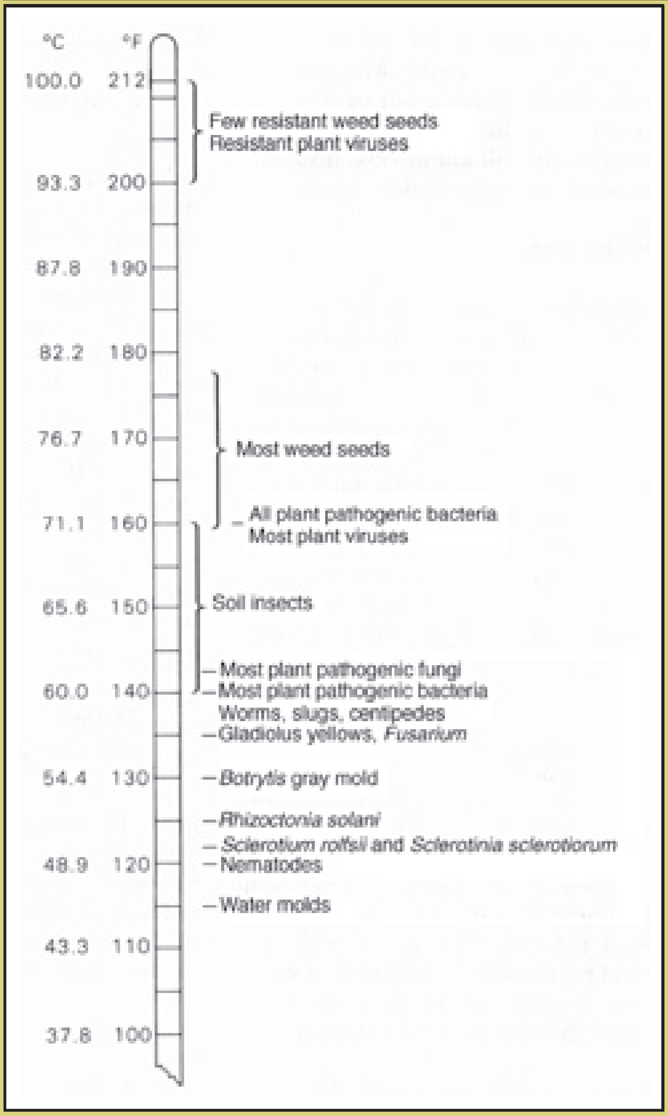

Figure 3–40—This thermometer shows the soil temperatures that will kill weed seeds, insects, and plant pathogens. Temperatures assume heat treatment for 30 minutes under moist soil conditions (Hartmann and others 1990).

Once the soil has been treated, minimize any further disturbance to the top 6 inches (about 150 millimeters) of the soil to prevent bringing viable weed seed deep in the soil to the surface, where it will germinate.

3.3 Concluding Thoughts on Soil

Here are the basic steps to remember when analyzing and working with soil.

- Select a reference site that is representative of the impacted site and that reflects project limitations, including soil limitations.
- Analyze the differences between the site to be treated and one or more reference sites.
- Work with a soil specialist to devise a prescription that will correct as many soil deficits as necessary.
- Use native and local soil sources to the extent possible, without damaging the borrow site.
- Use additional materials or supplements if native sources are not adequate.
- Monitor and maintain your site. If at first you don't succeed, try a different approach.
- Recognize that the process of correcting and rebuilding damaged soils is very slow and difficult, taking many years, if not decades. You should be able to notice the site improving as it becomes more like the desired native plant community.

3.4 Site Stabilization, Preparation, and Delineation

The precise order of actions taken to prepare a site may vary, but generally follows this sequence:

1. Recontour the site if needed.
2. Scarify the soil.
3. Install erosion-control features.
4. Install barriers.
5. Add additional soil needed for fill.

6. Add icebergs and posts for signs, if any are needed to discourage use of the site as it recovers.
7. Add soil amendments and additional organic material.
8. Leave the soil surface uneven (pitted).
9. Install crimping before seeding.

Site stabilization and delineation help create a stable area where native plants can reestablish themselves, given enough time. Your goal may be to further stabilize a relatively flat area (such as a campsite), or to stabilize an unstable slope (such as a steep site or trail slump) or a gully (such as an entrenched trail).

A site-stabilization strategy needs to be designed to handle peak annual waterflows. Peak flows may occur during snowmelt, the rainy season, or heavy thunderstorms.

A number of additional techniques for establishing vegetation and reducing erosion are described in more detail elsewhere in this guide. Such methods include:

- Using mulch and erosion-control blankets—see section 3.12, *Plant Protection and Establishment.*
- Preventing further damage to biological crusts—see section 3.1.3c, *Evaluating Biological Soil Crusts.*
- Inoculating plants with mycorrhizal fungi—see section 3.2.5b, *Inoculating Plants With Mycorrhizal Fungi.*
- Adding organic matter—see section 3.2.3c, *Amending Altered or Depleted Soils.*
- Selecting plant species that provide rapid cover and a variety of root forms—see section 3.10, *Plant Selection, Collection, and Propagation Techniques.*

Site delineation is the process of engineering a site to keep users where you want them. This involves designing visual cues or even physical barriers to concentrate use.

In the mechanical world of industrial-strength restoration, crawler tractors, backhoes, dump trucks, rippers, and imprinters make short work of site preparation. In the wilderness world, we work with modified stock panniers, 5-gallon (19-liter) buckets, stretchers, log carriers, come-alongs, pick axes, shovels, grub hoes, and McLeods—not to mention blood, sweat, and tears. In some areas, helicopters and wheelbarrows have been deemed the minimum tool, moving material more quickly and, in some cases, with less damage than other techniques.

Livestock can haul soil and gravel in specialized panniers (figure 3–41). These panniers are loaded from the top and unloaded from the bottom without removing them from the animal. *Gravel Bags for Packstock* (Vachowski 1995) offers alternative designs, sources, and even a plan for making your own specialized panniers.

Figure 3–41—Fabric bags (panniers) that can be loaded from the top and unloaded by releasing the bottom are handy when stock are used to haul gravel or soil.

3.4.1 Reestablishing Site Contours

Recontouring your site (figures 3–42a and 42b) is likely to be part of a restoration prescription. In an ideal world, a site would be restored to its original contour. However, the fill material needed to achieve such an ambitious goal may not be available. In addition, the slope angle may have become too steep to support successful restoration. A more intermediate set of goals could include: restoring a more natural appearing line, controlling the movement of water through the area to be replanted, and creating a favorable medium for reestablishing vegetation. Meeting such goals may involve rearranging existing site materials or building structures that are backfilled with rock and soil.

Runoff contributes more to erosion than all the trampling hooves and feet on a trail. Methods for evaluating erosion were addressed in the section on assessing soil conditions. Is water channeled into the site causing ongoing damage? Is it desirable to redirect water away from the site or would this cause unacceptable change to slope hydrology? Work with your soil scientist or geologist to address these issues.

For example, digging an uphill parallel ditch (figure 3–43), is a time-tested trail management strategy to dry up muddy trail segments and redirect water across the trail at a natural sag in the grade. This strategy drops the water table, which changes the vegetation on the site. Differing solutions

Figures 3–42a and 42b—This wide, severely eroded trail at Snow Lake in the Alpine Lakes Wilderness, WA (top), was brought back up to grade (bottom) by installing siltbars and adding many buckets of locally collected fill.

Figure 3–43—A small parallel ditch dug alongside this social trail will dry out the tread surface, reducing the likelihood that hikers will walk to the side of the trail, making it wider and wider. The salvaged plugs of plants and soil were transplanted into closed social trails nearby. The plant community may change because the water table will drop to the depth of the parallel ditch.

might come into play. Water can be redirected away from the site, channeled through the site, slowed while being allowed to continue moving through the site, fanned out across the site—or managed using any combination of these techniques. Bioengineering techniques also can be used to reduce excess water on projects (Eubanks and Meadows 2002).

Steep sites may be reworked to eliminate erosion channels by creating a smooth slope with no vertical rills, enabling water to spread out across the slope. Another approach is to harden erosion gullies with a series of structures designed to absorb the impact of flowing water and to trap sediment. Water has to go somewhere; if you don't plan for the flow, it is likely to cause erosion someplace else.

If the top of a steep slope is headcutting, the headcut (figures 3–44a and 44b) must be stabilized by laying back the slope. The headcut is where the slope is eroding the fastest, generally at the top. Where headcutting is occurring under mats of vegetation, it is sometimes possible to excavate underneath the vegetated mat and lay the mat down over the recontoured slope break.

Figure 3–44a—Soil lost because of extensive historical sheep grazing initiated the headcutting shown above, which continues eating into the bank, destroying the integrity of this subalpine meadow in the Alpine Lakes Wilderness, WA.

Figure 3–44b—This roadbank headcut will continue to erode unless it is treated. The slope angle could be reduced by hollowing out the bank from below. The mat of vegetation could be pinned to the soil substrate.

Arid land restorationist and researcher Jayne Belnap recommends recontouring with a 3:1 (33 percent), or shallower slope. She suggests that any slope steeper than 2:1 (50-percent slope) will be too steep to treat successfully (Belnap and Furman 1997). A series of terraces could be created on steeper slopes. In riparian areas, bioengineering techniques could be used.

3.4.2 Stabilizing Gullies

Three mechanisms contribute to the formation of gullies: headcutting, downcutting (erosion that deepens the gully), and lateral cutting into the banks (Prunuske 1987). You need to address all three mechanisms when you are stabilizing erosion in a gully. A deeply incised trail may not have headcutting, but it will be eroding through the other two mechanisms.

3.4.3 Stabilizing Headcuts

A headcut is where a gully is eroding the fastest, generally at the upper end. If a headcut is not treated, it will continue to eat its way upslope (figure 3–45). A bank headcut is found at the top of road or trail cutbanks.

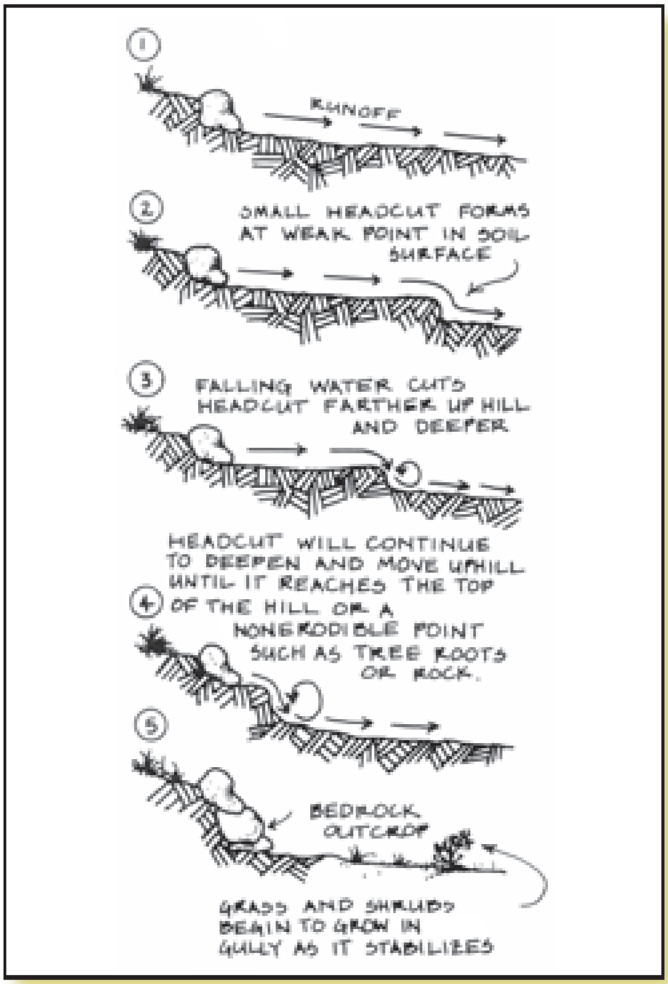

Figure 3–45—The process of gully movement. Drawing courtesy of Susan Pinkerton (Prunuske 1987).

A headcut with low gully erosion and low flow velocities may be treated by reshaping the headwall to a 3:1 or shallower slope (figure 3–46), armoring the slope with rock riprap, or revegetating the slope with herbaceous cover, shrubs, or trees. Moderate gully erosion requires a combination of treatments. Serious gully erosion requires the combination of shaping, rock riprapping, and establishing a variety of plants, including woody plants (Prunuske 1987).

Figure 3–46—The headcut is laid back to a 3:1 slope angle. Drawing courtesy of Liza Prunuske (Prunuske 1987).

3.4.4 Stabilizing Downcutting

Downcutting erodes the gully deeper (figure 3–47), which also drops the water table, changing vegetative characteristics. Downcutting can be slowed by reducing the speed of flowing water and raising the level of the gully. This is accomplished by constructing checkdams, then backfilling the checkdams or allowing adjacent surface erosion to fill the dams. Checkdams are small dams designed to check (stop) erosion, but not to store water. Checkdams that are more than 4 feet (about 1.2 meters) tall need to be designed by an engineer.

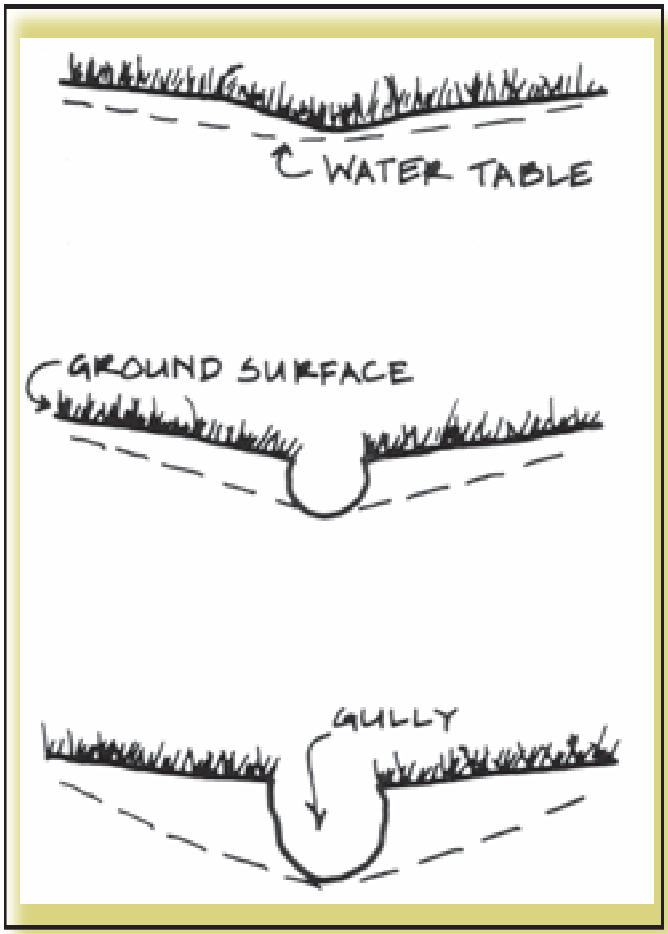

Figure 3–47—Downcutting in gullies not only increases soil lost through erosion, but also drops the groundwater table to the base of the gully. Drawing courtesy of Liza Prunuske (Prunuske 1987).

3.4.5 Stabilizing Lateral Erosion Into Gully Banks

Unless a gully is backfilled completely, its banks should be stabilized with vegetation. If the banks are too steep for vegetation to become established, the banks must be laid back to a shallow angle so plants can grow.

3.4.6 Surface Erosion Control

Riprap (figure 3–48) is a layer of heavy stones laid down to armor the soil surface, preventing further erosion. Riprap also may be used to armor trails, as is commonly the case in the Sierra Nevada Mountains of California and Nevada. Riprap has been used at rather grand scales—such as armoring entire stretches of riverbanks or shorelines. This guide just explores small-scale applications.

Figure 3–48—Riprap reduces surface erosion by providing a durable surface in Grand Canyon National Park, AZ.

The size of the largest rocks used to construct riprap is based on the water velocity at peak flows. Once you have placed the largest rocks, fit smaller rocks between them to construct a stable surface that doesn't wobble underfoot. Refer to tables 3–5 and 3–6 to determine rock weights and the relative proportions of different sizes of rocks.

Table 3–5—Determining the size of riprap (Prunuske 1987).

Water velocity feet per second (meters per second)	Approximate Rock diameter inches (millimeters)	Weight of a rock pounds (kilograms)
2 (0.6)	2 (51)	--
4 (1.2)	4 (102)	--
6 (1.8)	7 (178)	--
8 (2.4)	10 (254)	50 (23)
10 (3.1)	14 (356)	150 (68)
12 (3.7)	19 (483)	375 (170)
14 (4.3)	25 (635)	1,000 (454)
16 (4.9)	33 (838)	2,000 (907)

*This calculation assumes rock weighs 165 pounds per cubic foot (2,643 kilograms per cubic meter). Rock should have a minimum specific gravity of 2.5, meaning a cubic foot (0.028 cubic meter) of rock weighs 2.5 times as much as a cubic foot (0.028 cubic meter) of water.

Before riprap is installed (figure 3–49), a layer of filter material is laid down to prevent piping, a problem that develops when water sluices out of fill material underground. Natural filter materials include gravel or a thick layer of organic leaf litter. A commercial filter fabric can be installed using 6-inch (about 150-millimeter) staples. This option deters establishment of long-rooted plants. Riprap is installed from the base up. A trench is dug at the toe of the slope. Big rocks are keyed into this trench. Then angular rocks are fitted together working up the slope, using intermediate-sized rock to fill spaces between the larger rocks. Plantings can be incorporated between the rocks, if desired. Live stakes, which will sprout into shrubs, can be driven through openings between the rocks (see figure 3–62). During the first few years, areas of riprap where rocks have washed out will need to be patched.

Table 3–6—Determining relative proportions of stone sizes for riprap (Prunuske 1987).

Maximum weight of rock pounds (kilograms)	Minimum and maximum weight of rocks pounds (kilograms)	Weight range of 75 percent of rocks pounds (kilograms)
150 (68)	25 to 150 (11 to 68)	50 to 150 (23 to 68)
200 (91)	25 to 200 (11 to 91)	50 to 200 (23 to 91)
250 (113)	25 to 250 (11 to 113)	50 to 250 (23 to 113)
400 (181)	25 to 400 (11 to 181)	100 to 400 (45 to 181)
600 (272)	25 to 600 (11 to 272)	150 to 600 (68 to 272)
800 (363)	25 to 800 (11 to 363)	200 to 800 (91 to 363)
1,000 (454)	50 to 1,000 (23 to 454)	250 to 1,000 (113 to 454)
1,300 (590)	50 to 1,300 (23 to 590)	325 to 1,300 (147 to 590)
1,600 (726)	50 to 1,600 (23 to 726)	400 to 1,600 (181 to 726)
2,000 (907)	75 to 2,000 (34 to 907)	600 to 2,000 (272 to 907)

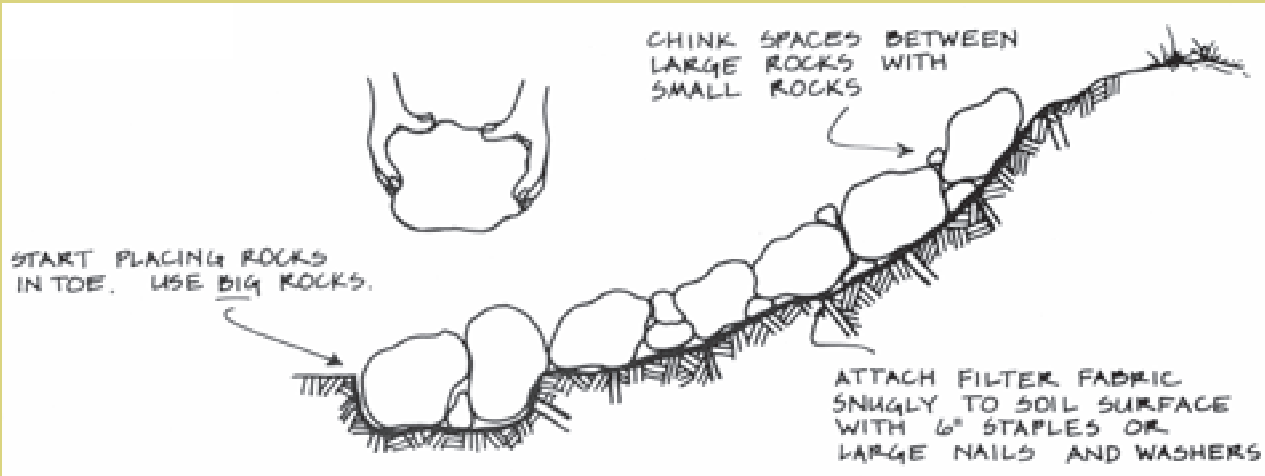

Figure 3–49—Placing rock for riprap. Drawings courtesy of Susan Pinkerton (Prunuske 1987).

3.4.7 Subsurface Erosion Control

In general, structures are installed in the order that creates the least additional disturbance. As much as possible, excavated soil or rock is piled within the existing disturbed area. Another suitable staging area might be located nearby to hold excess fill or salvaged plant materials. Work back toward a hardened "escape route." If possible, work your way downhill to avoid back strain. Training and constant reminders will prevent workers from walking on vegetation adjacent to the site, causing further damage.

Subsurface erosion-control structures fall into two broad categories, living and nonliving. Nonliving structures include siltbars or checkdams built of wood (figure 3–50), rock, or erosion-control blanket. On wet sites, native plant materials can be used to craft a variety of structures, a technique known as bioengineering. The plants not only physically stabilize the site, but also provide a plant community (figure 3–51).

Figure 3–50—Log checkdams are an example of a nonliving subsurface erosion control structure. The checkdams are keyed into the bottom and sides of an eroded hiking trail, preventing further erosion and collecting sediment.

Figure 3–51—The live trench pack stabilizing this gully is one example of a living subsurface erosion control structure (Eubanks and Meadows 2002).

3.4.8 Nonliving Siltbars and Checkdams

Siltbars are shallower than checkdams and are just one layer high. Siltbars are used to address erosion on low-angle slopes. They may be used to control erosion at campsites, on trails that are not too deeply incised, or in areas that don't have enough material for checkdams. Checkdams (sometimes called siltdams) are created by stacking siltbars one on top of another. Crimping, a technique that incorporates straw or native hay into the soil surface, can be used when log or rock checkdams would not be appropriate.

3.4.8a Materials Used To Construct Siltbars and Checkdams

In the wilderness and backcountry, native materials are preferred for siltbars and checkdams, if they can be obtained without further damage to the landscape. Checkdams should be constructed to allow water to percolate through the dam; an impervious checkdam is more likely to blow out during heavy runoff.

Native Rock Siltbars or Checkdams—Native rock, if available, is often the best material for siltdams because of rock's longevity and ability to blend with the environment. As is always the case with native materials, evaluate whether the rock can be collected without causing undue harm to ecological processes or the visual setting. For instance, partially submerged rocks with plants growing around them would be a poor choice for removal—the plants are likely to die once they are exposed and an unsightly hole will be left behind.

Log Siltbars or Checkdams—Log checkdams can be constructed from dead material nearby. Native materials also may be brought in using packstock or helicopters. Cedar rails are a common choice for checkdams in the national parks of the Pacific Northwest.

Dimensional Lumber Siltbars or Checkdams—If you strike out on native material, consider using dimensional lumber such as 2 by 6s or 2 by 8s; such material is more challenging to blend with the wilderness environment. You will also need wooden upright material for attaching planks.

Erosion-Control Blanket Siltbars—Erosion-control blankets can function as a siltbar when the blanket is partially buried and pinned with ridges protruding slightly above the ground surface. This technique has been used successfully in arid lands.

3.4.8b Installation of Checkdams

Siltbars (figure 3–52) and checkdams are installed perpendicular to the flow of water. The direction of flow may be tricky to determine in a sinuous gully. Construct siltbars and checkdams so they are deeper and wider than the opening they are blocking to prevent water from flowing under or around the checkdams.

Siltbars, whether rock or wood, are installed by toeing them into the base of the slope. The sides are anchored into the slope or are anchored with wooden pegs.

Checkdam installation involves more technical considerations. Start by digging a trench 6 inches (about 150 millimeters) deep contouring the slope (or perpendicular to the bed of the trail or gully). For eroded trails, continue the trench up the sidewalls of the gully to form a 6- to 12-inch- (about 150- to 310-millimeter-) deep vertical slot (called a *keyway*) slightly wider than your checkdam material (figures 3–53a and 53b).

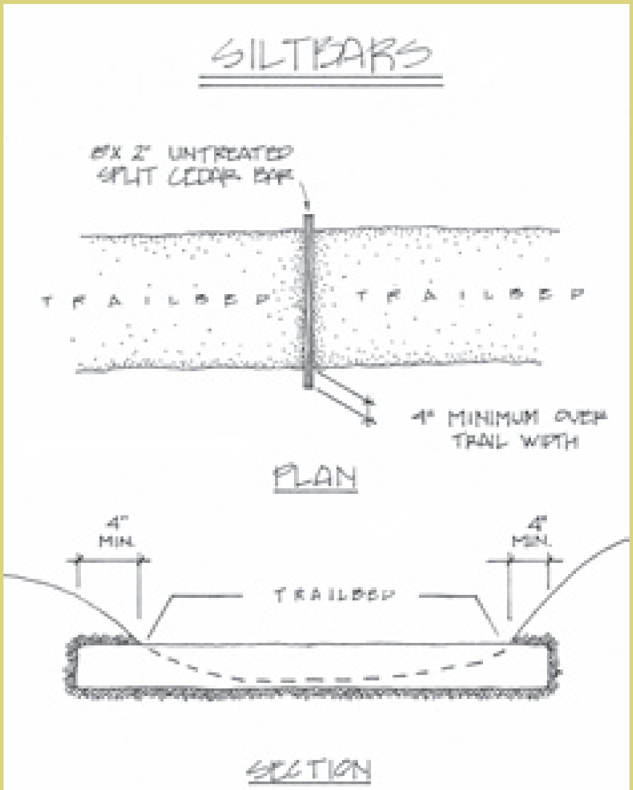

Figure 3–52—Siltbar installation. Siltbars have just one tier of material, unlike checkdams that have more than one tier of material. Drawing courtesy of Regina Rochefort (1990).

Figure 3–53b—In gullies, a keyway is excavated about 6 inches into each sidewall to pin the checkdam or siltbar material into place.

Once the trench has been established, begin fitting in the materials for the siltbar or checkdam. You may need to improve the trench to seat your materials properly. Check your work to assure that the base of the checkdam is well seated, preventing water from flowing under the material. Keep stacking materials until the desired height has been reached—ideally flush with the ground level (figure 3–54). It is not necessary for the top of the checkdam to be above the ground. Keep the checkdam level to avoid channeling water to one side.

Figure 3–53a—To properly seat a siltbar or checkdam, a trench is dug about 6 inches deep across the contour or perpendicular to the gully.

Figure 3–54—Keep stacking materials until the desired height has been reached—ideally flush with the ground level. (This photo has been digitally altered.)

If planks are used for the checkdam, attach them to upright 4 by 4s that have been buried into the bed of the gully to half the depth of the exposed checkdam. The deeply buried uprights prevent the planks from becoming misaligned, which could cause the checkdam to malfunction. Uprights should be about 3 feet (910 millimeters) apart for shorter dams, but no more than 2 feet (610 millimeters) apart for dams that are 3 to 4 feet (0.91 to 1.22 meters) tall (figure 3–55a).

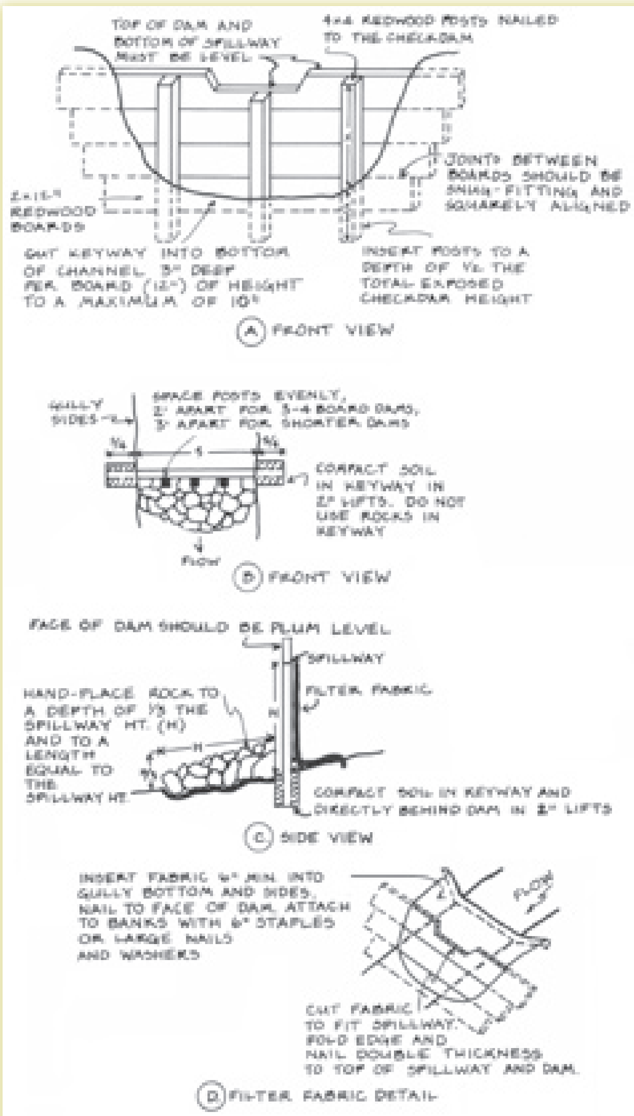

Figure 3–55a—Checkdam installation. Wooden checkdams are constructed by stacking logs or split rails. Drawings courtesy of Liza Prunuske (1987).

Firmly tamp the excavated soil back around the dam. Avoid backfilling the checkdam with rock. Rock backfill could direct water to the dam material, allowing some water to get through.

Rock checkdams (figure 3–55b) also require a trench. Using your very best dry stone masonry skills, select rocks that fit well together to build up a triangular-shaped wall that is broad at the base. Use the same principles you would when building a rock crib. Be sure to stagger the seams between rocks as you add each layer.

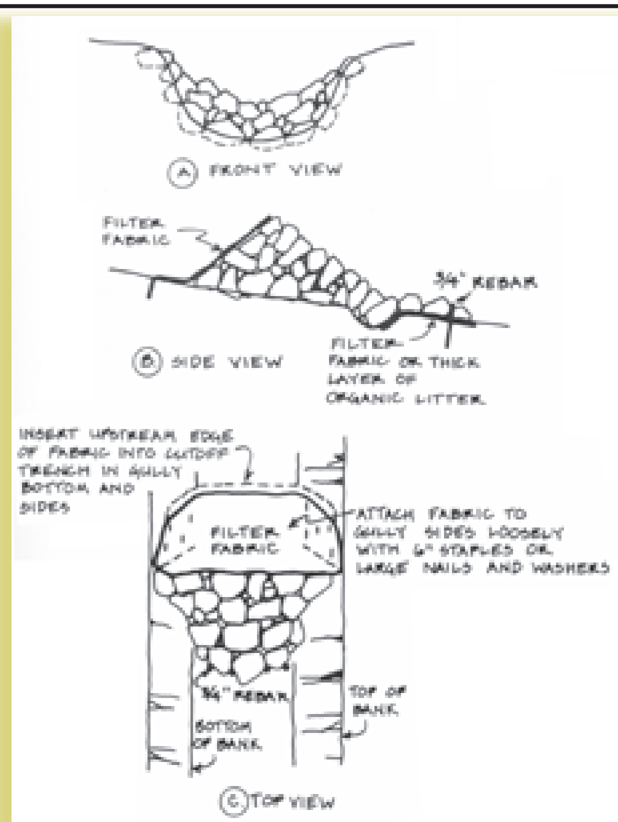

Figure 3–55b—Installing a rock checkdam. Drawings courtesy of Liza Prunuske (1987).

A Rock Checkdam That Worked

A more vertical and less beefy rock checkdam may be adequate if water flows have been redirected elsewhere. One of the authors had good success with this approach at White Pass in the Glacier Peak Wilderness of Washington.

A series of several rock walls were built in an eroded trail that was being closed and restored. A drain dip above the site had directed water off the trail.

Soil and vegetation salvaged from a short relocated trail was placed between the checkdams. The vegetation quickly became reestablished.

Five years later, the only real evidence of the project was the lowest checkdam (figure 3–56), which was serving as a small rock retaining wall.

Figure 3–56—Five years later, the only real evidence of the project was the lowest checkdam.

Perhaps you successfully redirected water off the trail or gully alignment before building the checkdam. But if you are engineering your installation to handle the continued flow of water, three more components are needed for each checkdam—a spillway, an apron just below the dam that serves to dissipate energy, and a filter behind the dam to prevent soil loss while allowing water to continue to flow.

The spillway is a depression in the center of each checkdam to keep water from eating out the banks. Use table 3–7 to determine the size for each spillway. If your checkdam is constructed of wood, make sure the plank or log is still 4 inches (about 100 millimeters) high at the spillway. Otherwise, the plank or log may break. A rock checkdam should have a dip in the center to function as a spillway.

Table 3–7—Spillway width and depth for checkdams (from Prunuske 1987).

Area in acres of gully watershed (hectares)	Depth in inches of a 12-in- (310-mm-) wide spillway (mm)	Depth in inches of an 18-in- (460-mm-) wide spillway (mm)	Depth in inches of a 24-in- (610-mm-) wide spillway (mm)	Depth in inches of a 36-in- (910-mm-) wide spillway (mm)
1 (25.4)	6 (152.4)	4 (101.6)	3 (76.2)	3 (76.2)
2 (50.8)	9 (228.6)	7 (177.8)	5 (127.0)	4 (101.6)
3 (76.2)	12 (304.8)	8 (203.2)	7 (177.8)	5 (127.0)
4 (101.6)	--	10 (254.0)	8 (203.2)	6 (152.4)
5 (127.0)	--	12 (304.8)	10 (254.0)	7 (177.8)

Apron Installation—While the spillway directs the flow of water down the center of the gully, the apron protects the gully and checkdam from the force of the falling water, (figure 3–57). Aprons generally are constructed of rock, but a live fascine (a bundle of live woody stems that will sprout) also could be anchored in the gully. The use of live fascines is explained in the bioengineering section. A filter is laid below the rock apron using techniques described for riprap. Rock is secured across the gully bottom in a low-angle wedge against the downstream side of the checkdam for at least 2 feet (610 millimeters) below the checkdam. If the waterflow is expected to be high velocity, wooden pegs, live stakes, or pieces of ¾-inch (about 19-millimeter) rebar are pounded into the gully bed to pin the lowest course of rock in place.

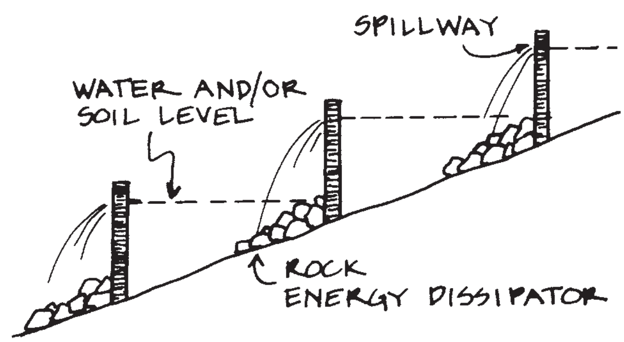

Figure 3–57—A profile of checkdams with aprons, also called rock energy dissipators. Drawing courtesy of Liza Prunuske (1987).

Filter Behind the Dam—Unless you anticipate low volumes of water or a large amount of leaf litter is likely to wash downstream, the final step before backfilling is to install a filter upstream from the checkdam. This measure is to prevent soil from washing through any cracks in the dam. A 6-inch (about 150-millimeter) layer of organic leaf litter can form the filter. Or you can install filter fabric. If you use fabric, it should be laid out loosely so that it won't pull out with the force of the water. The upstream side of the fabric is secured to the gully bed and banks by digging a trench, anchoring the fabric with 6-inch (about 150-millimeter) staples, then refilling the trench. The 6-inch (about 150-millimeter) staples also secure the loose fabric on the remainder of the bottom and sides. Refer to figure 3–55a or 3–55b for an installation diagram.

Checkdam Placement—In long gullies, checkdams are placed in a stairstep fashion. Ideally, the top of the downhill dam is as high as the bottom of the next dam upslope. This standard may not be feasible on steeper slopes. Maintain a 3:1 slope between checkdams, if necessary.

Sometimes it is necessary to segment siltbars or check-dams. For instance, if a site has lots of submerged rock, making it difficult to dig a continuous trench, it may be necessary to toe a siltbar into the rock, and then continue on the other side (figures 3–58a and 58b). Use pegs to secure the siltbar near the rock. A mallet or small sledge hammer is the best tool for driving pegs (figures 3–59a and 59b). You may need to use a small block of wood on top of the peg to avoid splitting it while pounding.

Figures 3–58a and 58b—This trail was as wide as a road at Snow Lake in the Alpine Lakes Wilderness, WA. A huge mantle of soil had been lost, making it infeasible to return the swale to its original contour. Instead, a series of smaller siltbars, comprised of rocks, logs, and split rails, were installed (top) wherever they could be toed in successfully. Topsoil was added behind each checkdam and seedlings grown in a greenhouse were planted. Ten years later (bottom), the erosion had stabilized and vegetation was thriving.

Figures 3–59a and 59b—Stout pegs are shaped with an ax or hatchet (top) and pounded into place with a sledge hammer (bottom). (This photo was digitally altered.)

Once all dams have been installed, fill material can be added. If possible, avoid walking on undamaged vegetation. If reconstructing a soil profile as described in the soils section, add the fill material in the correct order, saving the organic layer for last. If you will be adding rock in the bottom of the trench, be sure to mix in finer materials, such as gravel and soil, to prevent water from washing out the fill material. Assume that the fill material will settle some. If your goal is to completely refill an eroded site, keep adding fill until the checkdams or siltbars are no longer visible.

Rather than smoothing out fill, leave rough mounds and a rough soil surface with small depressions, called pitting, to help control erosion and help plants become established. The pits help catch water, improving seedling survival. In addition, the pits provide some protection from wind and sun.

3.4.8c Crimping

Crimping, also called spiking, incorporates straw or native hay into the soil surface. Crimping helps reduce erosion by slowing and deflecting water. In situations where log or rock checkdams would be inappropriate because of a lack of materials or their unnatural appearance, crimping may be a good option. Crimping also improves water infiltration.

In wilderness, native hay harvested onsite might be an option for material to crimp into the soil. Tall grasses, sedges, or fibrous forbs could be harvested with a scythe. If this is not an option, clean straw, certified weed free or purchased from a known reliable grower, could be used. If available, rice straw is an excellent choice for dry land projects because the water weeds associated with rice culture will not survive on dry land. Rice grown in the Central Valley of California is used extensively for arid land restoration projects.

3.4.9 Bioengineering Applications

Bioengineering offers promise for sites on streambanks, lakeshores, or other wet areas. A bioengineered structure not only will stabilize erosion, but will simultaneously provide living plant material, helping to return the site to a stable, ecologically productive state (figure 3–60). Bioengineering can reduce the need to build structures such as rock gabions, riprap, or terraces that are unattractive and make it difficult to establish vegetation. This guide will provide a few basic bioengineering techniques and concepts that apply to small remote sites. If your project includes extensive or complex riparian habitat, refer to *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (Eubanks and Meadows 2002), which explains in detail how to plan and implement riparian projects.

Figure 3–60—A live post, installed where there is adequate soil moisture, will root and sprout to become a tree or shrub (Eubanks and Meadows 2002).

Bioengineering applies many of the principles of restoration discussed elsewhere in this guide, such as how to assess slope stability, how to choose and handle plant species, and how to work with soil. A few considerations more specific to successful bioengineering applications are outlined here (Potash and Aubry 1997).

Remember to have a clear understanding of the situation you are treating in wilderness. Bioengineering generally is used to address slope and bank failures, often due to human disturbances such as impoundments. Bioengineering applications can be integrated into the construction of trail crib walls to strengthen the trail. Wilderness restoration projects rarely seek to restore a natural slope failure unless private property values are at risk.

Geology, Soils, and Hydrology

The hydrologist, geologist, or geomorphologist on your team should help with the site assessment and project design. Geologic history, types of sediment deposits, evidence of past slides, and soil type and depth are taken into consideration.

Excess water needs to be drained or diverted away from the project. Drainage patterns are noted and the possibilities for redirecting the flow of water are assessed.

Backfill material must allow for free drainage; coarse-grained granular material is best. It should have enough fines and organic material to support the selected plant species. However, the system's design also must take structural strength into account.

A bioengineering treatment will fail unless the cause of the damage has been addressed. For example, a steep undercut or a slumping bank requires earthwork to remove the slope overhang and round the slope for stability. With bank erosion, the toe of the slope is often compromised. Treatment methods must anchor the toe of the structure with rock, root wads, or rolled mat logs.

Vegetation Used for Bioengineering

Limit the removal of existing vegetation at the project site. Tree and shrubby plant species used for bioengineering are selected for their ability to resprout from cuttings, develop strong root systems, and survive in a riparian environment with floods, slides, and erosion. Selecting plants with a variety of root structures will help stabilize slopes (see section 3.10.2, *Plant Selection for Restoration Projects*). Table 3–8 lists a number of plant species well suited to bioengineering applications in the Western United States, based on the criteria that they root readily.

Generally, the plant materials used to build structures are gathered as cuttings from local sources (see section 3.10.1, *Genetic Considerations for Restoration Projects*). Take advantage of any opportunities to salvage plant material from nearby projects, such as trail relocations. Cuttings are best collected in the fall at the onset of plant dormancy, in the winter as long as the ground remains unfrozen, or in the early spring before dormancy is broken. Refer to the section on plant propagation techniques for proper handling of cuttings. Additional plants, such as sedges or forbs, may be incorporated into plantings. Often, these plantings are grown ahead of time in a greenhouse. The use of transplanted wildlings or direct seeding also may be incorporated into plantings.

Ideally, the project will be implemented during the fall, winter, or spring when the plant material can be collected fresh in its dormant stage. If this timing is not feasible, it may be necessary to use rooted cuttings, raising project costs.

Table 3–8—Riparian plant species of the Western United States that are effective in bioengineering applications (Eubanks and Meadows 2002).

Scientific name	Common name	Root structure
Acer circinatum	Vine maple	Fibrous, rooting at nodes
Baccharis glutinosa	Seepwillow	Deep and wide spreading, fibrous
Baccharis pilularis	Coyote brush	Fibrous
Baccharis salicifolia	Water wally	Deep and wide spreading, fibrous
Baccharis viminea	Mulefat baccharis	Fibrous
Cephalanthus occidentalis	Button bush	
Cornus sericea ssp. *sericea*	Redosier dogwood	Shallow
Lonicera involucrata	Black twinberry	Fibrous and shallow
Physocarpus capitatus	Pacific ninebark	Shallow, lateral
Populus angustifolia	Narrowleaf cottonwood	Shallow
Populus balsamifera	Balsam popular	Deep, fibrous
Populus deltoides	Eastern cottonwood	Shallow, fibrous, suckering
Populus fremontii	Fremont dogwood	Shallow, fibrous
Populus trichocarpa	Black cottonwood	Deep and wide spreading, fibrous
Rosa gymnocarpa	Baldhip rose	
Rosa nutkana	Nootka rose	
Rubus idaeus ssp. *strigosus*	Red raspberry	Fibrous
Rubus spectabilis	Salmonberry	Fibrous
Salix ssp.	Willow species	
Sambucus cerulea ssp. *mexicana*	Mexican elder	
Sambucus racemosa	Red elderberry	
Spirea douglasii	Douglas spirea	Fibrous, suckering
Symphoricarpos albus	Snowberry	Shallow, fibrous, freely suckering
Viburnum lentago	Nannyberry	

3.4.9a Selecting and Installing Bioengineered Structures

The structures included in this section are just a small sample of those that are available. These structures were chosen for their appropriateness and ease of application in the wilderness setting. Their descriptions were excerpted from *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (Eubanks and Meadows 2002). That report describes 24 structures that can be used alone or in combinations to address a wide variety of impacts. Refer to their report if your project involves a complex situation. The information excerpted in this guide is for treating small problems. The final structure included in this section, the woven checkdam, is from *Groundwork: A Handbook for Erosion Control in Northern Coastal California* (1987), by Liza Prunuske.

Tools and Supplies for Installing Bioengineered Structures

Loppers (to cut plant stems)

Hand pruners (to trim branches)

Pruning saws (to cut live posts)

Untreated twine (to tie cuttings into bundles)

Burlap bags moistened and lined with wet leaves or mulch (to protect cuttings)

Grub hoe (to dig trenches or reshape slopes)

McLeod rake (to grub, reshape, or rake)

Shovel (to dig holes and salvage plants)

Small sledgehammer or mallet (to drive stakes)

Small blocks of wood (to protect the top of live stakes when they are being pounded)

36-inch (about 910-millimeter) pieces of rebar (to drive pilot holes)

Chisel-tipped pry bar (to open a pilot hole in softer soils)

Dead stout stakes (to secure structures, figure 3–61 and table 3–9)

Crosscut saw or chain saw (to construct live cribwall)

Spikes (to secure cribwall members)

Erosion-control blankets, such as coconut-fiber matting (to build structures or cover loose slopes)

Come-along and chokers (to manipulate large logs)

Log carriers (to transport smaller logs)

Seed spreader (to distribute native seed)

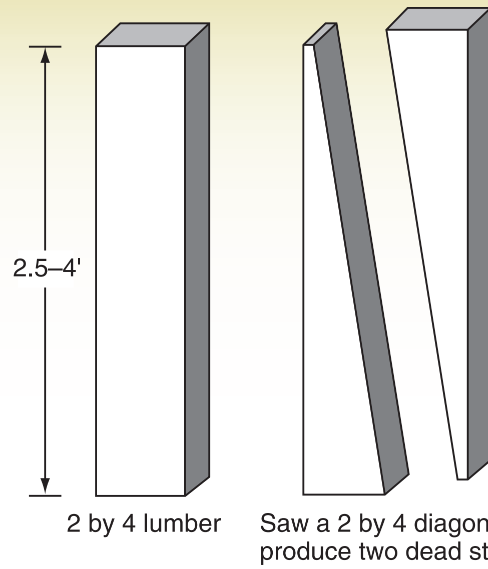

Figure 3–61—Dead stout stakes, cut from 2 by 4s (about 50 by 100 millimeters), are used in many soil bioengineering techniques to anchor branches or erosion control blankets, and to anchor erosion control blanket logs to the bank. (Eubanks and Meadows 2002).

Table 3–9—Recommended lengths of stakes.

Soil type	Stake length	
	Feet	Meters
Clay	2.5	0.76
Silt	3.0	0.91
Sand	4.0	1.22
Loam	2.5	0.76