essential to ensure success on upland sites, in riparian zones where seasonal construction periods limit installation to dry months, or where a wet-weather planting may have to endure a first-year drought. Initial costs are lowest with a simple overhead spraying system. Spray systems, however, have inefficient water delivery and have heightened potential for vandalism. Drip-irrigation systems are therefore more suitable at many sites (Goldner 1984). There is also a greater potential for undesirable species with spray irrigation since the area between individual plants receives moisture.

Fencing

If the plant species chosen for the site are suitable, little or no special effort will be necessary for survival and establishment. During the initial construction and postconstruction phases, however, plants will commonly need some measure of physical protection. Construction equipment, work crews, onlookers, grazing horses and cattle, and browsing deer and other herbivores can reduce a new plant installation to barren or crushed twigs in very short order. Vandalism is also a potential problem in populated areas. Fencing is an effective, low-cost method to provide

Figure 9.13: A well-mulched site. *Mulching is an effective method for improving the final outcome of stream corridor restoration.*

physical protection from these types of hazards and should be included in virtually any restoration.

The type of fencing should be chosen for the type of hazard anticipated. Inexpensive, fluorescent orange plastic fencing is very effective for controlling people and equipment during construction, but it rarely makes a suitable long-term barrier. Domestic cattle can be controlled by a variety of wood and wire fences (**Figure 9.14**). Depending on the density of grazing animals, these fences are best assumed to be permanent installations and their design chosen accordingly. Electric fences can also be effective, and the higher cost of the electrification equipment can be offset by lower costs for materials and installation. Where deer are a known problem, fencing must be robust, but it probably will not need to remain in place permanently after well-chosen plants have matured. Damage from small mammals may be halted with chicken wire alone, surrounding individual saplings, or below-ground collars. Individual wire cages or other control devices might be necessary to protect trees.

Inspection

Frequent, periodic inspection of work, whether done by a landowner, contractor, volunteer group, or government personnel, is mandatory. Defects such as poor planting methods, stressed plant materials, inadequate soil compaction, or sloppy erosion control, may become evident only weeks or months after completion of work unless the activities on the site are regularly reviewed. Some of those activities may require specialized testing, such as the degree of compaction of a fill slope. Most require little more than observations by an inspector familiar with all elements of the design.

Figure 9.14: A permanent livestock fence. *Fencing is an effective, low-cost method of providing physical protection to restoration sites.*

In the case of contracted work, it is the responsibility of the construction inspector to monitor installation activities to ensure that the contractor completes work according to the contract plans and specifications. At key points during construction, the inspector should consult with clients and design team(s) for assistance. The inspector should create comprehensive documentation of the construction history in anticipation of any future audit or quantity dispute. All inspections should result in a written record that includes at least the information shown in **Figure 9.15**.

Daily and weekly reports are invaluable to maintain clear communication about billable days, progress, and anticipated problems. These written reports establish the authority to release payment to the contractor and provide the main documentation in case of a dispute between the client and contractor. Completeness, timeliness, and clarity of documentation are critical.

Inspection of restoration elements that involve management actions (i.e., land-use controls, grazing restrictions, etc.) require follow-up communication with the resource manager or landowner. A

Inspector's Daily Report

Date:

Project:

Contractor:

Inspector:

Temperature: H____ L____ Precip:____ Hours: Workable____ Nonworkable____

Work Done ____________________

Contractor Equipment On-Site ____________________

Personnel On-Site ____________________

Materials Used and Location ____________________

Remarks ____________________

Inspection Time ____________

Inspector's Signature ________________

Figure 9.15: Sample of an inspector's daily report. *Frequent, periodic inspection is a mandatory part of restoration implementation.*

review of the action against the plan and applicable standards should be conducted. For example, rotational grazing may be a critical plan element to achieve restoration of the stream corridor. Inspection of this plan element would involve a review of the rotation scheme, condition of individual pastures or ranges, and condition of fencing and related watering devices.

Keep in mind that although plans and specifications should be specific to the conditions of the site, they might have been developed from generic sets or from those implemented elsewhere.

On-Site Inspection Following Installation

The final inspection after installation determines the conditions under which the contractor(s) can be paid and the contract finalized. It must occur promptly and should determine whether all elements of the contract have been fulfilled satisfactorily. Before scheduling this final inspection, the project manager and inspector, together with any other necessary members of the restoration team, inspect the work and prepare a list of all items requiring completion by the contractor. This "pre-final" inspection is in fact the most comprehensive review of the work that will occur, so it must be conducted with care and after nearly all of the work has been completed. The final inspection should occur with representatives of both the client and the contractor present after completion of all required work and after site cleanup, but before equipment is removed from the site to facilitate additional work if necessary. It must address removal of protection measures no longer needed, such as silt fences. These are an eyesore and might inhibit restoration. A written report should state the complete or provisional acceptance of the work, the basis on which that judgment has been made, and any additional work that is needed prior to final acceptance and payment.

Follow-up Inspections

Planning for successful implementation should always look beyond the period of installation to the much longer interval of plant establishment. Twelve or more additional site visits are advisable over a period of many months or years. Such inspections will generally require a separate budget item that must be anticipated during restoration planning. If they are included in the specifications, they may be the responsibility of the contractor. A sample inspection schedule is shown in **Table 9.2**. Although this level of activity after installation might seem beyond the scope of a project, any restoration work that depends on the growth of vegetation will benefit greatly from periodic review, particularly during the first two years.

Documentation of follow-up inspections is important, both to justify recommendations and to provide a record from which chronic problems can be identified. Documentation can include standard checklists, survey data, cross sections, data sheets, data summaries, and field notes. Sketches, maps, and permanent photo points can be used to document vegetation development. Videotape can be particularly useful to document the performance of structures during various flows, to illustrate wildlife use and floodplain storage of floodwaters, and otherwise to record the performance and functions of the corridor system.

Inspection reports are primarily intended to address maintenance issues. Problems discovered in the inspection process should be documented in a report that details deficiencies, recommends specific maintenance, and explains the consequences of not addressing the problems. Postplanting inspections to ensure survival require documentation and immediate action. Consequently, the reporting and response loop should be simple and direct so that inspections indicating the need for emergency structural repairs can be reported and resolved without delay.

General Inspection

To the extent feasible, the entire stream corridor should be inspected annually to detect areas of rapid bank erosion or debris accumulation (**Figure 9.16**). A general inspection can also identify inappropriate land uses, such as encroachments of roads near banks or uncontrolled irrigation water returns, that might jeopardize restoration measures, affect water quality, or otherwise

Table 9.2: Sample inspection schedule.

Time Since Installation	Inspection Interval
2 Months	2 weeks (4 total)
6 Months	1 month (5 total)
2 Years	6 months (3 total)

interfere with restoration objectives. The integrity of fences, water access, crossings, and other livestock control measures should be inspected (**Figure 9.17**). Lack of compliance with agreed-upon best management practices should be noted as well. Aerial photos are particularly useful in the overview inspection, but inspections by boat or on foot can be more informative in many cases.

Bank and Channel Structures

Special inspections should be conducted following high flows, particularly after the first flood event following installation. Soil bioengineering measures should be assessed during prolonged drought and immediately after high flows during the first few years fol-

Figure 9.16: Flood debris. *The entire corridor should be inspected annually to detect areas of debris accumulation from flood flows.*

lowing installation until the system is well established.

Most routine inspections of bank and channel measures should be conducted during low-water conditions to allow viewing of the measure as well as channel bed changes that might threaten its future integrity. This is particularly true of bank stabilization works where the principal mechanism of bank failure is undermining at the toe. A low water inspection should involve looking for displaced rock, settling or tilting, undermining, and similar problems (Johnson and Stypula 1993).

In the past, bank stabilization measures were routinely cleared of vegetation to facilitate inspection and prevent damage such as displacement of rock by trees uprooted from a revetment during a flood. However, evidence that vegetation compromises revetment integrity has not been documented (Shields 1987, 1988). Leaving vegetation in place or planting vegetation through rock blankets has been encouraged to realize the environmental benefits of vegetated streambanks. Consequently, agencies have modified inspection and maintenance guidelines accordingly in some areas.

igure 9.17: Fencing. *he integrity of encing should be nspected periodi-ally.*

Vegetation

Streambanks that have been stabilized using plantings alone or soil bioengineering techniques require inspections, especially in the first year or two after planting (**Figure 9.18**). It is important that the planted material be checked frequently to ensure that the material is alive and growing satisfactorily. Any dead material should be replaced and the cause of mortality determined and corrected if possible. If the site requires watering, rodent control, or other remedial actions, the problem must be detected and resolved immediately or the damage may become severe enough to require extensive or complete replanting. Competition from weeds should be noted if it is likely to suppress new plantings. If nonnative plants capable of invading and outcompeting native species are known to be present in the area, both plantings and existing native vegetation should be inspected. Any newly established nonnative populations should be eradicated quickly.

After the first growing season, semiannual to annual evaluations should be sufficient in most cases. At the end of a 2-year period, 50 percent or more of the originally installed plant material should be healthy and growing well (**Figure 9.19**). If not, determining the cause of die-off and subsequent replanting will probably be necessary. If the installation itself is determined to have been improper, any warranty or dispute-resolution clauses in the plant installation contract might need to be invoked.

The effectiveness of bank protection is based largely on the development of the plants and their ability to bind soils at moderate flow velocities. The bank protection measures should be inspected immediately after high-flow events in the first few years, particularly if the plantings have not fully established. Washouts, slumping of geogrids, and similar problems require detection and correction, since they might become the sites of further deterioration and complete failure if left uncorrected.

Floodplain and other off-channel plantings might be important components of the corridor restoration plan as well. Inspection requirements are similar to those on streambank sites but are less critical to the integrity of the project in terms of preventing additional damage. Nevertheless, several site visits are appropriate during the first growing season to detect problems due to browsing, insects, too much or too little water, and other causes. Inspection of plantings that require irrigation during establishment, as well as of the irrigation system, may be needed on a weekly or more frequent basis.

Techniques for inspecting vegetation survival are fairly straightforward. Satisfactory survival rates may be determined using stem counts within sample plots or estimates of cover percentages, depending on the purpose of the plantings. For example, Johnson and Stypula (1993) suggest that woody plantings established for streambank protection should not include open spaces more than 2 feet in dimension. In most cases, such criteria can be established in advance based on common-sense decisions regarding the adequacy of establishment relative to the objectives. Where more detailed monitoring is appropriate to document development of habitat quality or similar objectives, more rigorous monitoring techniques can be used. (See Section 9.B).

Urban Features

Stream corridor objectives may require periodic inspections of features other than the stream, streambank, and corridor vegetation. In urban areas, these features may be a major focus of the inspection program. Facilities, nest boxes, trails, roads, storm water systems, and similar features must be inspected to ensure they are in satisfactory condition and are not contributing to degradation of the stream corridor. Access points required to accomplish maintenance and emergency repairs should be checked for serviceability. Popular public use areas, particularly stream access points, should be evaluated to determine

Figure 9.18: Revegetation project. *It is important that the planted material be inspected frequently to ensure that it is alive and growing satisfactorily.*

Figure 9.19: Revegetation project, 1 to 2 years postconstruction. *At the end of a 2-year period, 50 percent or more of the original plantings should be healthy and growing well.*
Source: King County, Washington.

FAST FORWARD

Preview Section 9.B, Monitoring Techniques Appropriate for Evaluation Restoration.

whether measures are being damaged, erosion is being initiated, or project objectives are otherwise being impeded. Inspection should reveal whether signs, trail closures, and other traffic-control measures are in place and effective. Trash and debris dumping, off-road vehicle damage, vandalism, and a wide variety of other detrimental occurrences may be noted during routine inspections.

Maintenance

Maintenance encompasses those repairs to restoration measures which are based on problems noted in annual inspections, are part of regularly scheduled upkeep, or arise on an emergency basis.

- *Remedial maintenance* is triggered by the results of the annual inspection (**Figure 9.20**). The inspection report should identify and prioritize maintenance needs that are not emergencies, but that are unlikely to be addressed through normal scheduled maintenance.
- *Scheduled maintenance* is performed at intervals that are preestablished during the design phase or based on project-specific needs. Such maintenance activities as clearing culverts or regrading roads can be anticipated, scheduled, and funded well in advance. In many instances, the scheduled maintenance fund can be a tempting source for emergency funds, but this can result in neglect of routine maintenance, which may eventually produce a new, more costly, emergency.
- *Emergency maintenance* requires immediate mobilization to repair or prevent damage. It may include measures such as replacement of plants that fail to establish in a soil bioengineered bank stabilization, or repair of a failing revetment. Where there is a reasonable probability that repair or replacement might be required (e.g., anything that depends on vegetation establishment), sources of funding, labor, and materials should be identified in advance as part of the contingency planning process. However, there should be some general strategy for allowing rapid response to any emergency.

Figure 9.20: Remedial maintenance. *Soil bioengineering used to repair failing revetment.*

Many maintenance actions will require permits, and such requirements should be identified well in advance to accommodate permitting delays. Similarly, access to areas likely to require maintenance (e.g., bank stabilization structures) should be guaranteed at the time of construction, and the serviceability of access roads verified periodically.

Various agencies and utilities may have maintenance responsibilities that involve portions of the stream corridor, such as road and transmission line crossings. This work should be coordinated as necessary to ensure there are no conflicts with corridor objectives.

Channels and Floodplains

Corridor restoration that includes reconfiguration of the channel and floodplain may require remedial action if the system does not perform as expected in the first few years after work has been completed. Any repairs or redesign, however, should be based on a careful analysis of the failure. Some readjustment is to be expected, and a continuing dynamic behavior is fundamental to successful restoration. Because establishment of a dynamic equilibrium condition is usually the intent, maintenance should be limited to actions that promote self-sustainability.

Many traditional channel maintenance actions may be inappropriate in the context of stream corridor restoration. In particular, removal of woody debris may be contrary to restoration objectives (**Figure 9.21**). Appropriate levels of woody debris loading should be a design specification of the project, and the decision to remove or reposition particular pieces should be based on specific concerns, such as unacceptably accelerated bank erosion due to flow deflection, creation of ice jams causing an increased chance for flooding, or concerns about safety in streams with high recreational use. In cases where woody debris sources have been depleted, periodic addition of debris may be a prescribed maintenance activity. (See next page for story on engineered log jams.)

Protection/Enhancement Measures

Measures intended to enhance fish habitat, deflect flows, or protect banks are likely to require periodic maintenance. If failure occurs soon after installation, the purpose and design of the measure should be reevaluated before it is repaired, and the mechanism of failure should be identified. Early failure is an inherent risk of soil- bioengineered systems that are not fully effective until the plants are well rooted and the stems reach a particular size and density. Although a design weakness may be identifiable and should be corrected, more often the mechanism of failure will be that the measure has not yet developed

Figure 9.21: Accumulated woody debris. *Removal of woody debris may be contrary to restoration objectives.*

full resistance to high-flow velocities or saturation of bank soils. Replanting should be an anticipated potential maintenance need in this situation.

In many stream corridor restoration areas, the intent of streambank and channel measures is to provide temporary stabilization until riparian vegetation develops and assumes those functions. In such cases, maintenance of some structures might become less important over time, and they might eventually be allowed to deteriorate. They can be wholly or partially removed if they represent impediments to natural patterns of channel migration and configuration, or if some components (cables, stone, geofabrics) become hazards.

Vegetation

Routine maintenance of vegetation includes removal of hazardous trees and branches that threaten safety, buildings, fences, and other structures, as well as maintenance of vegetation along road shoulders, trails, and similar features.

Planted vegetation may require irrigation, fertilization, pest control, and similar measures during the first few years of establishment. In large-scale planting efforts, such as floodplain reforestation efforts, maintenance may be precluded. Occasionally, replanting will be needed because of theft.

Maintenance plans should anticipate the need to replant in case soil- bioengineered bank protection structures are subjected to prolonged high water or drought before the plants are fully established. Techniques using numerous cuttings establish successfully, it might be desirable to thin the dense brush that develops to allow particular trees to grow more rapidly, especially if channel shading is a restoration objective. Often, bank protection measures become popular points for people to access the stream (for fishing, etc.). Plantings can be physically removed or trampled. Replanting, fencing, posting signs, or taking other measures might be needed.

Other Features

A wide variety of other restoration features will require regular maintenance or repair. Rural restoration efforts might require regular maintenance and periodic major repair or replacement of fences and access roads for management and fire control. Public use areas and recreational facilities require upkeep of roads, trails, drainage systems, signs, and so forth (**Figure 9.22**). Maintenance of urban corridors may be intensive, requiring trash removal, lighting, and other steps. An administrative contact should be readily available to address problems as they develop. As the level of public use increases, contracting of maintenance services might become necessary, and administration of maintenance duties will become an increasingly important component of corridor management.

Restoration measures placed to benefit fish and wildlife (e.g., nest boxes and platforms, waterers) need annual cleaning and repair. These maintenance activities can be as time-consuming as the original installation, and structures that are in bad condition might draw public attention and criticism. The maintenance commitment should be recognized before such structures are installed. Special wildlife management units, such as moist-soil-management impoundments and green-tree reservoirs, require close attention to be managed effectively.

Flooding and drawdown schedules must be fine-tuned based on site-specific conditions (Fredrickson and Taylor 1982). Special equipment might be needed to maintain levees, to work on soft ground, to repair drainage structures, and to pump out facilities, all of which might incur substantial fuel costs. The maintenance needs in these kinds of situations require that professional resource managers be on site regularly. Not operating the restoration attentively can create nuisance or hazardous conditions, have severe detrimental effects on existing resources, and fail to produce the desired results.

Mosquito control may also be a maintenance concern near inhabited areas, particularly if the restoration encourages the development of slack-water areas, such as beaver ponds, backwaters, and floodplain depressions. In some cases, control techniques may directly interfere with restoration objectives, but threats to people and livestock might make them necessary.

Figure 9.22: Streamside trail. *Public use areas and recreational facilities require upkeep of roads, trails, and signs.*

9.B Monitoring Techniques Appropriate for Evaluating Restoration

As discussed in Chapter 6, the completion of implementation does not mark the end of the restoration process. Restoration practitioners must plan for and invest in the monitoring of stream corridor restoration. The type and extent of monitoring will depend on specific management objectives developed as a result of stream corridor characterization and condition analysis. Monitoring may be conducted for a number of different purposes including:

- *Performance evaluation:* Assessed in terms of project implementation and ecological effectiveness. Ecological relationships used in monitoring and assessment are validated through collection of field data.
- *Trend assessment:* Includes longer term sampling to evaluate changing ecological conditions at various spatial and temporal scales.
- *Risk assessment:* Used to identify causes and sources of impairment within ecosystems.
- *Baseline characterization:* Used to quantify ecological processes operating in a particular area.

This section examines monitoring from the perspective of evaluating the performance of a restoration initiative. Such initiatives seek to restore the structure and functions discussed in earlier chapters. Designing a monitoring program that directly relates to those valued functions requires careful planning to ensure that a sufficient amount of information is collected. Such monitoring uses measurements of physical, biological, and chemical parameters to evalu-

REVERSE

Review previous chapters for an introduction to the restoration of stream corridor structure and functions.

CASE STUDY

Engineered Log Jams for Bank Protection and Habitat Restoration

Most riverbank protection measures are not designed to improve aquatic or riparian habitat, and many restoration initiatives lack sufficient engineering and geomorphic analysis to effectively restore natural functions of riparian and aquatic ecosystems. The ecological importance of instream woody debris (WD) has been well documented. Woody debris within a stream can often influence the instream channel structure by increasing the occurrence of pools and riffles. As a result, streams with WD typically have less erosion, slower routing of organic detritus (the main food source for aquatic invertebrates), and greater habitat diversity than straight, even-gradient streams with no debris. Woody debris also provides habitat cover for aquatic species and characteristics ideally suited for fish spawning.

*Reintroduction of WD (or log jams) in many parts of the United States has been extensive, but limited understanding of WD stability has hampered many of these efforts. Engineered log jams (ELJs) can restore riverine habitat and in some situations can provide effective bank protection (**Figure 9.23**). Although WD is often considered a hazard because of its apparent mobility, research in Olympic National Park has documented that stable WD jams can occur throughout a drainage basin (Abbe et al. 1997). Even in large alluvial channels that migrate at rates of 30 ft./yr, jams can persist for centuries, creating a mosaic of stable sites that in turn host the large trees necessary to initiate stable jams. Engineered log jams are designed to emulate natural jams and can meet management or restoration objectives such as bank protection and debris retention.*

After learning about the uncertainty and potential risks of creating man-made log jams, landowners near Packwood, Washington, decided the potential environmental, economic, and aesthetic benefits outweighed the risks. An experimental project consisting of three ELJs was implemented to control severe erosion along 1,400 ft. of the upper Cowlitz River. The channel at the site was 645 ft. wide and had an average bank erosion rate of 50 ft./yr from 1990 to 1995. Five weeks after constructing the log jams, the project experienced a 20-year recurrence flow (30,000 ft.^{3}/s). Each ELJ remained intact and met design objectives by transforming an eroding shoreline into a local depositional environment (i.e., accreting shoreline). Approximately 93 tons of WD that was in transport during the flood was trapped by the ELJs, alleviating downstream hazards and enhancing structure stability. Improvements in physical habitat included creation of complex scour pools at each ELJ (Abbe et al. 1997).

Landowners have been delighted by the experiment. The ELJs have remained intact, increased in size, and reclaimed some of the formerly eroded property even after being subjected to major floods in February 1996 and March 1997. When compared to traditional bank stabilization methods, which typically employ the extensive use of exotic materials such as rock rarely found in low-gradient alluvial channels, ELJs can offer an effective and low-cost alternative for erosion control, flood control, and habitat enhancement. The cumulative effect of most traditional bank stabilization methods over time results in progressive channel confinement and detachment of the riparian environment from the channel (e.g., loss of streamside vegetation). In stark contrast, the cumulative effects of using ELJs include long-term protection of a significant floodplain, improvement of instream and riparian habitat, and bank stabilization (Abbe et al. 1997).

Comprehensive geomorphic and hydraulic engineering analysis is required to determine the type of WD needed and the appropriate size, position, spacing, and type of ELJ structure for the particular site(s) and project objectives. Inappropriate design and application of ELJs can result in negative impacts such as local accelerated bank erosion, unstable debris, or channel avulsion. Acknowledging the potential risks and uncertainties of ELJs, their use should be limited to well-documented experimental situations. Continued research and development of ELJs involving field application in a variety of physiographic and climatic conditions is needed. ELJs can provide a means to meet numerous objectives in the management and restoration of rivers and riparian corridors throughout the United States.

Figure 9.23: Engineered log jams. *Engineered log jams (ELJs) can restore riverine habitat and in some situations provide effective bank protection.*

REVERSE

Review Chapter 7D's section on analytical methods for evaluating biological attributes.

Adaptive management provides the opportunity for course correction through evaluation and action.

ate the effectiveness of the restoration and to facilitate adaptive management where needed. Sampling locations, measurements to be made, techniques to be used, and how the results will be analyzed are important considerations in monitoring.

Adaptive Management

The implementation, effectiveness, and validation components of performance monitoring provide a vehicle to determine the need for adaptive management. Adaptive management is the process of establishing checkpoints to determine whether proper actions have been taken and are effective in providing desired results. Adaptive management provides the opportunity for course correction through evaluation and action.

Implementation Monitoring

Implementation monitoring answers the question, "Were restoration measures done and done correctly?" Evaluating the effectiveness of restoration through physical, biological, and/or chemical monitoring can be time-consuming, expensive, and technically challenging. Time and partnerships are needed to build the capability for evaluating project effectiveness based on changes in ecological condition. Therefore, an important interim step to this goal is implementation monitoring. This comparatively simple process of documenting what was done and whether or not it was done properly can yield valuable information that promotes refinement of restoration practices.

Effectiveness Monitoring

Effective monitoring answers the question "Did restoration measures achieve the desired results?" or more simply "Did the restoration initiative work?" Effectiveness monitoring evaluates success by determining whether the restoration had the desired effect on the ecosystem. Monitoring variables focus on indicators that document achievement of desired conditions and are closely linked with project goals. It is important that indicators selected for effectiveness monitoring are sensitive enough to show change, are measurable, are detectable and have statistical validity. This level of monitoring is more time-consuming than implementation monitoring, making it more costly. To save time and money, monitoring at this level is usually performed on a sample population or portion of a project with results extrapolated to the whole population.

Validation Monitoring

Validation monitoring answers the question "Are the assumptions used in restoration design and cause-effect relationships correct?" Validation monitoring considers assumptions made during planning and execution of restoration measures. This level of monitoring is performed in response to nonachievement of desired results once proper implementation is confirmed. A restoration initiative that fails to achieve intended results could be the result of improper assumptions relative to ecological conditions or selection of invalid monitoring indicators. This level of monitoring is always costly and requires scientific expertise.

Evaluation Parameters

Physical Parameters

A variety of channel measurements are appropriate for performance evaluation (**Figure 9.24**). The parameters presented in **Table 9.3** should be considered for measurement of physical performance and stability. Stream pattern and morphology are a result of the interaction of eight measurable parameters—width, depth, channel slope, roughness of channel materials, discharge, velocity, sediment loads, and sediment size (Leopold et al. 1964). These parameters and several other dimensionless ratios (including entrenchment, width/depth ratio, sinuosity, and meander/width ratio) can be used to group stream systems with similar form and pattern. They have been used as delineative criteria in stream classification (Rosgen 1996). Natural streams are not random in their variation.

A change in any of the primary stream variables results in a series of channel adjustments, resulting in alterations of channel pattern and form, and attendant changes in riparian and aquatic habitat.

Figure 9.24: Measurement of a stream corridor. *Monitoring the physical aspects of the stream corridor system is important in evaluating the success of any restoration effort.*

REVERSE

Review Chapters 2 and 7 for information on chemical water parameters and their sampling. Also, review Chapter 8's section on reference reaches.

Biological Parameters

Biological monitoring can cover a broad range of organisms, riparian conditions, and sampling techniques. In most cases, budget and staff will limit the diversity and intensity of evaluation methods chosen. Analytical methods for evaluating biological attributes are discussed in Section 7.D of this document.

Table 9.4 provides examples of the biological attributes of stream ecosystems that may be related to restoration goals. Biological aspects of the stream corridor that may be monitored as part of performance goals include primary productivity, invertebrate and fish communities, riparian/terrestrial wildlife, and riparian vegetation. This may involve monitoring habitat or fauna to determine the degree of success of revegetation efforts or instream habitat improvements.

Biological monitoring programs can include the use of chemical measures. For example, if specific stressors within the stream system, such as high water temperatures and low dissolved oxygen, limit biological communities, direct monitoring of these attributes can provide an evaluation of the performance of more intensive remedial practices, including point source pollution reduction.

Chemical Parameters

Monitoring is necessary to determine if a restoration initiative has had the desired effect on water chemistry. The type and extent of chemical monitoring depends upon the goal of the monitoring program. Major chemical parameters of water and their sampling are discussed in Chapters 2 and 7.

A factor in designing a chemical monitoring approach is the amount of change expected in a system. If the

Table 9.3: Physical parameters to be considered in establishing evaluation criteria for measurement of physical performance and stability.

Plan view	Sinuosity, width, bars, riffles, pools, boulders, logs
Cross sectional profiles — by reach and features	Sketch of full cross section
	Bank response angle
	Depth bankfull
	Width
	Width/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 (all reaches)	Varies with classification system
Assessment of hydrologic flow regimes through monitoring	2-, 5-, 10-year storm hydrographs
	Discharge and velocity of base flow
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

restoration goal, for example, is to reduce the salinity in a stream by 5 percent, it would be much more difficult to detect than a goal of reducing salinity by 50 percent.

Chemical monitoring can often be used in conjunction with biological monitoring. There are pros and cons for using chemical and biological parameters when monitoring. Biological parameters are often good integrators of several water quality parameters. Biological indicators are especially useful when determining the bioaccumulation of a chemical.

Water chemistry samples are typically easier to replicate, can disclose slow changes over time, and be used to prevent catastrophic events when chemical characteristics are near toxic levels. For example, water quality monitoring might detect a slow decrease in pH over a period of time. Some aquatic organisms, such as trout, might not respond to this gradual change until the water becomes toxic. However, water quality monitoring could detect the change and thereby avoid a catastrophic event. An ideal monitoring program would include both biological and chemical parameters.

Important chemical and physical parameters that might have a significant influence on biological systems include the following:

- Temperature
- Turbidity
- Dissolved oxygen
- pH
- Natural toxics (mercury) and manufactured toxics
- Flow
- Nutrients
- Organic loading (BOD, TOC, etc.)
- Alkalinity/Acidity
- Hardness
- Dissolved and suspended solids
- Channel characteristics
- Spawning gravel
- Instream cover
- Shade
- Pool/riffle ratio
- Springs and ground water seeps
- Bed material load
- Amount and size distribution of large woody debris (i.e., fallen trees)

These parameters may be studied independently or in conjunction with biological measurements of the ecological community.

Table 9.4: Examples of biological attributes and corresponding parameters that may be related to restoration goals and monitored as part of performance evaluation.

Biological Attribute	Parameter
Primary productivity	Periphyton
	Plankton
	Vascular and nonvascular macrophytes
Zooplankton/diatoms	
Invertebrate community	Species
	Numbers
	Diversity
	Biomass
	Macro/micro
	Aquatic/terrestrial
Fish community	Anadromous and resident species
	Specific populations or life stages
	Number of outmigrating smolts
	Number of returning adults
Riparian wildlife/ terrestrial community	Amphibians/reptiles
	Mammals
	Birds
Riparian vegetation	Structure
	Composition
	Condition
	Function
	Changes in time (succession, colonization, extirpation, etc.)

Reference Sites

Understanding the process of change requires periodic monitoring and measurement and scientific interpretation of the information as it relates to the stream corridor. In turn, an evaluation of the amount of change attributed to restoration must be based on established reference conditions developed by the monitoring of reference sites. The following are important considerations in reference site selection:

- What do we want to know about the stream corridor?
- Are identified sites minimally-disturbed?
- Are the identified sites representative of a given ecological region, and do they reflect the range of natural vari-

Performance Evaluation of Fish Barrier Modifications

Fish barrier modifications provide a good example of a technically difficult performance evaluation. The goal of the restoration is easily understood and stated. Barrier modification provides one of two options—to increase populations (increase upstream and downstream movement) or to decrease populations (restrict movement).

In all cases, the specific target species should be identified. If the goal is to restore historic runs of commercial fishes, data for commercial landings may be available to provide guidance. Habitat models are available for species such as Atlantic salmon and can provide insight into expected carrying capacities of nursery habitat. Existing runs in adjacent or nearby river(s) may be examined for population levels and trends that can provide insight into realistic goals. Barriers may be planned for only short-term protection of some species (e.g., protection against cannibalism) or for longer term exclusion of problematic or undesirable species.

*Methodologies to evaluate the success of fish barrier modifications can use a variety of field methods to count the number of adult spawners, to determine the abundance of fry, to estimate the size of the outmigrating juvenile population, or to monitor the travel time between specific points within a watershed (**Table 9.5**). However, consideration needs to be given to factors that may influence the success of the population outside the study area. Commercial fishing, disease, predation, limited food supply, or carrying capacity of juvenile or adult habitat may be more important controlling factors than access to spawning and nursery habitat.*

Table 9.5: Methods to evaluate effectiveness of fish barrier modifications.

Modification	Method
Fishway counts	Observation windows
	Hydroacoustics
	Fish traps/weirs
	Netting
Population estimates	Mark and recapture
	Snorkel counts
	Redd counts
	Creel census
	Direct counts of spawning adults
Timing of migration between observation points	Radio tagging
	Pit tags
	Dyes and other external marks
	Computer-coded tags

The performance evaluation must allow ample time for the species to complete its life cycle. Many anadromous species have life spans of 4 to 7 years; sturgeon live for decades. Adequate homing to natal areas may require several generations to build a significant migrating population and to fill all year classes. Floods or droughts can impact fry and juvenile life stages and do not become apparent in adult spawning populations until several years have elapsed. Restoration and monitoring goals need to be formulated to take these non-restoration-limiting factors into account. Examination of year-class structure of returning adults might be useful, or investigations that average the size of spawning runs for multiple years might be appropriate.

Performance evaluation study methodologies must use appropriate monitoring techniques. Collecting techniques need to be relatively nondestructive. Collecting weirs, traps, or nets need to be designed to limit injury or predation and should function over a wide range of flow and debris levels. Monitoring techniques should not extensively *limit movement. Weirs and traps should not cause excessive delays in migration, and fish tags should not encumber movement. Techniques are often species- and life stage-specific. Fish tags, including radio tags, may be appropriate for older, larger individuals, whereas chemical marks, dyes, fin clips, or internal microtags may be appropriate for smaller organisms. Certain fish, such as alosids (American shad and river herring), may be more difficult to handle than others, such as salmonids (trout and salmon), and appropriate handling techniques need to be used. Avoiding extreme environmental conditions (excessively high or low water temperature or flow) may be important. Nondestructive techniques, such as hydroacousitics and radio tags, have several advantages, but care needs to be taken to differentiate between background noise (mechanical, debris, entrained air, nonlaminar flow), other species, and target species.*

ability associated with a given stream class?

- What is the least number of sites required to establish reference conditions?
- What are the impediments to reference site access?

Reference sites provide examples of a properly functioning ecosystem. It is from these reference sites that desired conditions are determined and levels of environmental indicators identified. Environmental indicators become the performance criteria to monitor the success of a initiative.

Human Interest Factors

Human activities requiring use of a healthy environment may often be important factors for evaluating stream corridor restorations (**Figure 9.25**). In these cases, the ability of the stream corridor to support the activity indicates benefits drawn from the stream corridor as well as adding insight into stream ecosystem condition. Many human interest-oriented criteria used in performance evaluations can serve the dual function of evaluating elements of human use and ecological condition together:

Many human interest-oriented criteria used in performance evaluations can serve the dual function of evaluating elements of human use and ecological condition together.

Figure 9.25: Human interest in the stream corridor. *Aesthetics are a highly valued benefit associated with a healthy stream corridor.*

Additional References for Monitoring

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- Human health (disease, toxic/fish consumption advisories)
- Aesthetics (odor, views, sound, litter)
- Non-consumptive recreation (hiking, birding, whitewater rafting, canoeing, outdoor photography)
- Consumptive recreation (fishing, hunting)
- Research and educational uses
- Protection of property (erosion control, floodwater retention)

Use surveys, which determine the success of the restoration in terms of human use, can provide additional biological data. Angler survey, creel census, birding questionnaires, and sign-in trail boxes that request observations of specific species can also provide biological data. Citizens' groups can participate effectively, providing valuable assistance at minimal cost.

9.C Restoration Management

Management is the long-term manipulation and protection of restoration resources to achieve objectives. Management priorities for the stream corridor ecosystem are set during the planning phase and refined during design. These priorities should also be subject to ongoing revision based on regular monitoring and analysis. Management needs can range from relatively passive approaches that involve removal of acute impacts to intensive efforts designed to restore ecosystem functions through active intervention. Whereas a preceding section described the need to provide adequate maintenance for the restoration elements, restoration management is the collective set of decisions made to guide the entire restoration effort to success.

Management needs can range from relatively passive approaches that involve removal of acute impacts to intensive efforts designed to restore ecosystem functions through active intervention.

The restoration setting and the priorities of participants can make management a fairly straightforward process or a complex process that involves numerous agencies, landowners, and interested citizens. Development of a management plan is less difficult when the corridor and watershed are under the control of a single owner or agency that can clearly state objectives and priorities. Some stream corridor restorations have, in fact, involved extensive land acquisition to achieve sufficient management control to make restoration feasible. Even then, competing interests can exist. Decisions must be made regarding which resource uses are compatible with the defined objectives.

More commonly, stream corridor management decisions will be made in an environment of conflicting interests, overlapping mandates and regulatory jurisdictions, and complex ownership patterns, both in the corridor and in the surrounding watershed. For example, in a Charles River corridor project in Massachusetts, the complex ownership pattern along the river requires direct active management in some areas and easements in others. In the remainder, management is largely a matter of encouraging appropriate use (Barron 1989). Many smaller restorations might be similarly diversified with management decisions involving a variety of participants. Participation and adherence to restoration best management practices (BMPs) may be encouraged through various programs, such as the NRCS's Conservation Reserve Program, multi-agency riparian buffer restoration initiatives, and cost-sharing opportunities available under the EPA Section 319 Program.

Programs intended to reduce nonpoint source pollution of waterways often encourage the use of practices to address problems such as agricultural runoff or sediment generated by timber harvest operations. Because many practices focus on activities within the stream corridor, existing practices should be reviewed to determine their applicability to the stream corridor restoration plan (**Figure 9.26**). Although the ecological restoration objectives for the corridor might require more restrictive management, existing practices can provide a good starting point and establish a rationale for minimum management prescriptions. In stream corridor restoration efforts involving numerous landowners, it might be appropriate to develop a revised set of practices specific to the restoration area. Participants should have the opportunity to participate in developing the practices and should be willing to commit to compliance before the restoration is implemented.

Regulatory controls influencing management options are increasingly complex and require regular review as management plans evolve and adapt. In some areas, regulatory oversight of activities in streamside areas and in the vicinity of wetlands involves fairly rigid rules that may conflict with specific proposed management actions (e.g., selective tree removals). Implementation of management actions in such cases will require coordination and approval from the regulating agencies. Many state and local jurisdictions vary their restrictions according to classification systems reflecting the condition of the streamside area or wetland in terms of "naturalness"; for example, sites with large trees might receive a higher level of protection than sites that have been heavily disturbed.

Restoration is intended specifically to improve the condition of the stream corridor; however, an activity that is allowable initially might be regulated as the corridor condition improves. These changes should be anticipated to the extent possible in developing long-term management and use plans.

Streams

In effect, stream corridor restoration and ongoing monitoring constitute stream management. Many problems detected during monitoring can be resolved by manipulation of the stream corridor vegetation (**Figure 9.27**), land uses, where possible, and only occasionally, by direct physical manipulation of the channel. If "resetting" of the channel system is necessary, it essentially becomes a redesign problem. Where lateral erosion occurs in unanticipated areas and poses an unacceptable threat to function, property, or infrastructure, another restoration approach might have to be initiated.

Figure 9.26: Livestock fences used as a BMP. *Reviewing existing BMPs can be useful in establishing management prescriptions.*

Figure 9.27: Pruning streamside vegetation. *Monitoring might detect the need for manipulation of streamside vegetation.*

In cases where streamflow control is an option, it likely will be a significant component of the management plan to maintain baseflows, water temperatures, and other attributes. However, appropriate flow patterns should have been defined during the design phase, with components of corridor management prescribed accordingly. If hydrologic patterns change after the restoration is established, significant redesign or management changes might be required for the entire corridor. Ultimately, a well-planned, prepared stream corridor restoration design predicts and addresses the potential for hydrologic change.

Forests

In forested environments, the planning and design phases of stream corridor restoration should set specific objectives for forest structure and composition within the corridor. If existing forests are developing in the desired direction, action may not be needed. In this case, forest management consists of protection rather than intervention. In degraded stream corridor forests, achieving desired goals requires active forest management. In many corridors economic return to private and public landowners is an important objective of the restoration plan. Stream corridor restoration may accommodate economic returns from forest management, but management within the stream corridor should be driven primarily by ecological objectives. If the basic goal is to restore and maintain ecological functions, silviculture should imitate natural processes that normally occur in the corridor.

Numerous forest management activities can promote ecological objectives. For example, some corridor forest types might benefit from prescribed fire or wildfire management programs that maintain natural patterns of structural and compositional diversity and regeneration. In other systems, fire might be inappropriate or might be precluded if the stream corridor is in an urban setting. In the latter case, silvicultural treatments might be needed to emulate the effects of fire.

Recovery of degraded streamside forests can be encouraged and accelerated through silvicultural efforts. Active intervention and management may be essential to maintain the character of native plant communities where river regulation has contributed to hydrology and sedimentation patterns that result in isolation from seed sources (Klimas 1991, Johnson 1994). Streamside forests used as buffers to prevent nutrients from reaching streams may require periodic harvests to remove biomass and maintain net uptake (Lowrance et al. 1984, Welsch 1991). However, buffers intended to intercept and degrade herbicides might be most effective if they are managed to achieve old-growth conditions (Entry et al. 1995).

Management of corridor forests should not proceed in isolation from management of adjacent upland systems (**Figure 9.28**). Upland harvests can result in raised water tables and tree mortality in riparian zones. Coordinated silvicultural activities can reduce timber losses as well as minimize the need for roads (Oliver and Hinckley 1987).

Forests managed by government agencies are usually subject to established restrictions on activities in riparian areas. Elsewhere, BMPs for forestry practices are designed to minimize nonpoint source pollution and protect water quality. BMPs typically include restrictions on road placement, equipment use, timber removal practices, and other similar considerations. Existing

Figure 9.28: Streamside forests and adjacent uplands. *Management of streamside forests should not proceed in isolation from management of adjacent upland systems.*

state BMP guidelines may be appropriate for application within the restoration area but often require some modification to reflect the objectives of the restoration or other pre-identified constraints on activities in the vicinity of streams and wetlands.

Grazed Lands

Livestock grazing is a very important stream corridor management issue in most nonforested rangelands and in many forested areas. Uncontrolled livestock grazing can have severe detrimental effects on streambanks, riparian vegetation, and water quality, particularly in arid and semiarid environments (Behnke and Raleigh 1978, Elmore and Beschta 1987, Chaney et al. 1990) (**Figure 9.29**). Livestock naturally concentrate in the vicinity of streams; therefore, special efforts must be made to control or prevent access if stream corridor restoration is to be achieved.

In some cases, livestock may act as an agent in restoration. Management of livestock access is critical to ensure their role is a positive one. Existing state BMPs might be sufficient to promote proper grazing, but might not be innovative or adaptive enough to meet the restoration objectives of a corridor management program.

Complete exclusion of livestock is an effective approach to restore and maintain riparian zones that have been badly degraded by grazing. In some cases, exclusion may be sufficient to reverse the damage without additional intervention. In some degraded systems, removal of livestock for a period of years followed by a planned management program may allow recovery with-

Figure 9.29: Livestock in stream. Uncontrolled livestock grazing can have severe detrimental effects on streambanks, riparian vegetation, and water quality.

CASE STUDY

Partners Working for the Big Spring Creek Watershed

The Big Spring Creek watershed occupies a diverse, primarily agricultural landscape in central Montana, where the nation's third largest freshwater spring (Big Springs) provides untreated drinking water for the 7,000 residents of Lewistown and is the source of one of Montana's best trout streams, Big Spring Creek.

Conservation work by federal, state, and local agencies, private organizations, and citizens in the 255,000-acre Big Spring Creek watershed is not new. Actually, various projects and developments have occurred over the last several decades. For example, the flood control project that protects the city of Lewistown has its roots in the 1960s when, after experiencing a series of floods, the city of Lewistown and community leaders decided to take action. The Fergus County Conservation District, Fergus County Commissioners, City of Lewistown, U.S. Natural Resources Conservation Service, and many community leaders all worked together on this project. The Big Spring Creek Flood Control Project now protects the city of Lewistown from recurrent flooding.

Conservation work now, though, goes beyond flood control. It involves working to solve resource problems on a watershed basis, recognizing that what happens upstream has an effect on the downstream resources. We should look beyond property boundaries at the whole watershed, considering the "cumulative effects" of all our actions. With that in mind, the Fergus County Conservation District, with assistance from its citizen committee, has been working the last few years to improve and protect the watershed. With funding from the Montana Department of Environmental Quality (Section 319), the Big Spring Creek Watershed Partnership was formed.

*This project helps agricultural producers and other landowners to plan and install conservation practices to prevent erosion and keep sediment and other pollutants out of streams and lakes. Area landowners are implementing conservation practices such as improving the riparian vegetation (**Figure 9.30**), treating streambank erosion, and developing water sources off the stream for livestock. Because the project has been well received by the agricultural producers, it has been possible for cooperating agencies to participate in additional watershed improvements. The U.S. Fish and Wildlife Service Partners for Wildlife program has provided funding for several stream restoration and riparian improvement projects. In addition, the Montana Department of Fish, Wildlife and Parks is actively participating in fisheries habitat projects, including the Brewery Flats Stream Restoration.*

Implementation of the Big Spring Creek Watershed Partnership has brought many positive changes to the predominantly agricultural Big Spring Creek watershed. Since most of the agricultural operations are livestock or grain, the major emphasis is on riparian/stream improvement and grazing management. Thus far, more than 30 landowners have participated in the project by installing conservation practices that include over 8 miles of fencing, and 13 off-stream water developments, with more than 10 miles of stream/riparian area protected.

Studies show that stream characteristics and water quality are the best indicators of watershed vitality. Thus, an active monitoring strategy in the watershed provides feedback to measure any improvements. Preproject and postproject fisheries (trout) surveys are conducted in cooperation with the Montana Department of Fish, Wildlife and Parks on selected streams. On East Fork Spring Creek, fencing and off-stream water development were implemented on a riparian/stream reach that was severely degraded from livestock use. Fish populations and size structure changed dramatically from preproject to postproject work. Salmonid numbers increased from 12 to 32 per 1,000 feet, and average size increased by 50 percent. In addition to *fisheries surveys, benthic macroinvertebrate communities are collected and analyzed on a number of streams. This analysis relates to the stream's biological health or integrity. Community structure, function, and sensitivity to impact are compared to baseline data. Habitat conditions on three of six monitoring sites on Big Spring Creek from 1990 to 1997 have shown improved conditions from a sub-optimal to an optimal rating. Monitoring will continue on major streams in the watershed, which will help to provide important feedback as to the project's effectiveness.*

Although the major emphasis is on improving and protecting the riparian areas and streams in the watershed, other ongoing efforts include participating in the "Managing Community Growth" initiative, preserving agriculture and open space, and developing recreational and environmental resources. An active committee of the group is involved in one of the largest stream restoration initiatives ever to be undertaken in Montana, planned for 1998. Included in this project is an environmental education trial site being developed with the local schools.

Working with watersheds is a dynamic process, and as a result new activities and partners are continually incorporated into the Big Spring Creek Watershed Partnership. The following agencies and organizations are currently working together with the citizens of the watershed to protect this "very special place."

Fergus County Conservation District

M.S.U.-Extension Service, Fergus County

U.S. Natural Resources Conservation Service

U.S. Fish and Wildlife Service

Montana Department of Fish, Wildlife and Parks

Montana Department of Environmental Quality

Montana Department of Natural Resources and Conservation

(a)

(b)

Figure 9.30: The Big Spring Creek watershed. *(a) A heavily impacted tributary within the Big Spring Creek watershed and (b) the same tributary after restoration.*

U.S. Forest Service

City Of Lewistown

Fergus County Commissioners

Snowy Mountain Chapter Trout Unlimited

Central Montana Pheasants Forever

Lewistown School District No.1

Lewistown Visioning Group

Lewistown Area Chamber of Commerce

out permanent livestock exclusion (Elmore and Beschta 1987). Systems not badly damaged might respond to grazing management involving seasonal and herd size restrictions, off-channel or restricted-access watering, use of riparian pastures, herding, and similar techniques (Chaney et al. 1990). Response to grazing is specific to channel types and season.

In off-channel areas of the stream corridor, grazing may require less intensive management. Grazing might have limited potential to be used as a habitat manipulation tool in certain ecosystems, such as the Northern Plains, where native grazing animals formerly controlled ecosystem structure (Severson 1990). However, where grazing occurs within the stream corridor, it might conflict directly with ecosystem restoration objectives if not properly managed. Corridors that include grazing or have livestock in adjacent areas require vigilance to ensure that fences are maintained and herd management BMPs are followed.

Corridors that include grazing or have livestock in adjacent areas require vigilance to ensure that fences are maintained and herd management BMPs are followed.

Fish and Wildlife

Stream and vegetation care are the focus of many fish and wildlife management activities in the stream corridor. Hunting and fishing activities (**Figure 9.31**), nuisance animal control, and protection of particular species may be addressed in some restoration plans. Special management units, such as seasonally flooded impoundments specifically designed to benefit particular groups of species (Fredrickson and Taylor 1982), might be appropriate components of the stream corridor, requiring special maintenance and management. Numerous fish and wildlife management tools and techniques that address temporary deficiencies in habitat availability are available (e.g., Martin 1986). Inappropriate or haphazard use of some techniques can have unintended detrimental effects (for example, placing wood duck nest boxes in areas that lack brood habitat). Programs intended to manipulate fish and wildlife populations or habitats should be undertaken in consultation with the responsible state or federal resource agencies.

Restoration of a functional stream corridor can be expected to attract beaver in many areas. Where beaver control is warranted because of possible damage to private timberlands or roads, increased mosquito problems, and other concerns, controls should be placed as soon as possible and not after the damage is done. Techniques are available to prevent beaver from blocking culverts or drain pipes and destroying trees. In some cases, effective beaver control requires removal of problem animals (Olson and Hubert 1994).

Human Use

Stream corridors in urban areas are usually used heavily by people and require much attention to minimize, control, or repair human impacts. In some cases, human disturbance prevents some stream corridor functions from being restored. For example, depending on the amount of degradation that has occurred, urban streams might support relatively few, if any, native wildlife species. Other concerns, such as improved water quality, might be addressed effectively through proper restoration efforts. Addressing impacts from surrounding developed areas (such as uncontrolled storm water runoff and predation by pets) requires coordination with community agencies and citizen groups to minimize, prevent, or reverse damage. Management of urban corridors might tend to em-

CASE STUDY

A Creek Ran Through It

Portland, Oregon, sprang up along the Willamette River. As time went on and the city grew, it came to occupy a sequestered spot between the Willamette and Columbia Rivers and the higher reaches of the Sylvan Hills. But before the city expanded to this point, a creek ran through it—Tanner Creek.

The Tanner Creek watershed, comprising approximately 1,600 acres, extended from the forested hills through a canyon and across the valley floor to the Willamette River. During summer months, the creek was placid if not dry. But during the heavy winter rains, the creek became a raging torrent.

As the city of Portland expanded, the creek was diverted into the sewer system and the creek floodway was filled in to make way for development. These combined sewers drained directly to the Willamette River and the Columbia Slough until a series of interceptor pipes and a municipal sewage treatment plant were constructed in the 1940s and 1950s.

However, this new system did not have sufficient capacity to handle the combined sewage and storm water flows during periods of heavy rain, which frequently occur during the winter months. As a result, rather than flowing to the treatment plant for processing and disinfection, the combined sewage and storm water overflowed to outfalls along the Willamette River and the Columbia Slough. Tanner Creek became a part of the cause of combined sewer overflows (CSOs).

In the early 1990s, the city of Portland began to develop a plan to eliminate CSOs. The Tanner Creek Stream Diversion Project was identified early in the CSO planning process as a cornerstone project, a relatively inexpensive method of removing clean storm water from the combined system, thereby reducing CSOs. Nearly 10 miles of pipe ranging from 84 inches to 60 inches in diameter will be constructed to once again carry storm water directly to the river. In addition, best management practices for storm water management will be included. Finally, opportunities for water feature enhancements and educational and cultural opportunities will be explored in partnership with the community and other agencies.

Principal among these opportunities is daylighting a portion of the stream in the city's River District. In partnership with community leaders, special interest groups, a private developer, and other agencies, the city's Bureau of Environmental Services is leading a study of possible design alternatives. For more information contact: Nea Lynn Robinson, Project Manager, Tanner Creek Stream Diversion Project, City of Portland, Oregon.

Figure 9.31: Local fisherman. *Fishing and other recreational activities must be considered in restoration management.*

igure 9.32: Off-road ehicle. *Low- and igh-impact use areas hould be clearly narked within public tream corridors.*

phasize recreation, educational opportunities, and community activities more than ecosystem functions. Administrative concerns may focus heavily on local ordinances, zoning, and construction permit standards and limitations.

Community involvement can be an important aspect of urban stream corridor restoration and management. Community groups often initiate restoration and maintain a feeling of ownership that translates into monitoring input, management oversight, and volunteer labor to conduct maintenance and management activities. It is essential that community groups be provided with professional technical guidance including assistance in translating regulatory requirements. It is also important that proposed management actions in urban corridors be discussed in advance with interested groups affected by tree cutting or trail closures.

In nonurban areas, recreation can usually be accommodated without impairing ecological functions if all concerned parties consider ecosystem integrity to be the priority objective (Johnson and Carothers 1982). Strategies can be devised and techniques are available to minimize impacts from activities such as camping, hiking (trail erosion), and even the use of off-road vehicles (Cole and Marion 1988) (**Figure 9.32**). Recreationists should be educated on methods to minimize impacts on the ecosystem and on restoration structures and vegetation. Location of areas designated for low-impact use and areas off-limits to certain high-impact activities (such as off-road vehicles, biking, horseback riding, etc.) should be clearly marked. Access should be restricted to areas where new vegetation has not yet been fully established or where vegetation could be damaged beyond the point of survival.

All the flowers of all the tomorrows are in the seeds of today.

—Chinese proverb

There will come a time when you believe everything is finished. That will be the beginning.

—Louis L'Amour