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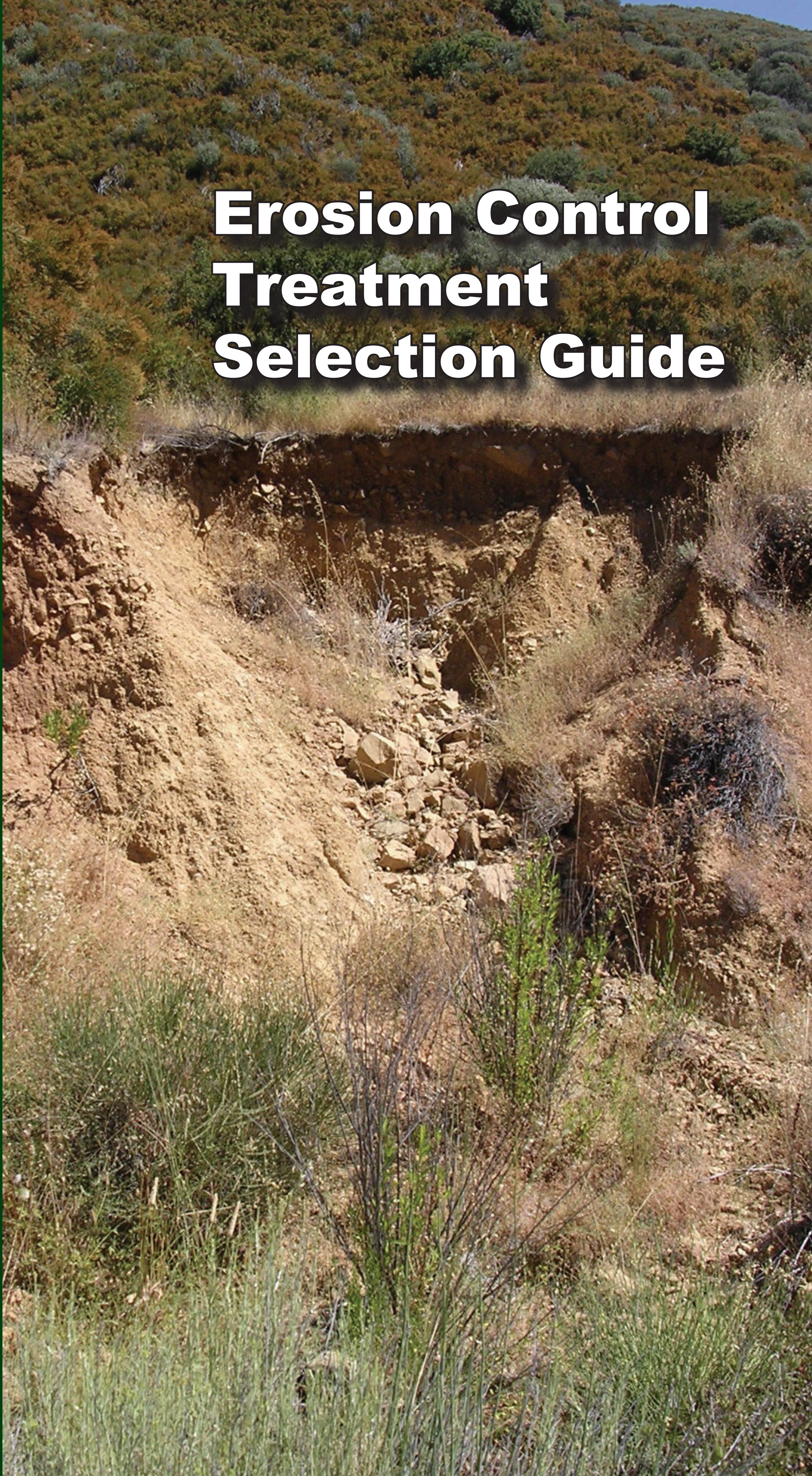
# Erosion Control Treatment Selection Guide



# Erosion Control Treatment Selection Guide

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## INTRODUCTION

**Why Erosion Control is Important**

Much of the U.S. Department of Agriculture (USDA) Forest Service infrastructure is located in areas of relatively steep, sometimes unstable, and highly erodible soil. Erosion is a naturally occurring process that many times is accelerated by earth-disturbing projects. Erosion from these activities may damage the ecosystem and visual environment, increase maintenance costs, increase water treatment costs, and leave the land susceptible to noxious weeds. Effective erosion control may help reduce the spread of invasive plant species, part of the four threats to the nation's forests and grasslands. In addition to mitigating the negative impacts of erosion, control is often needed to satisfy Federal, State, and local laws and policies. Earth disturbing forest projects can be a significant source of erosion that is challenging, sometimes expensive, but necessary to control. Cost-effective erosion control on USDA Forest Service lands is needed to mitigate the impacts of erosion as part of caring for the land.

**Purpose and Scope**

This guide presents a strategy and information to assist professional judgment in developing cost-effective erosion control treatments for conditions commonly encountered on USDA Forest Service lands. This guide focuses on erosion control treatment and does not specifically address sediment control. While the guide emphasizes permanent, long-term erosion control on steep slopes (greater than 50-percent slope gradient), the strategy and information may also apply to temporary construction-related erosion control and on flatter slopes. In addition, a strategy is presented for considering complicated and high-risk erosion conditions, such as gullies and landslide prone areas. However, solutions are not provided for these complex situations. Instead they are addressed in general terms to assist with determining when additional analysis or technical assistance may be needed. This guide is a starting point for treatment selection that considers site-specific conditions requiring professional judgment and includes:

- Erosion-Control Principles
- Erosion Types
- Soil Types
- Erosion-Control Treatments
- Erosion-Control Treatment Selection
- Erosion-Control Resources

## EROSION-CONTROL PRINCIPLES

Six generally accepted principles for effective erosion control are:

1. Reduce erosive forces and increase resisting forces. Erosion occurs when the erosive force (generally water or wind in conjunction with gravity) exceeds the soil's ability to resist the erosive force. The only methods to reduce erosion are reducing the erosive forces, increase the resisting forces, or a combination of the two. This is the basis of all effective erosion-control treatments.

2. Apply good erosion control for good sediment control. It is generally more cost effective and easier to prevent soil from eroding than to remove the soil after it is deposited elsewhere. Use sediment-control treatments (not necessarily addressed in this guide) to keep sediment from leaving the site.

3. Modify topography or grade. Effectively designed topography reduces sediment yield and increases vegetation establishment. Shorter and flatter slopes generally erode less and produce less sediment than longer, steeper slopes. Creating benches, terraces, steps, or using some soil bioengineering methods reduce slope length and angle. However, significant modifications may not be possible due to terrain, cost, and right-of-way limitations.

4. Limit soil exposure. Soil is especially prone to erosion during wet seasons. Divert or route excess water flowing over unprotected soil to avoid excessive erosion. Leave established vegetation undisturbed when possible; it is one of the most effective and least expensive methods to reduce erosion. Surface disturbance should occur only when the ground is relatively dry and the site is not subject to frequent intense storms or snowmelt. Install permanent protection as soon as possible after the disturbance.

5. Keep runoff velocities low. Reducing the slope gradient of the water or increasing surface roughness reduces water's velocity and erosive power. However, soil roughening, grade control structures (e.g., rock check dams) and silt fences should not be used for steep slopes.

6. Inspect and maintain treatments. Proper installation and maintenance of erosion-control treatments is important. Generally, after installation, inspect erosion-control treatments at least every 7 days on active sites, every 14 days on inactive sites, and within 24 hours following a rainfall event of 0.5 inches or more (Wright 2001), or during significant snowmelt. Correct any deficiencies or modify treatments as appropriate.

## EROSION TYPES

Understanding erosion processes is important when selecting appropriate erosion-control treatments. Each mechanism requires a somewhat different approach, although they can be related. The principle agents of erosion include water, gravity, wind, ice, and chemical action. The actions of these agents form a continuous spectrum of erosion that may be related. This spectrum includes some forms that are not traditionally included in the erosion definition, such as landslides. Consider these nontraditional forms of erosion for successful erosion control. For example, even the best designed and installed treatment will not be effective if it is part of a landslide.

Complicated high-risk projects may need specialists such as geotechnical engineers, hydrologists, soil scientists, and agronomists. Particularly complicated erosion situations occur in large gullies, coastlines and channels (streams), or steep slopes subject to landslides and other mass-movement. A broad framework for considering these situations is presented, but details are left to other publications and experts. It is noted however, that many erosion-control techniques presented are applicable to correct some or portions of these processes.

A number of the erosion processes occur mostly at the soil's surface. Often treatments for these processes are similar. Therefore these processes will be collectively called surface erosion. Surface erosion includes erosion caused by water (interrill and rill only), gravity (dry ravel only), and wind.

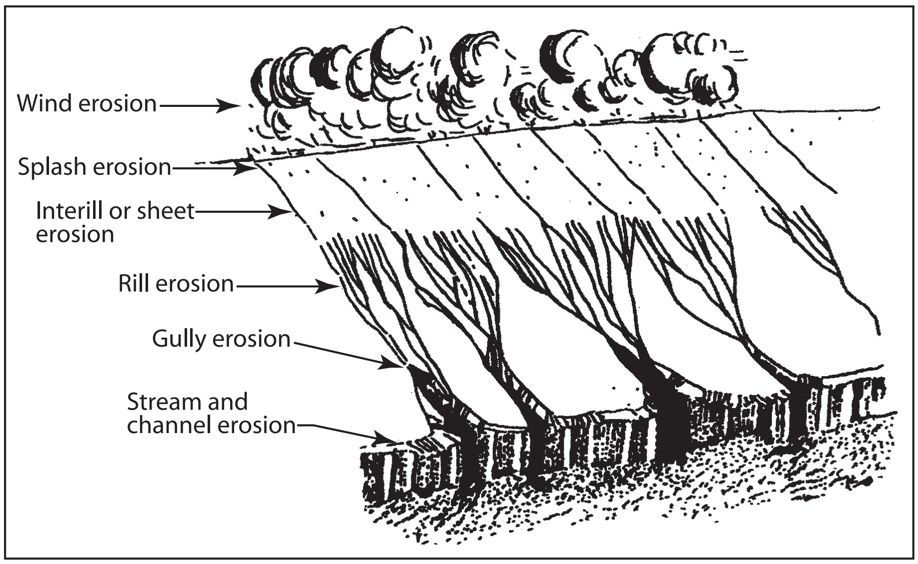


*Figure 1—How erosion features form.*

### Water-Caused Erosion

#### *Interrill (sheet) erosion*

Interrill erosion is composed of two parts. The first part of interrill erosion, splash erosion, occurs where rain impacts bare soil, dislodging the surface soil particles. This splash can also create a crust "seal" on the soil, called surface sealing, making it less permeable and reducing vegetation establishment. The second part of interrill erosion occurs when water forms very shallow surface flow, often referred to as "sheet erosion." Interrill erosion can occur on any soil that is impacted by water drops and/or where water begins to flow over the soil surface. The occurrence and severity of interrill erosion depends on soil erodibility, slope length and angle, storm duration, rate and duration of snowmelt, and vegetative cover. If untreated, it may develop into the generally more severe rill erosion.

*Figure 2—Interrill (sheet) erosion with rills and gullies forming.*

### Rill erosion

Rill erosion is erosion by water in small micro-channels, typically 0.2 to 1.2 inches wide and up to 3 inches deep. It occurs where rain or snowmelt contacts bare soil for durations long enough for the water to develop micro-channels. The occurrence of rill erosion depends on the soil erodibility, slope length and angle, storm duration and intensity, rate and duration of snowmelt, and vegetative cover. Rill erosion can occur on any slope with erodible soil, but is often more severe on steeper slopes. The volume of eroded material increases as the number of rills increase. Generally, increasing clay content decreases the chance of rill formation. If untreated, it may develop into the generally more severe gully erosion.

*Figure 3—Rills formed primarily by surface runoff.*

### *Gully erosion*

Gully erosion occurs in channels with U- or V-shaped cross sections located in valleys or hillslopes and is characterized by periodic flow and high width-to-depth ratios. Dimensions range from hundreds of millimeters to many meters. Untreated rills on slopes may develop into V-shaped gullies. Gully erosion is a significant problem on steep forested areas. Often it occurs where concentrated flow begins on relatively steep long slopes with erodible soils. Gully-erosion processes may be similar to channels and can be quite complex.

*Figure 4—Typical gully erosion.*

### *Channel and coastal erosion*

Channels differ from gullies in that they typically have low width-to-depth ratios, shallower side slopes, more consistent and often continual water flow, and may be larger than gullies. Erosion in the channel or on the banks of the channel may be linked to the channel system. This interaction can be very complex. Similarly, coastal erosion by wave action may also have complex causes and solutions.

### *Seepage erosion*

Seepage erosion is the removal of soil particles by water flowing through soil or bedrock which dislodges and transports soil particles. It occurs where permeable soil layers or underlying jointed bedrock exist. It may occur as part of other erosion processes such as channel, mass movement, and chemical erosion.

## Gravity-Caused Erosion

### *Dry-ravel erosion*

This is the removal and transport of particles downslope by gravity after the particle loses its cohesion from exposure to the elements, typically by losing moisture. Dry-ravel erosion is often recognized by the lack of rills and other water erosion features but with large amounts of eroded material deposited at the base of the slope.

### *Mass-movement erosion*

Mass-movement erosion is the movement of a mass of rock, debris, or earth down a slope. Examples include landslides and debris flows. This can be complicated and sometimes expensive to control.

## Wind-Caused Erosion

Wind erosion is the detachment and transport of soil particles by wind where particles move suspended in air (suspension), by bouncing (saltation), or rolling (surface creep). It can be a more significant erosion source than water in dry climates or windward facing slopes with frequent high winds.

*Figure 5—Wind erosion.*

### Ice-Caused Erosion

***Freeze/thaw erosion***

Freeze/thaw erosion occurs during the expansion of freezing water and the contraction of thawing ice. It requires freezing temperatures, time for ice to form, soil moisture, and frost-susceptible soils. It can loosen and remove rock and soil and displace seeds in fine-textured soil. It is not specifically addressed in this guide.

***Glacier or moving ice erosion***

Glacier or moving ice erosion occurs by large amounts of ice entrapping, grinding, and moving soil and rock. It can move soil and rock many miles from its origin. It is not specifically addressed in this guide.

### Chemical-Caused Erosion

Chemical erosion is the transport of rock and soil and/or its transformation into another substance through chemical processes. Rock and soil may be transformed by chemical reactions into another substance and subsequently removed. In addition, rock and soil may be dissolved and transported by another substance, such as water. Chemical-caused erosion can be significant and complex, such as the formation of sink holes in limestone. This form of erosion is not specifically addressed in this guide

## SOIL TYPES

Successful erosion control strategies consider the soil properties including its erodibility and its capability soil to support vegetation establishment. A standard description (classification) of the soil types is necessary for effective communication. Two common soil classifications are the USDA Soil Texture Classification (see Soil Survey Staff 1960) and the Unified Soil Classification System (USCS – see ASTM 1998). A qualitative assessment of the typical erosion potential of soils described by both systems is shown in table 1. Provided the right conditions, any soil is susceptible to mass movement. Seepage erosion generally requires high enough permeability to allow seepage and small enough particles to be moved easily. Therefore, seepage-erosion risk should be low for gravels (large particles, but potentially high permeability) and clays (small particles, but generally low permeability). One notable exception is dispersive clays, which are very erodible. Loamy sands are prone to surface sealing, which increases runoff.

The soil type also significantly impacts vegetation establishment. Generally, loamy or silty soils are ideal for vegetation establishment. Sandy gravely soils often lack fines, nutrients, and the water-holding capacity of silty soils. Heavy plastic clays and silts often have poor aeration, and resist root penetration. The soil density can also significantly affect vegetation establishment. Dense soils generally have lower permeability and poor aeration that impede root growth. The nutrient and chemical properties (such as pH) also affect vegetation establishment. It may be necessary to improve the soil properties for effective vegetation establishment, such as when mineral soils are exposed in road cuts.

Table 1—Suggested general surface erosion potential and plant growth capability of selected soils (based on Gray and Leiser 1982, Gray and Sotir 1996, and Bell, 2000)

| USDA Soil Texture* | USCS group symbol | USCS Soil Description | Surface Erosion Potential (rill/interrill/wind) | Support of Vegetation Establishment |
|---|---|---|---|---|
| Gravel | GW | Well-graded gravel | Low to medium | Poor |
| Gravel | GP | Poorly-graded gravel | Low | Very poor |
| Gravel/silt | GM | Silty gravel | Low to medium | Poor to fair |
| Gravel/clay | GC | Clayey gravel | Low | Poor to fair |
| Sand | SW | Well-graded sand | Medium to high | Poor to fair |
| Sand | SP | Poorly-graded sand | Medium to high Wind erosion-high | Very poor |
| Loamy sand | SM | Silty sand | Medium to high | Good to very good |
| Sandy clay loam | SC | Clayey sand | Medium to high | Good to very good |
| Silt | ML | Silt | High Wind erosion-high to very high | Good to very good |
| Clay | CL | Clay | Low to medium | Fair to good |
| Silt | MH | Silt, high plasticity | Medium | Good |
| Clay | CH | Clay, high plasticity | Low to medium | Fair to good |
| | PT, OL/OH | Peat/Organic silts/clays | Low to high | Very good |

* The USDA soil texture system does not correlate well with some aspects of the USCS, especially for gravelly and organic soils.

## EROSION-CONTROL TREATMENTS

Erosion control is a two-step process; short-term erosion control generally followed by the establishment of vegetation for long-term erosion control. Sometimes in steep or severe conditions, a structural solution, such as a retaining wall, is required. The ideal erosion-control product promotes germination and plant growth while it protects the soil from short-term erosion. There are numerous treatments, combinations of treatments, and emerging products that may be suitable for a site. This guide is a starting point in selecting various treatments. The general erosion-control treatment categories and corresponding tables are:

- Grade-related (table 2)
- Seed, fertilizer, and soil amendments (table 3)
- Soil stabilizers and tackifiers (table 4)
- Mulch (table 5)
- Rolled Erosion-Control Products (table 6)
- Hard armor (table 7)
- Soil bioengineering (table 8)

Biotechnical stabilization uses mechanical (structures) and biological elements to prevent severe erosion. These may include nonvegetated structures, such as retaining walls. Soil bioengineering, the use of plants in biotechnical slope stabilization as the main structural component, is a part of biotechnical stabilization. Biotechnical stabilization, including soil bioengineering, is a specialized field and consultation with experts and other guides is highly recommended.

Tables 2 through 8 address methods common for each treatment. A description of each method, how it functions, when it is typically used, and its limitations for use are noted. The conditions of use and limitations are those generally found in literature, or in some cases, are based on the author's and reviewers' experience.

Table 2—Grade-related treatments.

| **Functions** | **Typical uses** | **Limitations** |
|---|---|---|
| **Grading and shaping** | | |
| • Flattens slope for stability.<br>• Modifies soil surface and topography to control runoff and establish vegetation.<br>• Optimizes slope angles and shapes for reduced water erosion and sediment yield. | • Use to improve final appearance, improve stability, enhance vegetation establishment, and reduce erosion.<br>• Use to reduce costs and increase effectiveness of treatments. | • May reduce vegetation establishment if surface is compacted on sites with high silt and clay content.<br>• May have limited options due to topography.<br>• Final grading should be compatible with the land use objectives. |
| **Soil roughening** | | |
| • Reduces and detains runoff and improves vegetation establishment. | • Use to loosen the soil for improved soil properties for improved vegetation establishment. | • May not be suitable for steep slopes.<br>• May temporarily increase erosion prior to vegetation establishment. |
| **Tracking (Tracking cleated construction equipment up and down or across a slope)** | | |
| • Roughens the soil surface to reduce runoff, increase infiltration, trap sediment, and promote seed germination and growth. | • Use to reduce erosion and sediment yield, particularly for sandy slopes, if the cleats are <u>parallel</u> to the contour. | • May compact the surface if used on clay and silt soils.<br>• Increases erosion if used with cleats <u>perpendicular</u> to the contour.<br>• May increase time to finish slopes.<br>• May not be suitable for steep slopes. |
| **Terraces (Berm or bench-like earth embankment, with a nearly level plain bounded by rising and falling slopes. Based on slope, terraces are either level (placed on contour) or graded (sloped to drain).** | | |
| • Improves infiltration, reduces effects of interrill and rill erosion, and assists vegetation establishment.<br>• Reduces slope distance. | • Use on long, steep, stable cut and fill slopes 2H:1V or steeper.<br>• Use to prevent erosion with paved on-contour terrace drainage ditches. | • May be susceptible to instability if not well compacted.<br>• May be difficult in rocky, hard soils.<br>• May reduce sediment yield but not erosion. |
| **Constructed wattles (A constructed linear feature placed in contact with the soil surface, generally on contour, that breaks a longer slope into a series of shorter slopes, such as small rock walls, woven wooden fences, or logs.)** | | |
| • Retains seeds and soil, slows runoff.<br>• Breaks a long slope into a series of smaller slopes.<br>• Improves conditions for plant establishment immediately upslope of wattle. | • Use to shorten slope distance, retain sediment, and reduce rill formation.<br>• Use for long-term protection after vegetation is established.<br>• Use on gentle or steep slopes (up to 1H:1V).<br>• Use in combination with soil bioengineering, such as a bender board fence, to help establish vegetation for steep and dry sites.<br>• Use log wattles for fire rehabilitation. | • May require maintenance to remain effective.<br>• May require skilled, time-consuming labor to install.<br>• Has limited sediment capture capability.<br>• Should not be used on creeping or slumping soils or for high flows.<br>• May be ineffective for interrill erosion. |

| **Manufactured wattles (Natural plant materials such as coir, rice or wheat straw, or flax encased in tubes of netting and placed securely on the slope, generally on contour, to break a longer slope into a series of shorter slopes.)** | | |
|---|---|---|
| • Retains seeds and soil, slows runoff.<br>• Breaks a long slope into a series of smaller slopes to reduce rill erosion.<br>• Improves conditions for plant establishment immediately upslope of wattle. | • Use to shorten slope distance, retain sediment, and reduce rill formation.<br>• Use for temporary 2-3 year protection until plants are established.<br>• Use for quick, relatively easy installation.<br>• Use on gentle or steep slopes (up to 1H:1V). | • Requires intimate contact with ground.<br>• May require maintenance to remain effective.<br>• Has limited sediment capture capability.<br>• Should not be used on creeping or slumping soils or for high flows.<br>• May be ineffective for interrill erosion. |

Table 3—Seed, fertilizer, and soil amendments (Broadcast of seeds, fertilizer and or amendments on or into the surface of the soil)

| **Seed** | | |
|---|---|---|
| **Functions** | **Typical uses** | **Limitations** |
| • Helps erosion control after germination, and increases performance as plants grow.<br>• Encourages water retention and infiltration.<br>• Improves esthetics. | • Use of dry seed and fertilizer may be effective on slopes up to 1.5H:1V.<br>• Use seed and mulch to provide adequate vegetation for erosion protection prior to harsh weather conditions. | • May be less effective on higher slopes if seed, hydromulch, or straw mulch with tackifier are used.<br>• May require additional interim erosion control treatments. |
| **Fertilizer and Soil Amendments** | | |
| • Provides nutrients and desirable soil properties for vegetation growth. | • Use for long-term vegetation establishment by applying to soils lacking nutrients or other desirable properties, such as favorable pH.<br>• Use hydraulically applied composted manure on cutslopes with low nutrient content. | • May require hydraulic application on difficult steep slopes. |

*Figure 6—Relatively recent cutslope vegetated with native seeding.*

Table 4—Soil stabilizers and tackifiers (Organic or inorganic products applied in solution to the soil surface that form a protective surface film or infiltrate and bind the soil particles together or seed and mulch to the surface.)

### Soil stabilizers and tackifiers

| Functions | Typical uses | Limitations |
|---|---|---|
| • Aids vegetation establishment while temporarily protecting surface of steep slopes.<br>• Reduces seed loss and evaporation, increases infiltration, moderates soil temperature, and adds nutrients.<br>• Holds mulch fibers in place.<br>• Encourages vegetation establishment in dry climates by preventing soil surface sealing while vegetation develops.<br>• Increases infiltration rate of soils in dry climates (phosphogypsum (PG)). | • Use to tack mulches on hard to reach areas and increase mulch durability.<br>• Use alone or with hydraulic mulch to increase vegetation establishment especially for short, high intensity rainfall on sandy loam slopes.<br>• Use polysaccharide (PS) and PG or polyacrylamide (PAM) and PG as very effective treatments in dry climates for slopes up to 1H:1V with no significant difference between the two combinations of treatments.<br>• Use to reduce surface sealing of soil. | • May have varied application needs and effectiveness depending on temperature, soil moisture, and dilution.<br>• Will become less effective with time.<br>• May reduce vegetation establishment in some cases.<br>• May be less effective if used on frost-heave susceptible soils or when applied near freezing weather.<br>• May increase soil biological activity and reduce the efficiency of PS in warm weather and moist soil.<br>• May have reduced effectiveness of PG when subject to high intensity storms or applied to long, windward slopes. |

Table 5—Mulch (See glossary for definition and discussion on long-fibered and short-fibered mulch)

| **General** | | |
|---|---|---|
| **Functions** | **Typical uses** | **Limitations** |
| • Provides seed coverage and reduces splash erosion.<br>• Improves soil structure and nutrients.<br>• Reduces surface crust formation.<br>• Detains and reduces runoff.<br>• Moderates soil temperature. | • Use to establish vegetation at sites with surface erosion, daily temperature fluctuations, lack of available moisture, acidic soils, lack of nutrients, and lack of organic material.<br>• Use as a supplement to other erosion control treatments such as seeding and soil bioengineering.<br>• Use tackifiers or nettings for steep slopes. | • May be ineffective in some applications if used alone.<br>• Will not control concentrated water erosion.<br>• May sometimes increase seedling mortality.<br>• May require addition of nitrogen when straw or wood is used. |
| **Straw mulch (Typically long-fibered wheat or oat stems, or hay.)** | | |
| • See general functions above. | • See general typical uses above.<br>• Use for relatively inexpensive and readily available mulch.<br>• Use with fertilizer and tackifier up to 1.25H:1V slopes.<br>• Use with netting up to 1H:1V slopes.<br>• Use with pneumatic spreader or hand place. | • See general limitations above.<br>• Decomposes rapidly.<br>• May introduce weeds, even when certified weed free.<br>• May be removed by wind and water and require anchoring onto surface. |

| | | |
|---|---|---|
| **Pine needle mulch (Mulch made from coniferous tree needles.)** | | |
| • See general functions above<br>• Forms interlocking matrix that is difficult to move by wind, water, and gravity. | • See general typical uses above.<br>• Use for establishing plants, such as conifers, which thrive in acidic soil.<br>• Use on steep slopes up to 1.25H:1V, maybe steeper. | • See general limitations above.<br>• May not be readily available in some regions. |
| **Wood mulch (Typically wood fibers including wood chips, excelsior, coconut, jute, or burlap.)** | | |
| • See general functions above.<br>• Hardwood bark is effective due to its weight and interlocking fibers.<br>• Onsite shredded small trees (6 inch) are effective and plentiful in areas being thinned. | • See general typical uses above.<br>• Used in rolled erosion control products (RECPs) or applied with hydro seeder, hydromulcher, or pneumatic spreader. | • See general limitations above.<br>• May not be as effective as straw or hay.<br>• May reduce vegetation establishment if applied too thick.<br>• May be easily washed or blown away, especially on steep slopes. |
| **Wood strand mulch (Wood manufactured into approximately 1.6 to 6.3-inch strands approximately 0.125 mm thick by 0.24 inches wide.)** | | |
| • See general functions above<br>• Forms an interlocking 3-D matrix that is difficult to move by wind, water, and gravity.<br>• Increases overland flow path length.<br>• Reduces rill formation by creating mini-debris dams. | • See general typical uses above.<br>• Use to reduce rill formation.<br>• Use as weed- and pesticide-free substitute for straw and pine needle mulch.<br>• Use as possible longer-term, allergy friendly, foraging reducing, more wind-resistant alternative to straw mulch. | • See general limitations above.<br>• May require advanced planning with manufacturer for availability.<br>• May cost more than straw mulch. |
| **Recycled paper/pulp mulch (May be referred to as cellulose and applied with a hydraulic seeder or hydraulic mulcher.)** | | |
| • See general functions above. | • See general typical uses above.<br>• Use as a less expensive alternative to wood fiber, hay, and straw mulches. | • See general limitations above.<br>• Less effective alternative to wood fiber, hay, and straw mulches.<br>• Short fibers are easy to move, even when bonded with a tackifier.<br>• Decomposes quickly.<br>• Ineffective for significant surface runoff. |
| **Hydraulic mulch (Wood, cellulose, paper pulp, or recycled fibers sprayed on slopes in a slurry, typically with seed and fertilizer.)** | | |
| • See general functions above. | • See general typical uses above.<br>• Use for one-step application.<br>• Use on steep slopes with tackifier rather than dry loose mulch.<br>• Use on sites inaccessible to loose mulch blowers yet near a water supply and road.<br>• Use as less expensive alternative to RECPs. | • See general limitations above.<br>• Less effective on short fibers without tackifier than long fibers.<br>• Long fibers may clog applicators.<br>• Relatively short effectiveness.<br>• Less effective than RECPs for high intensity storms. |

| Bonded-fiber matrices (BFMs) (Fiber mulch material combined with chemical adhesives or gypsum based compounds that are more resistant to water once cured and dried.) | | |
|---|---|---|
| • Reduces interrill and rill erosion through close ground contact.<br>• Increases strength over mulch from bonding agents, even when wet.<br>• Supplies some soil nutrients.<br>• Holds water well in small pores. | • See general typical uses above.<br>• Use on rough, irregular slopes.<br>• Use for high seed retention.<br>• Use to assist vegetation establishment.<br>• Use as more durable alternative to hydraulic mulch. | • See general limitations above.<br>• Generally denser and lower tensile strength than Erosion Control Blankets (ECBs).<br>• May have weather dependant application.<br>• May not perform well under high intensity rainfall. |

*Figure 7a—Close-up of straw mulch.descending fillslope with vegetation starting.*

*Figure 7b—Close-up of wood mulch.*

*Figure 8a—Wood mulch on cutslope with vegetation starting.*

*Figure 8b—Sprayed mulch on descending fillslope with vegetation starting.*

Table 6—Rolled Erosion Control Products

| **Rolled erosion control products (RECPs) (Flexible organic or synthetic nets, mats or rolls that are rolled out to reduce surface erosion.)** | | |
|---|---|---|
| **Functions** | **Typical uses** | **Limitations** |
| • Reduces splash, sheet, and rill erosion when in contact with the soil, reduces surface sealing, and increases infiltration.<br>• Reduces and detains runoff and lessens erosion if water moves along fibers. | • Use for immediate surface erosion protection.<br>• Use to combine long-fibered mulch benefits with the tensile strength of anchoring nets.<br>• Use on steep slopes and low to moderate velocity flow.<br>• Use when ease of handling and storage of materials are important. | • Requires intimate contact with the ground.<br>• May fail by soil eroding beneath RECP.<br>• May be lifted off the ground by seedlings.<br>• May be more costly than other surface cover treatments.<br>• Correct installation is critical for success.<br>• Soil surface needs to be graded smooth to establish soil contact. |
| **Mulch control nets (MCNs) (A planar woven natural fiber or extruded geosynthetic mesh used as a temporary degradable RECP to anchor loose fiber mulches.)** | | |
| • Anchors mulch to the slope to provide stronger mulch-soil contact.<br>• Improves erosion control only when combined with mulch. | • Use to improve loose mulch performance for moderately steep sites.<br>• Use photodegradable for short-term control.<br>• Use ultraviolet (UV) stabilized for long-term control. | • May be internally weaker than glued or mechanically bonded RECPs.<br>• Slopes flatter than 1H:1V.<br>• May be labor intensive to install.<br>• May entrap rodents, birds, and reptiles, especially for synthetic material. |
| **Open Weave Textiles (OWTs) (A temporary degradable RECP composed of processed natural or polymer yarns woven into a matrix, used to provide erosion control and facilitate vegetation establishment.)** | | |
| • Provides erosion protection in combination with mulch or by itself due to the close weave. | • Use for higher tensile strength than MCN.<br>• Use as facing for vegetated geotextiles that can be photodegradable or UV stabilized. | • Typically for up to 2H:1V slopes.<br>• May entrap rodents, birds, and reptiles. |
| **Erosion control blankets (ECBs) (A temporary degradable RECP composed of processed natural or polymer fibers mechanically, structurally or chemically bound together to form a continuous matrix to provide erosion control and facilitate vegetation establishment.)** | | |
| • Acts as mulch but is physically connected to an MCN or OWT for greater strength.<br>• May reduce erosion as much as 90 percent. | • Use on sites requiring durable, long-lasting, erosion control beyond anchored or unanchored mulch.<br>• Use for erosion control until plant establishment.<br>• Use on steep slopes and/or erodible soils. | • May be relatively expensive.<br>• May not be any significant performance difference between different ECBs.<br>• Typically up to 1.5H:1V, maybe up to 1H:1V.<br>• May entrap rodents, birds, and reptiles, especially for synthetic material. |

| **Turf reinforcement mats (TRMs) (A rolled erosion control product composed entirely or mostly of nondegradable synthetic fibers, filaments, nets, wire mesh and/or other elements, processed into a permanent, three-dimensional matrix of sufficient thickness.)** | | |
|---|---|---|
| • Retains seeds and soil, stimulates germination, and accelerates growth.<br>• Provides permanent reinforcement for roots.<br>• Provides immediate erosion protection. | • Use in channels, ditches, shorelines, or steep slopes where plants need extra long-term reinforcement.<br>• Use as alternative to riprap or other “hard armor” techniques. | • May have higher erosion rates initially than bare ground if backfilled.<br>• May be used up to 0.5H:1V with careful installation and anchoring.<br>• Requires a smooth surface for installation. |

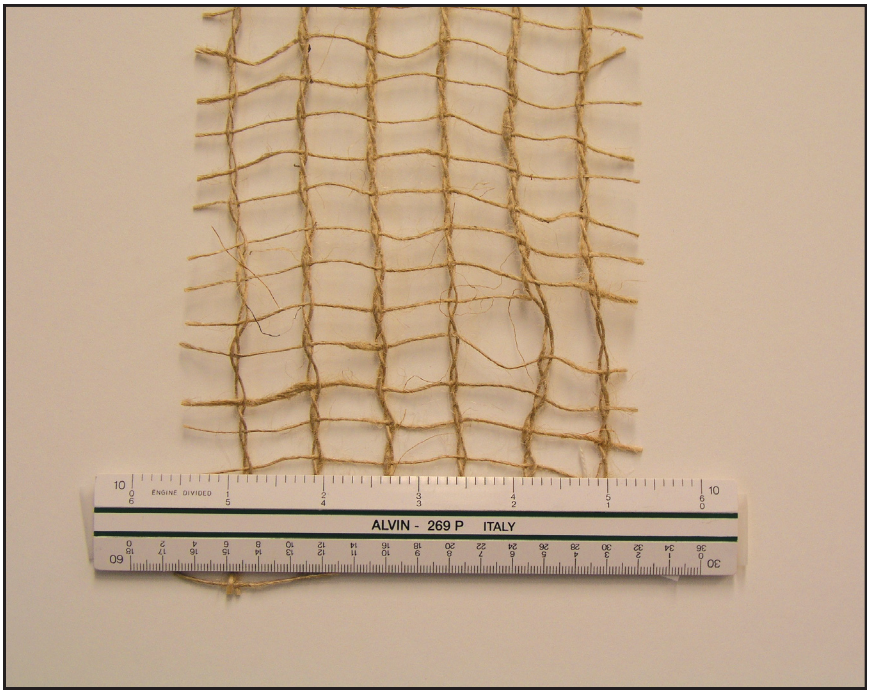


*Figure 9—Close-up of erosion control net, natural coir fiber.*

*Figure 10—Various erosion control blankets (l to r) – straw, excelsior (natural), excelsior (dyed green), coir, and netless wood/ synthetic.*

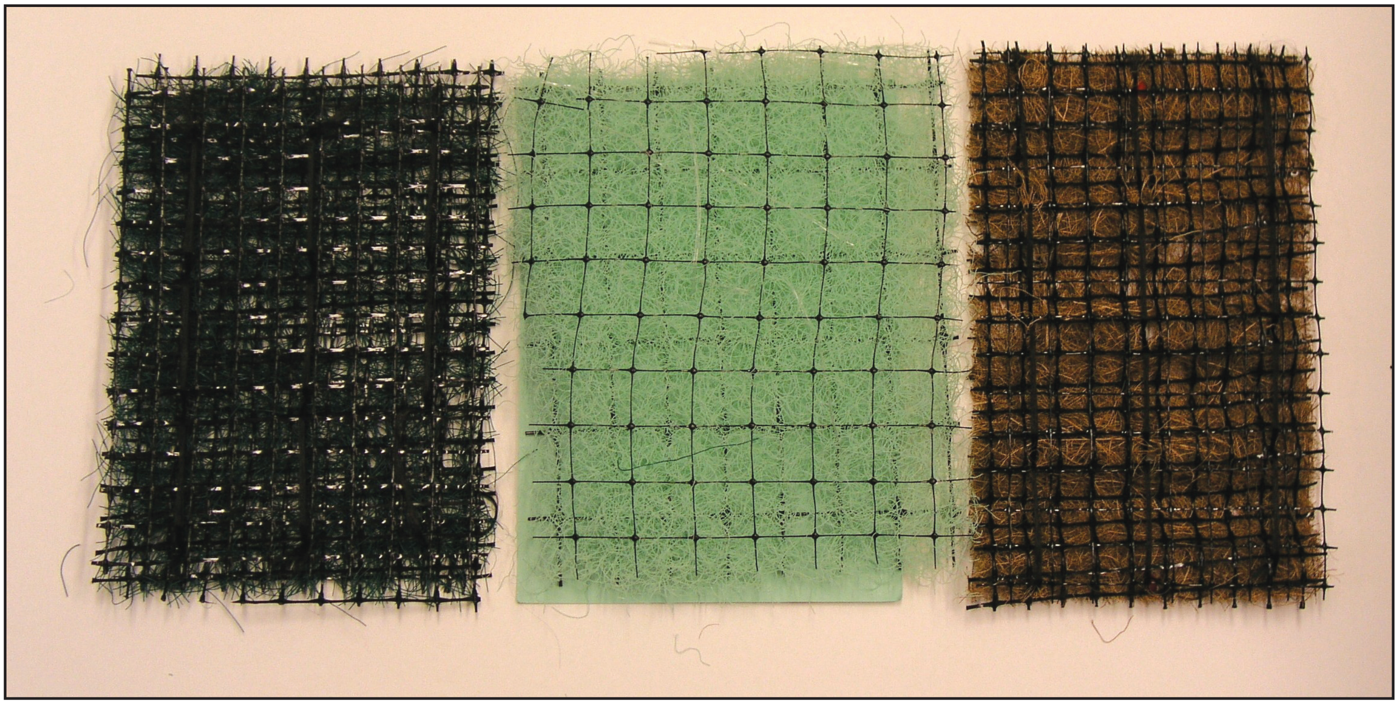

*Figure 11—Various turf reinforcement mats.*

Table 7—Hard armor

| **Geocellular containment systems (GCSs) (Synthetic three-dimensional cells up to 8 inches deep filled with soil, sand, or rock and anchored to the slope.)** | | |
|---|---|---|
| **Functions** | **Typical uses** | **Limitations** |
| • Increases shallow soil strength.<br>• Assists vegetation establishment in cells. | • Use on gentle or steep slopes (<1H:1V).<br>• Use to minimize excavation and utilize low quality backfill.<br>• Use to confine cohesionless soil like sand. | • Cell walls limit strength of rooted plants.<br>• Not for rough, severely rilled, or gullied slopes.<br>• May be undermined on steep slopes. |
| **Riprap or rock blankets (Rock placed on ground surface.)** | | |
| • Protects soil from surface erosion.<br>• Reduces runoff velocities, encouraging infiltration.<br>• Provides shelter for growth of some species of plants on uneven surface.<br>• Reduces seepage erosion when used with filter fabric. | • Use with sites located near quality rock of suitable size and quantity.<br>• Use on dry, difficult to vegetate sites.<br>• Use with filter to reduce seepage erosion.<br>• Use with live stakes or plant between riprap stones for improved performance and looks. | • Quality rock of suitable size needs to be close for economic feasibility.<br>• May not be aesthetically pleasing to some.<br>• Unstable riprap on steep cutslopes can be a safety hazard.<br>• Filter needs to be properly designed.<br>• Planting between stones can be difficult. |

*Figure 12—Riprap erosion protection on cutslope above retaining wall.*

Table 8—Soil Bioengineering (see also Lewis (2000), Atkins and others (2001), and Gray and Sotir (1996))

| **Live stakes (Tamping of live, rootable vegetative cuttings into the ground.)** | | |
|---|---|---|
| **Functions** | **Typical Uses** | **Limitations** |
| • Roots strengthen soil as plants grow.<br>• Plants remove soil moisture through evapotranspiration.<br>• Stakes provide some immediate buttressing effect.<br>• Increases effectiveness as plant grows. | • Use on relatively steep, raveling cut and fill slopes.<br>• Use for staking of RECPs.<br>• Use on wet seeping sites needing pioneering cover.<br>• Use for added root strength in benches or riprap.<br>• Use as a relatively inexpensive way to establish woody vegetation. | • Requires time to grow for full effectiveness.<br>• May be relatively labor intensive. |
| **Live fascine (Stems and branches of rootable plant material tied together in long bundles and secured in shallow trenches.)** | | |
| • Roots strengthen soil and remove soil moisture as plants grow.<br>• Slows runoff and traps sediment.<br>• Reduces slope into series of smaller slopes.<br>• Plants increase protection as they grow. | • Use on steep slopes subject to surface erosion.<br>• Use to support vegetation establishment on wet, seeping sites.<br>• Use on cutslopes rather than brushlayers.<br>• Use on rocky, wet, difficult to dig slopes.<br>• Use on cut and fill slopes up to 1.5H:1V. | • May be undermined on steep or long slopes.<br>• May require large quantity of plant material.<br>• Can dry out if not properly installed.<br>• May be difficult to dig on rocky slopes.<br>• May be relatively labor intensive.<br>• Not recommended for dry, coarse soil. |

| | | |
|---|---|---|
| **Pole drains (Rows of live fascines oriented down slope, connecting to a central drain.)** | | |
| • Acts as conduit for water.<br>• Plants strengthen soil and remove soil moisture through evapotranspiration. | • Use on wet slopes with subsurface seepage.<br>• Use if seepage is causing down slope erosion.<br>• Use to divert water from top of slope.<br>• Use may be beneficial for large patches of unstable material. | • May not be suitable for rocky sites.<br>• May experience clogging and cause adjacent erosion in fine grained soil.<br>• May be relatively labor intensive. |
| **Willow fences (Short retaining walls (i.e., a constructed wattle) built of living cuttings placed horizontally behind supporting vertical posts.)** | | |
| • Reduces effective slope angle.<br>• Catches sediment and raveling material.<br>• Provides cover for pioneering woody vegetation as cuttings grow.<br>• Holds soil in place on moist sites while allowing it to drain. | • Use on steep cutslopes or landslide scarps.<br>• Use on stable slopes up to 1.3H:1V.<br>• Use for raveling and eroding material with moist conditions.<br>• Use for fine texture soils that are wet during growing season. | • May not be suitable for dense or very coarse material.<br>• May require nearby suitable plant material.<br>• Requires moisture for fence to grow.<br>• May require significant plant material.<br>• May be labor intensive. |
| **Brushlayers (Crisscross pattern of live cut, rooting branches placed between layers of soil.)** | | |
| • Removes soil moisture by evapotranspiration.<br>• Reinforces surface soils with roots.<br>• Catches raveling material.<br>• Establishes pioneering vegetation.<br>• Increases infiltration on dry sites and drains wet sites. | • Use on steep, raveling, or eroding slopes.<br>• Use during fill construction.<br>• Use on sites too dry for willow fencing. | • Can use only on cutslopes flatter than 2H:1V.<br>• Can be used only on slopes with less than 15 feet vertical height.<br>• May be labor intensive.<br>• May be effective for ravel control only after plant establishment. |
| **Modified brushlayers (Brushlayers combined with constructed or manufactured wattles such as small logs, short boards, or willow fencing.)** | | |
| • Reduces effective slope angle for steep slopes and breaks slope into series of smaller slopes.<br>• Reinforces soil.<br>• Catches slope ravel and rolling rocks.<br>• Increases infiltration on dry sites.<br>• Assists drainage of wet sites.<br>• Establishes pioneering plants from cuttings. | • Use logs or boards for sites too dry for willow fencing.<br>• Use willow fencing in fine textured soils or where suitable summer moisture available.<br>• Use willow fencing and maybe log or board for wet, seeping sites. | • For dry sites, vegetation establishment above log, board, or fence is critical.<br>• May requires significant amounts of plant material.<br>• Should construct 2H:1V slope above fence, board, or log.<br>• May be labor intensive. |
| **Branchpacking (Alternating layers of live branch cuttings and compacted fill between wooden stakes.)** | | |
| • Removes soil moisture by evapotranspiration.<br>• Reinforces soil with roots and stems.<br>• Reduces runoff and surface erosion while trapping eroding sediment. | • Use for small slumps, slips, holes, and head cuts in natural slopes, cuts, and embankments.<br>• Use for slumps up to 4 feet deep and 5 feet wide. | • Fill should be moist.<br>• Not recommended for rocky sites.<br>• May be labor intensive. |

| **Live slope grating (Array of vertical and horizontal wood members fastened to a slope, filled with soil, and planted with cuttings.)** | | |
|---|---|---|
| • Provides new slope surface.<br>• Supports itself from the base.<br>• Protects underlying slope surface from weathering and erosion. | • Use on slopes greater than 1.5H:1V up to 1H:1V.<br>• Use on steep slopes requiring anchoring (plants or mechanical) to the slopes for revegetation.<br>• Use for very little required excavation. | • Does not armor or buttress the slope.<br>• May be labor intensive.<br>• May be quite expensive compared to other methods. |

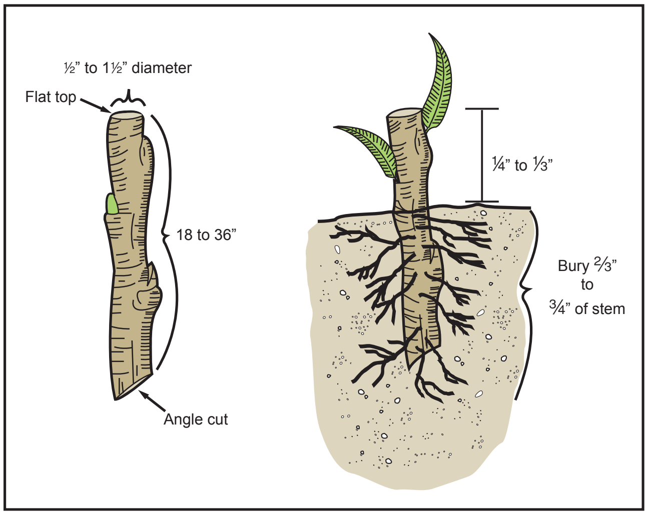


*Figure 13—Typical live stakes. (Lewis 2000)*

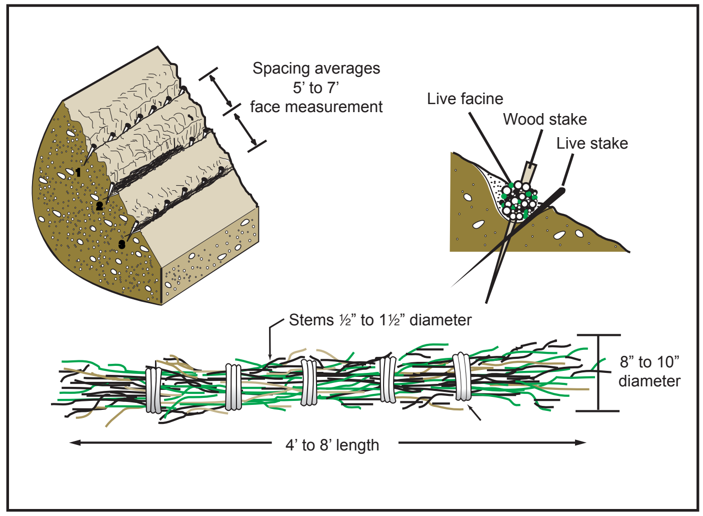


*Figure 14—Typical live fascine. (Lewis 2000)*

*Figure 15—Brushlayer modified with willow fencing. (Lewis 2000)*

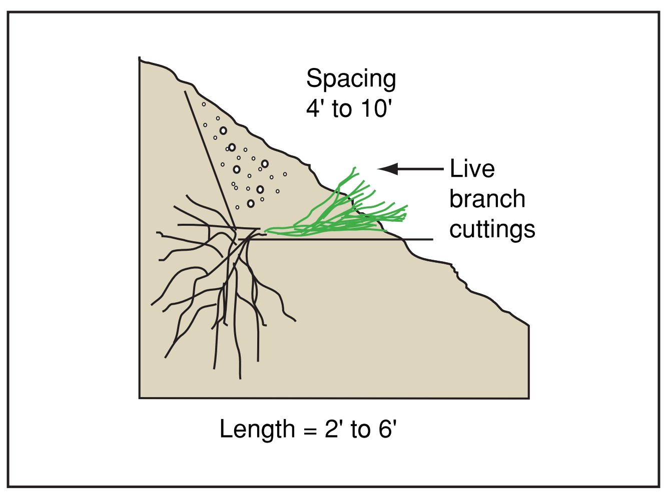


*Figure 16—Typical brushlayers. (Lewis 2000)*

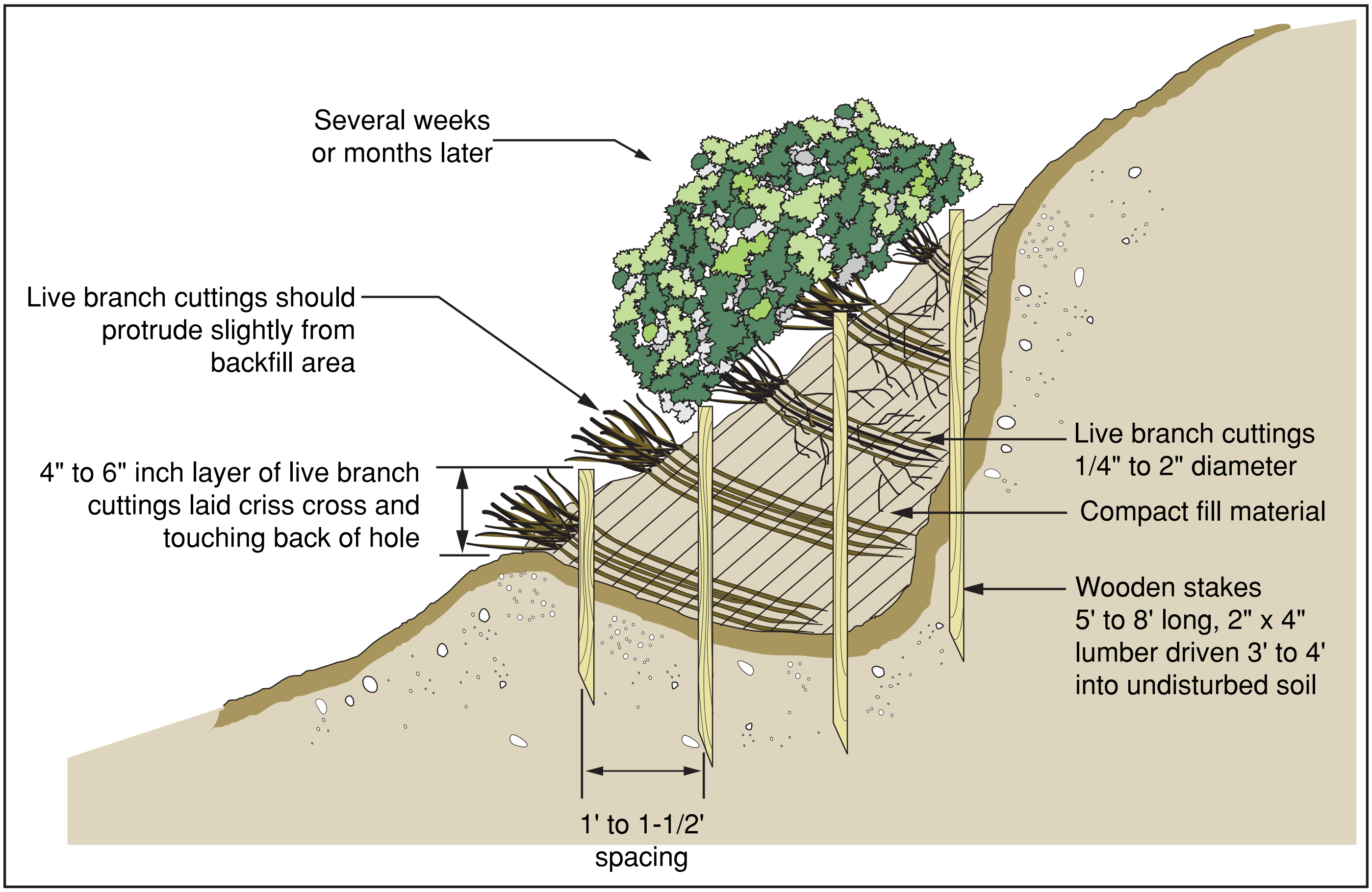


*Figure 17—Typical branchpacking. (Lewis 2000)*

## PROPER TREATMENT SELECTION

Erosion control treatment selection is based on six steps. This process provides a consistent and effective approach to selecting appropriate erosion control treatments.

- Step 1. Assess project site
- Step 2. Establish objectives
- Step 3. Collect site-specific data
- Step 4. Assess erosion potential
- Step 5. Evaluate alternative treatments
- Step 6. Select treatment

**Step 1. Assess project site.** Consider the location, extent, and severity of existing erosion as well as the potential for future erosion. The initial assessment will determine the resources for cost-effective erosion-control treatment selection by considering the risk. Generally, low-risk sites require minimal resources and assessment while high-risk sites may require significant technical analysis, time, and financial resources.

The parameters to consider during the project assessment include erosion potential, regulations and policies, environmental concerns, risk and liability, cost and funding, and project timing. Details for each parameter include:

***Erosion potential.*** Consider severity of existing erosion, potential for future erosion, and location and extent of erodible areas.

***Regulations and policies.*** Consider regulations and policies affecting the site and their impacts on the project. Schedule necessary time for obtaining permits.

***Environmental concerns.*** Consider compliance with environmental regulations, effects of environmental damage from erosion, potential for noxious weed invasion, and potential wildlife habitat enhancement or degradation.

***Risk and liability.*** Consider potential for erosion control failure and consequences. This may include safety, compliance with laws, recreation value, and public opinion.

***Cost and funding.*** Consider potential installation, maintenance, and monitoring costs; amount and duration of funding; and direct and indirect monetary loss from uncontrolled erosion.

***Project timing***. Consider duration of the project and timing of project activities relative to seasons of high erosion potential.

**Step 2. Establish Objectives.** Objectives define successful erosion control. Objectives can vary significantly between projects but generally address the parameters identified as significant during the project assessment. Objectives are obtainable and specific as possible. Using performance based objectives, as outlined in appendix B, is one method to establish obtainable and specific objectives.

**Step 3. Collect Site-Specific Data**. Treat each site uniquely. Obtain site data for appropriate treatment selection. The level of data necessary is directly related to the project's scope. Sites with higher risks and costs require more extensive data collection and analysis. A draft site data sheet to record important site conditions (figure A1) is included in appendix A.

**Step 4. Assess Erosion Potential**. The two ways to assess erosion potential are qualitative and quantitative. Different levels of analysis are needed to assess erosion potential depending on the project's scope as identified in the project assessment. Always provide an initial qualitative assessment of the erosion potential after a site visit. Additional information that can be used in a qualitative assessment, including the draft site data sheet, is found in appendix A. These include site characteristics such as topography, climate, and vegetation.

A qualitative erosion potential assessment is all that is needed for most sites without unusual circumstances. However, a quantitative erosion potential analysis may be necessary depending on the scope of the project or as sometimes required by regulatory agencies. Several models exist for estimating erosion potential. See the references in appendix B for information on these soil loss analysis models.

**Step 5. Evaluate alternative treatments.** Process-based treatment evaluation helps to choose a treatment that meets the project goals. Use the erosion potential assessment developed in step 4 to assist with selecting potential erosion control treatments. Always consider how a treatment affects the erosion processes to be controlled. The seven basic steps of the suggested process-based evaluation and selection model are:

> ***Step A: Is there channel related or coastal related erosion?*** Erosion in channels or on the coast can be quite complex. The cause of erosion on channel banks could be related to the dynamic response of the channel to watershed scale changes. Some "solutions" may actually make the situation worse or create problems elsewhere. Coastal erosion can behave in a similarly complex manner. Consult experts in channel and coastal behavior such as hydrologists and hydraulic engineers for cost-effective solutions.

***Step B: Is there gully related erosion?***

Gullies often behave in a complex, dynamic manner similar to channels. Gullies cannot be repaired by surface treatments and often require multiple mitigation measures strategically located. Treatment of all but the smallest (nearly rill size) should be done with consultation of gully-repair experts such as hydrologists and hydraulic engineers for cost-effective solutions. Use professional judgment for treating near rill size gullies on slopes and consider treating them as rills.

***Step C: Is there global instability (mass-movement erosion)?***

Similar to channels, coasts, and gullies, the causes and solutions for mass-movement erosion can be complex. A few indicators that a slope is at risk for mass-movement are shown in appendix A (table A2). Often vegetation and weathering mask these signs from easy observation. Consult slope stability experts such as geologists and engineers if signs of potential mass-movement erosion are encountered.

***Step D: Is there shallow gravity instability (mass-movement erosion < 3 feet deep)?***

Shallow mass-movement erosion may be mitigated by treatments in this guide in certain cases. Shallow mass-movement erosion potential may be estimated as discussed in appendix B. Fractured soils and rocks, various soil layers, or the presence of seams of certain soils often make estimations difficult. Depending on the scope of the project and your skill, consider consulting slope stability experts. Treatments to consider include grading treatments such as reducing the slope angle and/or length, terraces, riprap blankets, geocellular containment systems, and soil bioengineering. It may be important to treat shallow gravity instability and seepage erosion simultaneously.

***Step E: Is there seepage related erosion?***

Seepage can be complex, especially for fractured soils and rocks, layered soils, and soils with seams of varying permeability. This form of erosion may also be related to mass movement, channel, and gully erosion. Often it is important to consult experts for seepage erosion treatment, such as engineering geologists or geotechnical engineers. This is especially important if the seepage is deeper then 3 feet from the surface. A side affect of eliminating seepage could be reduced vegetation establishment and long-term erosion control. Some techniques in this guide may be effective at controlling shallow seepage erosion (less than 3 feet from the surface). These include some soil bioengineering techniques and rock blankets or riprap with a filter.

***Step F: Is there surface erosion?***

Surface erosion is defined as interrill, rill, dry ravel, and wind erosion. Erosion control practitioners are encouraged to work closely with product suppliers when evaluating alternative treatments for surface erosion.

- Interrill - For treatment, vegetation establishment is generally important. Seed, fertilizer, and mulch may be all that is necessary. If surface is smooth and/or hard, use soil roughening and/or tracking prior to seeding, but only on slopes that are not too steep. On steeper slopes, rolled erosion control products may be required. If soil nutrients are lacking or the soil structure is poor, soil amendments may be necessary.

- Rill - For treatment, removing the rills and vegetation establishment is important. Seed, fertilizer, and mulch may be easily removed by water in the rills and should be used only after the rills are removed. Soil stabilizers and tackifiers may hold seed and mulch on slopes. If the surface is smooth and/or hard, use soil roughening and/or tracking prior to seeding, but only if the slopes are not too steep. If rills are extensive or very deep, grading may be required to smooth the surface. Consider reducing the slope angle and length if feasible. Constructed or manufactured wattles and mulch may be very effective at preventing rill formation. On steeper slopes, rolled erosion control products may be required instead of mulch. If soil nutrients are lacking or the soil structure is poor, soil amendments may be necessary.

- Dry Ravel - Treatments may include reducing the slope angle, seed, fertilizer, mulch, geocellular containment systems, rolled erosion control products, riprap or rock blankets, and soil bioengineering. In extreme cases, an earth retaining wall may be needed. If soil nutrients are lacking or the soil structure is poor, soil amendments may be necessary.

- Wind - For treatment, the creation of barriers (artificial or vegetative) perpendicular to the prevailing wind is important. In general, vegetation establishment is important. In some cases seed and mulch tacked to the slope may be sufficient. For frequent and/or high wind areas, well installed rolled erosion control products or bonded-fiber matrices may be sufficient. Structures or plants perpendicular to the wind may be necessary for extreme wind erosion. If soil nutrients are lacking or the soil structure is poor, fertilizer, and soil amendments may be necessary.

***Step G: Compare alternatives to original goals.***
Alternative treatments should be compared against the original project goals. If the goals successfully meet the range of alternatives, then go to step 6. If they are not met, reconsider the project goals and repeat steps 1 to 5 as necessary.

**Step 6. Select treatments.** Consider long-term erosion control and project-specific parameters for treatment selection. Important selection parameters include: soil conditions, topography, climate, vegetation, cost, installation, social environment, and effectiveness. Tips can be found for considering these parameters in appendix C. Additional selection and installation tips can be found in appendix D.

## SUMMARY

Erosion control is an important part of caring for USDA Forest Service lands. This guide presents a strategy and information to assist professional judgment in selecting cost-effective erosion control treatments. Treatments are selected considering a range of treatments, the erosion potential assessment discussed in appendixes A and B, the selection parameters in appendix C, and the selection and installation tips in appendix D. Information on each treatment can be found in this guide, from manufacturers and suppliers, or from other sources. Selected additional sources that may be useful for treatment selection are found in appendix E. When working with others, the terminology in appendix F may promote a common understanding. The information from all these sources, experience, and good professional judgment leads to selecting cost-effective erosion control treatments.

## APPENDIX A—QUALITATIVE EROSION POTENTIAL ASSESSMENT

Figure A1 is designed to assist erosion control practitioners during an initial qualitative field survey of a potential project needing treatment. Often this information is all that is needed, depending on the project's scope. It is designed to provide a systematic approach to collecting field information to assist professional judgment.

| | | | | | |
|---|---|---|---|---|---|
| **SITE VISIT INFORMATION FOR EROSION CONTROL TREATMENT SELECTION** | | | | | |
| Name | | | | Date | |
| Location | | | | Project | |
| Weather | | | | Altitude | |
| **SOIL** | | | | | |
| Moisture conditions | Wet | Damp | Dry | Frozen | Snow |
| Depth | Deep | Moderate | Shallow | | |
| Rock type | Bedrock | Boulders | Large rocks | Medium rocks | Small rocks |
| Rock coverage | Extensive | Moderate | Light | Localized | Random |
| Soil type | Gravel | | Sand | | |
| | Gravel with silt | Gravel with clay | Loamy sand | Sandy clay loam | |
| | Silt | Clay | Organic | Other | |
| | Plastic silt | Very plastic clay | | | |
| **VEGETATION** | | | | | |
| Vegetation description | | | | | |
| Planspecies (consider photos) | | | | | |
| **TOPOGRAPHY** | | | | | |
| Slope | Cut slope | Fillslope | Natural | Other: | |
| Slope angle | Min: | Max: | Typical: | | |
| Slope length | Min | Max: | Typical | | |
| Slope aspect | | | | | |
| **EROSION PROCESSES** | | | | | |
| **Gravity erosion** | | | | | |
| Mass-movement | Present | Likely | Not likely | Undetermined | |
| Shallow-mass movement | Present | Likely | Not likely | Undetermined | |
| Dry-ravel | Present | Likely | Not likely | Undetermined | |
| **Water erosion** | | | | | |
| Live channels | Present | Not present | Width | Depth | |
| Coastline | Present | Not present | Severity: | | |
| Gullies | Present | Likely | Width | Depth | Severity |
| Rills | Present | Likely | Width | Depth | Severity |
| Interrill | Present | Likely | Severity | | |
| Seepage | Present | Likely | Severity | | |
| **Wind erosion** | | | | | |
| Slope located on top of ridge? | Yes | No | Slope exposed to predominent wind? | Yes | No |
| Observed wind speed | Strong | Moderate | Light | None: | |
| Expected wind speed | Max: | Min: | Typical: | | |
| Slope on flat, barren ground | Yes | No | Wind comments: | | |
| **GENERAL COMMENTS:** | | | | | |

Figure A1—Site visit information for erosion control treatment selection.

Tables A1 and A2 complement professional judgment for initial erosion potential assessment. These tables include many simplifications and generalizations that may not apply to actual conditions.

Table A1—Suggested general erosion processes indicated by selected site characteristics

| Treatment Parameter | Site Characteristic | Erosion processes |
|---|---|---|
| Climate | Long, low-intensity storms, or melting snow | Interrill, rill, seepage erosion, |
| | Short, high-intensity storms | Rill erosion |
| | Dry climate | Wind, interrill |
| Vegetation | Water-loving plants (hydrophilic) | Seepage, gully |
| | Sparse vegetation | Wind, interrill |
| Topography | Cutslope | Seepage, rill, interrill |
| | Fillslope | Rill and interrill |
| | Gullies nearby | Gully |
| | Unprotected concentrated flow | Gully |
| | Level terrain or top of ridges | Wind |
| | Springs and seeps | Gully, seepage, rill |
| | Long, steep slopes | Gully, rill |

Table A2. Signs of slope instability (Modified from Tori 2000, Gray and Sotir 1996, Prellwitz and others, 1994)

| Indicator | Significance |
|---|---|
| Poor or uneven vegetation cover. | Areas of much different vegetation (e.g., water-loving plants or pioneering species) may indicate recent landslides or unstable ground. |
| Linear features such as cracks, scarps, fissures, or minor terracing. | Strong indication of an active, recently active, or potentially active mass movement. |
| Hummocky slopes. | Common in areas prone to periodic, successive mass movement. |
| Bent ("Jacksawed") tree trunks. | Previous mass movement occurred on these slopes, although it can be related to heavy snow loads. |
| Lobate slope forms. | Occur in areas of former mass movement. |
| Hillside ponds. | Often occurs in grabens (see below). May increase chance of future mass movement. |
| Hillside seepage. | Common in areas at high risk for mass movement. Identified by presence of water-loving plants. |
| Bedding planes or joints. | Soil and rock features prone to mass movement. |
| Abrupt change in slope. | Indicates past mass movement or two different soils with different erosion rates. Lower-angle slope is often weaker. |
| Grabens or stair-stepped topography. | Nested series of mass movements with a "tiered" appearance. Indicates unstable area. |

## APPENDIX B—QUANTITATIVE EROSION POTENTIAL ASSESSMENT INTRODUCTION

A quantified assessment allows the erosion professional to compare the effectiveness of the alternative treatments. Collecting the data and applying the models takes time, money, and professional judgment and may not always fit the scope of the project. The first section discusses a method for using the results of quantitative models to assist with treatment selection. The second section discusses some models that can be used for quantifying surface erosion and sediment yields. The last section introduces a model for comparing the effectiveness of treatments at reducing shallow mass-movement erosion.

### *Performance-Based Objectives And Treatment Selection*

A standard is needed to measure the effectiveness of a treatment. A suggested standard (performance objective) can assist in selecting appropriate erosion-control treatments from the alternatives. Any potential treatments determined from the processed-based treatment selection should meet this performance objective.

Depending on the type of erosion, different performance objectives are needed. Consult channel experts for assistance with defining performance goals for channel and gully erosion. Slope stability experts should be consulted for seepage and slope stability erosion performance goals. Fifield hinted that performance objectives for surface erosion may be written as (modified after Fifield 2001):

$$PO = \left[1 - \left(\frac{E_h}{E_{nt}}\right)\right](100 - R) \qquad (1)$$

Where:

- $P$ = performance objective, expressed as a percent.
- $E_h$ = pre-disturbance (historic) erosion rate or sediment yield.
- $E_{nt}$ = erosion rate or sediment yield with no treatment (often considered “bare-ground” for erosion rates).
- $R$ = reduction factor, in percent, allowing increased erosion or sediment yield above historic values.

The reduction factor is necessary to allow for increases in erosion and sediment yield above historic levels. This increase encompasses a number of considerations. Treatments may not be capable of cost effectively returning a site to predisturbance levels. Additionally some treatments, such as soil bioengineering, increase in effectiveness as plants grow. After installation, these types of treatments should not be expected to match predisturbed conditions immediately. In addition, returning a site to historic conditions may not be cost effective given the risk and scope of the project. Determining an appropriate value for the reduction factor is more subjective than objective.

Determining when a treatment meets this performance objective requires an estimate of its efficiency. This can be estimated using the models discussed in the following section, Surface Erosion and Sediment Yield Potential Estimation. Fifield hinted that the equation for efficiency may be written as (modified after Fifield 2001):

$$EF = \left[1 - \left(\frac{E_t}{E_{nt}}\right)\right]100 \qquad (2)$$

Where:

- $EF$ = efficiency of the treatment, in percent
- $E_t$ = erosion or sediment yield with the treatment applied
- $E_{nt}$ = erosion or sediment yield with the treatment not applied

If the efficiency of the treatment or combination of treatments is less than the performance objective, another treatment should be selected. Alternatively, it is possible that the original performance objective is unrealistic and should be revised. Be sure that consistent units and procedures are used for the equations.

Performance objectives are a powerful tool for selecting cost-effective erosion control treatments. They should be used with caution, however. Performance objectives are limited by the quality of data that is input into the models. They are also limited by how affective the models are at reproducing results that match observed conditions. As a result, it is not recommended to use performance objectives as a legal standard for erosion control effectiveness.

***Surface erosion and sediment yield potential estimation***

There are a number of models for quantifying estimates of surface erosion and sediment yield for comparing alternative treatments. All models are simplifications of complex natural processes that have a high degree of variability. It is unlikely that predicted erosion rates and sediment yields will reflect actual site conditions.

It is not clear which model works best for a particular site without comparing results against measured data. The advantage of a process-based model is that it should apply to a wider range of conditions. Consult with model experts, as there is no universally accepted “best” model. Comparison of some common models is included in table B1 (Fifield 2001; Williams and Berndt 1977; Dissmeyer and Foster 1984; Hudson 1995; Galetovic 1998; Flanagan and Nearing 1995; Elliot and Hall 1997; Elliot and others 2000).

Table B1. Summary of selected erosion and sediment yield prediction models

| Model | Advantages | Limitations |
|---|---|---|
| Universal Soil Loss Equation (USLE) | • Includes all the major factors affecting erosion rates.<br>• Well established.<br>• Simple to use. | • Does not estimate gully, channel erosion, or sediment yield.<br>• Estimates relative, not actual rate.<br>• Missing many recent advances.<br>• Limited slopes (<16%). |
| Modified Universal Soil Loss Equation (MUSLE) | • Similar to USLE.<br>• Estimates sediment yield.<br>• Can be used for specific events. | • Does not estimate gully or channel erosion.<br>• Estimates relative and not actual erosion rates.<br>• Missing many recent advances. |
| Revised Universal Soil Loss Equation (RUSLE) | • Better estimates for western States than the USLE.<br>• Accounts for seasonal changes.<br>• Applies to more complex site conditions than the USLE.<br>• Greater flexibility than the USLE.<br>• Can be used for construction sites.<br>• A computer program is available to assist the user in developing reasonable scenarios. | • Similar to USLE.<br>• Estimates are long-term averages.<br>• Does not show where erosion is.<br>• Calculations more involved than the USLE.<br>• Aspect, snow accumulation, orographic effects, and wind direction need to be considered.<br>• May not be valid for dense vegetation, certain soils, or steep slopes. |
| Water Erosion Prediction Project (WEPP) | • It is process based and should apply to most conditions.<br>• Users can see where and when erosion occurs.<br>• Can be used for a wide range of time.<br>• Accommodates varying soil and vegetation characteristics.<br>• Forest WEPP accounts for orographic effects. | • May require a lot of data collection and input.<br>• As with all models, it is a simplification of complex natural processes and should be calibrated with measured data.<br>• It is a complex model that should be used by those familiar with the processes and the model.<br>• User’s should exercise professional judgment for input data and evaluation of output. |

The Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation, (MUSLE), and Revised Universal Soil Loss Equations (RUSLE) are very similar and share a common history. The USLE was the first comprehensive erosion prediction model developed. Subsequent research and modifications produced the MUSLE and the RUSLE. The basic form of the USLE equation is similar to the MUSLE and RUSLE. The USLE equation is:

$$A = R * K * L * S * C * P \tag{3}$$

- $A$ = Computed spatial and temporal average soil loss per unit of area.
- $R$ = Rainfall-runoff erosivity factor – expression of the erosivity of rainfall and runoff for a particular location.
- $K$ = Soil erodibility factor – expression of the inherent erodibility of soil or surface material under standard experimental conditions.
- $L$ = Slope length factor – ratio of soil loss from the slope to soil loss from a 72.6-foot slope under identical conditions.
- $S$ = Slope steepness factor – ratio of soil loss from the field slope gradient to soil loss from a 9-percent slope under identical conditions.
- $C$ = Cover-management factor – expression of the effects of surface covers and roughness, soil biomass, and earth moving activity on the rate of erosion (values less than 1 denote erosion protection with the smaller value meaning greater protection).
- $P$ = Support practice factor – ratio of erosion with a support practice, such as sediment basins or terracing, to soil loss without the practice.

Replacing the rainfall energy factor, R, with a runoff rate factor yields the MUSLE. For further information on the MUSLE see Williams and Berndt 1977 or Williams 1975. See Renard 1997 for information on the RUSLE and Dissmeyer and Foster 1984 for forest applications of the USLE. Recently the RUSLE was updated for use on newer operating systems and released as RUSLE2. Products, such as erosion control blankets (ECBs), often list a C or P value in the product literature. C and P values are highly dependant on site conditions. It is unlikely that a product will have the same C or P value at the intended location.

The USLE, MUSLE, and RUSLE are semiempirical models while WEPP is a process-based model that is expected to replace the RUSLE in the future (Renard 1997). WEPP has hundreds of input variables, although templates have been developed for USDA Forest Service application. These include:

- X-Drain, a lookup table of a 130,000 runs of WEPP for sediment delivery from roads.
- WEPP: Road, similar to X-Drain but allows greater variability. Disturbed WEPP, similar to X-Drain but for skid trails, prescribed fires, wild fires, and young and mature forest conditions.

Table B2 provides links to additional resources for the RUSLE and WEPP models, including downloads of the computer models.

Table B2. Internet resources for erosion and sediment yield prediction models

| Organization | Significance | Web Link |
|---|---|---|
| USDA Agriculture Research Service National Soil Erosion Research Laboratory | Official RUSLE2 Web site. | http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm |
| U.S. Department of the Interior Office of Surface Mining – Western Region Office of Technology Transfer | Online guide for the RUSLE: "Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands." | http://www.ott.wrcc.osmre.gov/library/hbmanual.htm |
| The National Soil Erosion Research Laboratory at Purdue University | Official WEPP Web site. | http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html |
| USDA Forest Service Rocky Mountain Research Station Forestry Sciences Laboratory | USDA Forest Service WEPP applications and documentation. | http://forest.moscowfsl.wsu.edu/engr/software.html |

***Shallow mass-movement erosion potential estimation***

Models for predicting erosion and sediment yield do not account for shallow mass-movement erosion. Shallow mass-movement erosion is often dispersed throughout a location and is therefore difficult to model. Often an infinite slope equation is appropriate for estimating the risk of shallow mass movement. This can be applied when the failure occurs by sliding parallel to the ground surface and the ratio of slope length to depth of failure is large (Gray and Sotir 1996, McCullah 2003, Coppin and Richards 1990). According to Gray and Sotir 1996, Gonsior and Gardner suggest the infinite slope equation applies when length-to-depth ratios are greater than 20 (Gonsior and Gardner 1971). Situations where these conditions may be encountered include (modified from Gray and Sotir 1996, McCullah 2003):

- Homogenous, coarse-textured soil without cohesion.
- Layer of loose soil weathered from underlying rock.
- Soil deposited over bedrock.
- Thawing soils.
- Rock slopes with joints parallel to the slope.
- Outside margin of road fills.

For additional information see Gray and Sotir 1996, Coppin and Richards 1990, McCullah 2003, Denning 1994, and Prellwitz 1994.

## APPENDIX C—TREATMENT SELECTION PARAMETERS

Tables C1 through C7 complement professional judgment for initial erosion potential assessment. These tables include many simplifications and generalizations that may not apply to actual conditions.

Table C1—Soil treatment parameters

| | |
|---|---|
| Soil moisture | • Soil moisture capacity is often the key soil characteristic for effective long-term erosion control.<br>• Large water-holding capacities are generally favorable for vegetation, although too high can reduce plant establishment.<br>• Ability of a treatment to supply water to plants is important, especially in dry climates.<br>• Climate strongly influences vegetation establishment by affecting soil moisture. |
| Soil nutrients | • Weathering or decomposition of treatment may increase or decrease soil fertility.<br>• Additional fertilizer, pesticides, and other applications may be necessary for vegetation establishment.<br>• Soil pH can inhibit vegetation establishment, although nitrogen and phosphorous deficiency are more common problems. |
| Soil temperature | • Climate influences vegetation establishment by affecting soil temperature.<br>• Reducing soil temperature may encourage plant establishment by reducing soil moisture loss on south and west slopes.<br>• Increasing soil temperature may encourage plant establishment by reducing freezing condition on north and east slopes. |

Table C2—Topography treatment parameters

| | |
|---|---|
| Slope angle | • Treatment cost increases and effectiveness decreases as slope angle increases.<br>• As a general rule, maximum solar radiation occurs at a slope angle equal to the latitude of the site (add 15 degrees for winter, subtract 15 degrees for summer) ([NREL] 2003). |
| Uninterrupted slope length | • Treatments may have limiting slope lengths.<br>• Erosion generally increases for longer slopes. |
| Slope aspect | • South slopes generally have significantly higher rates of erosion than north slopes.<br>• Rainfall on windward slopes may cause significantly more erosion than on leeward slopes.<br>• South slopes have higher potential evapotranspiration rates than north slopes, often reducing plant establishment. |
| Drainage | • Many surface treatments do not perform well when subject to concentrated flows. |
| Altitude | • Treatments that work well at lower elevations often do not perform as well at high altitudes. |

Table C3—Climate treatment parameters

| | |
|---|---|
| Precipitation | • Periodic, intense thunderstorms may contribute to majority of total erosion.<br>• Some treatments perform significantly better for high-intensity or long-duration storms than others.<br>• Water availability often determines whether vegetation establishment succeeds in dry climates.<br>• Timing and distribution of precipitation may be more important consideration than annual precipitation for long-term erosion control, especially in dry climates. |
| Temperature | • Long growing seasons and low freeze/thaw frequency generally increase vegetation establishment.<br>• Freeze/thaw conditions may reduce treatment effectiveness substantially.<br>• High humidity and temperatures may increase decomposition rate of natural materials. |
| Snow | • Snowmelt may increase vegetation establishment by increasing soil moisture.<br>• Snow may contribute to physical failure or reduce effectiveness of treatments by increasing weight, and increasing runoff and erosion while melting. |
| Wind | • Wind may cause surface treatments to fail.<br>• Wind erosion is a serious problem for dry climates. |

Table C4—Vegetation treatment parameters

| | |
|---|---|
| Native plant establishment | • Treatments should not inhibit growth of desirable native plants for long-term erosion control.<br>• Vegetation is readily established in humid climates if the soil and topography are suitable. |
| Germination | • A treatment's ability to retain soil moisture and moderate temperature affects seed germination rates.<br>• Increased runoff reduces seed germination. |

Table C5—Cost treatment parameters

| | |
|---|---|
| Material cost (Includes shipping and all items necessary for installation) | • For dissimilar products, determine the cost per unit area treated for comparison, including importing materials from offsite.<br>• Tackifiers, staples, and other material costs should be converted to cost per unit area for comparison. |
| Installation cost (Includes surface preparation) | • Varies depending on number of laborers, type of equipment needed, and construction sequence.<br>• Based on required man-hours. |
| Maintenance cost | • Improper maintenance is often the main cause of treatment failure.<br>• All erosion controls require varying degrees of inspection, maintenance, or modification during establishment. |

Table C6—Installation treatment parameters

| | |
|---|---|
| Durability (Ability to remain effective after shipment, storage, and handling) | • Treatments may be less effective after improper handling during installation.<br>• Weight and packaging may indirectly affect durability through rough handling.<br>• Index tests may provide insight into product durability. |
| Construction difficulty | • Fewer steps or simpler procedures reduce chance of improper installation.<br>• Specialty tools to assist installation may encourage proper installation.<br>• Importing materials from offsite and curing time of some hydraulic methods may increase difficulty. |

Table C7—Effectiveness treatment parameters

| | |
|---|---|
| Sediment yield | • Use the USLE, MUSLE, RUSLE, WEPP or other erosion and sediment yield prediction models.<br>• Compare amount of sediment and not concentration of sediment, as lower sediment yields may have higher sediment concentrations. |
| Areal density (Measures percentage of soil covered by treatment) | • May be compared using the cover factor (C) in the USLE.<br>• High areal density reduces splash erosion, increases infiltration, and reduces effective runoff velocities.<br>• Too high of areal density inhibits plant growth. |
| Runoff | • A measure of a treatment's ability to absorb or adsorb water.<br>• Reducing runoff is important for reducing sediment yield. |
| Infiltration | • Treatments that encourage infiltration may perform better, especially for vegetation establishment in dry climates. |
| Duration (How long the treatment effectively lasts) | • Permanent solutions require vegetation or nondegradable applications.<br>• Treatments that degrade too slowly may inhibit vegetation establishment, but dry sites may need 2 years of protection. |

## APPENDIX D— TIPS FOR TREATMENT SELECTION AND INSTALLATION

Useful selection and installation tips will help the reader select an effective treatment. The reader must review the available treatments along with the applicable tips and use professional judgment throughout the selection process. Combinations of methods may be used for cost-effective erosion control. However, a multifaceted approach may be technically superior to a single treatment but may not be cost effective. Erosion control success depends on a number of factors including; timing of application, treatment type, application rate, soil erodibility, slope angle, and whether the slope is exposed to concentrated flow.

### Selection tips

Proper treatment selection requires consideration of multiple parameters. Some important treatment-selection tips are included below.

***Mulch-selection tips***

- Supplier reasonably close by reduces haul distance and possibly the cost.
- Wood-fiber mulch may establish vegetation better on clay soil than recycled fiber/pulp mulch.
- Long-fibered mulches (e.g straw, hay, and wood bark) generally last longer and perform better than short-fibered mulches (e.g. hydromulch, wood fibers, cellulose, and paper).
- Wood fiber, recycled paper/pulp, or seed and fertilizer may encourage vegetation establishment on sandy soils equally well.
- Wood chips, rock mulches, and hydraulic mulch without tackifier may not be suitable for steep slopes.
- For dry climates, mulches with lower density but greater thickness may provide better vegetation establishment and reduce runoff more than other mulches.
- For dry climates, hydraulic mulches deteriorate and release more sediment after 5 months, but treatments may need to last up to 2-years for effective vegetation establishment.
- Effectiveness of short-fibered mulch improves when tackifier is added.
- Wood strands and straw may be equally effective at reducing erosion on coarse-textured soils on slopes up to 3H:1V.
- Wood strands may be more effective than straw on fine-textured soils on slopes up to 3H:1V.
- Thinner wood strands may speed decomposition, be a more effective aid in vegetation establishment, and decrease application costs than thicker wood strands.

**Rolled erosion control product (RECP) selection tips** (Sutherland 1998a, Austin and Ward 1996, Gray and Sotir 1996, Baxter 2003, Fifield and Malnor 1990)

- More effective the shorter the water run-off producing event lasts
- Contact with soil and firm attachment is more important than surface-cover percentage.
- Some natural fibers may shrink (e.g., jute) or expand (e.g., coconut) and may lose contact with the ground.
- RECP should include high surface coverage and reasonable thickness while still allowing for vegetative growth.
- Erosion rates decrease as surface cover of open-weave RECPs increase.
- Vegetation establishment may be poor for large open-weave RECPs due to sunlight exposure, seed displacement, or both.
- RECPs with random fiber orientation and significant three-dimensionality outperform open-weave RECPs.
- Manufacturers provide recommendations based on slope angles and lengths; test results may be available.
- Photodegradable netting on products should not be used for shaded areas.
- Photodegradable netting may leave unsightly netting pieces in various stages of degradation on the ground.

- Crust and rills may form under more rigid synthetic products (dry climates).
- Products often have to be effective for at least 2 years in dry climates to establish long-term vegetation.
- Semiarid-plant establishment (dry climates) depends on increasing thickness of RECPs.
- Natural RECPs appear to increase growth of cool-season grass while synthetic RECPs appear to increase growth of warm-season grass (dry climates).
- Synthetic materials appear to generate more runoff but less sediment than natural materials (dry climates).

**Installation tips**
Use these tips to ensure proper installation and effectiveness of the treatments and sometimes for selecting treatments:
***Grading-installation tips***
- Soil surface should be as rough as possible to improve mulch adherence, increase infiltration, reduce runoff velocities, and encourage sedimentation of eroded soil.
- Overhangs should be removed and top and bottom of slopes rounded to meet natural ground.
- Soil surface may need to be smoothed somewhat to eliminate highly erosive rills.
- Level terraces promote infiltration on dry sites and graded terraces facilitate drainage on wet sites.
- Terrace vertical cut to horizontal cut of stairs should be less than 1H:1V, with in-sloping benches.
- Terrace cuts should not be more than 0.6 m high on soft soils or more than 0.9 m on rocky soils
- Topsoil can be placed on terraces to promote vegetation on infertile soils.

***Seeding-installation tips*** *(ODOT 1999)*
- Best time for seeding varies from region to region.
- Place vegetation requiring moisture in concave areas (valleys) collecting runoff and moisture and drought-resistant plants on convex areas (hillslopes) with little runoff or seepage.
- Design seed mix for rapid vegetation establishment.
- Consider growth season, method of natural propagation, and root depths when designing a seed mix. These factors vary by climate.
- Base seeding rate on the pure live seed weight (PLS - that portion of the desired seed that is live).
- Verify that the seed purity and quality, inert material, weed seed, other seeds, and hard seed percentages are labeled and total 100 percent.
- Ensure that seed is labeled correctly and backed up with a lab report.
- Double the seeding rate when seed and mulch are applied together.
- Hard-seed percentage is the viable seed percentage not germinated after the test.
- Seed-soil contact is the key to germination.
- Apply seed before mulch, immediately after soil disturbance, while soil is loose and moist and before seasonal rains or freezing temperatures.
- Using seed and fertilizer without mulch may be ineffective, especially for steep slopes.

***Mulch-installation tips*** *(Yanosek and others 2006, Norland 2000, ODOT 1999, Fifield 1992, Fifield and Malnor 1990)*
- Use certified weed-free mulch.
- Apply mulch before active runoff, weed growth, or dry conditions for best results.
- Ensure that mulch is uniformly distributed at desired rate and depth for effectiveness.
- Anchor lightweight mulches such as straw, wood cellulose, and wood fiber either manually, mechanically, or chemically.
- Use mechanical anchoring (crimping) for slopes less than 3H:1V, otherwise use manual or chemical anchoring.
- Apply chemical tackifiers at the same time—or just after—the mulch.

- Use native-hay mulch with long fibers and native seeds to help establish vegetation.
- Use wood-fiber mulch on slopes greater than 1.5H:1V. Do not use wood bark or woodchips on slopes.
- Use rotary spreaders for moderately rolling terrain, and pneumatic and hydraulic spreaders on steeper slopes.
- Use hand spreading for small, hard to reach areas on steep slopes beyond the reach of blowers or sprayers.
- Use pneumatic spreaders to dispense mulch easily, evenly, and in closer contact to the ground than hand spreading.
- Use dry blowers to cover large areas quickly and apply a tackifier.
- Use onsite mulching materials. They may be less expensive for remote sites than imported mulches with high transportation costs.
- Use less mulch on north-facing slopes than on south-facing slopes.
- Use less than 2 inches of mulch for large seeds, and less than 0.5 inches for small seeds.
- Use of too much mulch may kill seeds and prevent growth from heat generated during decomposition.
- Use higher mulch rates for erosion control of silts and clays than sands.
- Use lower mulch thickness with fine-grained soils so root aeration is not reduced.
- Use higher mulch rates for woody plant establishment.
- Use dark colored mulches to warm the soil and light colored mulches to cool the soil.
- Apply seed and fertilizer before wood mulch on dry sites to help establish vegetation.
- Realize that woodchips, sawdust, and pine needle mulch may be less desirable. They are lightweight and may float.
- Use hydraulic spreaders for wood fiber and cellulose and to reach areas inaccessible by other methods. They can only treat a small area with each load. Ensure that a water source is nearby. Filling and transporting water may take time.
- Use thicker mulch for dry climates to reduce sediment yield.
- Apply mulch at higher rate to produce better vegetation establishment on sandy soils than seed and fertilizer alone.
- Add tackifier to improve the effectiveness of short-fibered mulch.
- Apply typical long-fibred mulches by nonmechanical methods so they don’t have to be chopped into smaller pieces for mechanical application.
- Apply wood strand mulch to obtain about 50-percent surface cover for optimal surface cover in most circumstances.
- Consider increasing wood strand surface cover for fine-grained soils. It is less likely to have an impact on coarse-grained soils.
- Apply wood strands by hand or helicopter.
- Apply wood strands by helicopter higher and faster than aerial straw application.
- Use a mixture of long strands (about 6.3 inches) with shorter strands (1.6 to 3.1 inches long) for wood strand mulch to control inter-rill and rill erosion.

***Bonded-fiber matrix (BFM)-installation tips*** *(Spittle 2002, Cabalka and Lancaster 1997, Roberts and Bradshaw 1985)*

- BFM with crimped fibers may decrease the density and increase the thickness 50 percent more than other BFMs.
- BFM may function from 4 to 6 months or, with crimped fibers from 6 to 12 months.
- BFMs should not be applied to moist soils.
- Apply seed directly to soil in dry areas. Seeds suspended in the mulch may dry.
- Quality of BFM material depends on the applicator’s skill.
- Omit chemical stabilizers for better vegetation establishment on sand slopes in humid climates.
- BFM can be shot up to 225 feet. A 3-person crew—with access to water—can cover about 4 acres per day.

***Soil amendment installation tips*** *(Norland 2000, Fifield 2001, Harding 1994, Agassi and Ben-Hur 1992)*

- Application rate is based on dry weight and dilution ratio.
- Soil moisture is important when applying chemical additives to soils. This affects the dilution and ultimately their performance.
- Amendments may not perform well if applied during cool weather with high soil moisture.
- Dilutions that produce runoff should be avoided. Runoff conditions may require an application outside of the hydraulic seeding and mulching operation.
- Dilution rate, soil properties, climate, and amendments may determine performance.
- Erosion control performance differences may exist between chemicals applied on different soils.
- Chemical stabilizers do not appear to have any impact on vegetation establishment on sands in humid climates.
- Soil stabilizers and mulches together may provide the same protection for less material than either one alone.
- Chemical tackifiers are applied in solutions to bind mulches together and to the soil.
- Soil sealants may require permeable soils with voids for effective treatment.
- Application of polyacrylamide may be more difficult than phosphogypsum due to its higher viscosity and lower dissolution rate.

***Rolled Erosion Control Product (RECP) installation tips*** *(Cabalka and Lancaster 1997, Norland 2000, Sutherland 1998b, (ODOT 1999, Theisen 1992)*

- Apply with skilled installers for effective application. Material quality is consistent, so installation is the key to success.
- Prevent excessive damage from wind and water with proper maintenance.
- Stake RECP and bury edges to prevent wind from lifting RECP off the soil.
- Use fewer seams to reduce erosion.
- Apply seed and fertilizer prior to installation.
- Add check slots along steep slopes to prevent rilling beneath product.
- Consider using mulch in combination with jute netting because of its open structure.
- Ensure that manufacturer's recommendations are followed and the RECP is installed properly.
- Use mulch, mulch and netting, bonded-fiber matrix, or an erosion control blanket to protect surface from erosion when using a geocellular containment system.

***Soil bioengineering installation tips***

The use of soil bioengineering treatments to control erosion is a specialized endeavor. Useful installation tips are found in three publications as well as by talking to experienced contractors. Two readily available government publications are Lewis (2000) and Atkins and others (2001). Links to these are available in appendix E. A fairly complete commercially available text on the subject is Gray and Sotir (1996).

## APPENDIX E—ADDITIONAL RESOURCES

There are a number or organizations, Web sites, and documents available when selecting erosion control treatments. Some provide product manufacturer and distributor lists. Consult product manufacturers when selecting erosion control treatments. Other organizations listed provide standard classifications, testing procedures, conferences, and education opportunities. This is not a comprehensive list, but a starting point. Resources available on the Internet are included in table E1.

Table E1—Useful Internet resources

| Organization | Significance | Information available | Contact Information |
|---|---|---|---|
| Erosion Control Technology Council | RECP standardization and selection guide | • Terminology for RECPs<br>• Interactive RECP selection guide<br>• Index testing procedures and terminology<br>• Guidelines with graphics for installing RECPs | Erosion Control Technology Council<br>P.O. Box 18012<br>St. Paul, MN 55118<br>http://www.ectc.org/ |
| ASTM International | Erosion control index and performance standards | • Includes standards for RECPs and other erosion control materials | ASTM<br>100 Barr Harbor Drive<br>West Conshohocken, PA 19428-2959<br>Phone: 610–832–9585<br>Fax: 610–832–9555<br>http://www.astm.org |
| International Erosion Control Association | Erosion control research papers, books, products, and links | • Conferences, seminars, and education opportunities<br>• Erosion Control Journal periodical (free with membership)<br>• Online IECA proceedings (members only)<br>• Federal and State erosion control regulations Web site links<br>• Online bookstore<br>• Annual buyer's guide of erosion control products<br>• Links to other erosion control organizations, manufacturers, and distributors Web sites | International Erosion Control Association<br>P.O. Box 774904 1355 S Lincoln Avenue<br>Steamboat Springs, CO 80477-4904<br>Phone: 970–879–3010<br>Fax: 970–879–8563<br>Email: ecinfo@ieca.org<br>http://www.ieca.org/ |
| International Fabrics Association International | Geotechnical Fabrics Specifier's Guide | • Monthly periodical<br>• Yearly Specifier's Guide<br>• Selected RECP information | Available online with paid subscription only.<br>www.gfrmagazine.info |
| Geosynthetica.net | Technical information and buyers guide | • Free technical information resource for all geosynthetics users<br>• Lists erosion control suppliers. | www.geosynthetica.net |
| LandscapeOnline.com | Lists vendors, manufacturers, and consultants of erosion control products | • List of categorized erosion control products and services: | http://www.landscapeonline.com/ |

There are many other documents for erosion control help. While they often lack information for conditions in forests, a select few are listed in table E2.

Table E2—Federal government and other erosion control documents

| | |
|---|---|
| **U.S. EPA Best Management Practices Manuals**<br>Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices<br>http://www.epa.gov/npdes/pubs/owm0307.pdf<br>NPDES Storm Water Publications Library<br>http://cfpub.epa.gov/npdes/pubs.cfm?program_id=6<br>EPA Region 6 Storm Water Forms and Documents<br>http://www.epa.gov/Region06/6en/w/formsw.htm | **Best Management Practices Handbook: Hillslope Restoration in British Columbia, Canada**<br>http://www.for.gov.bc.ca/HFD/Pubs/Docs/Mr/Mr096.htmor |
| **Erosion and Sediment Control Handbook**<br>Goldman SJ, Jackson K, Bursztynsky TA. 1986. Erosion and Sediment Control Handbook. New York: McGraw-Hill Book Company. [Variable pages]. | **Water/Road interaction field guide**<br>Water/Road Interaction Core Team. September 2000. Water/Road Interaction Field Guide. San Dimas Technology and Development Center, USDA Forest Service. Publication 0077 1803-SDTDC. 50 p. Available from: San Dimas Technology and Development Center, http://fsweb.sdtdc.wo.fs.fed.us. |
| **Soil Bioengineering, an alternative for roadside management**<br>Lewis L. September 2000. Soil Bioengineering, an alternative for roadside management. San Dimas Technology and Development Center, USDA Forest Service. Publication 0077 1801-SDTDC. 43 p. Available from: San Dimas Technology and Development Center, http://fsweb.sdtdc.wo.fs.fed.us. | **Biotechnical slope protection and erosion control**<br>Gray D.H., Leiser A.T. 1982. Biotechnical slope protection and erosion control. New York: Van Nostrand Reinhold Company. 271 p., Out of print, see Gray and Sotir, 1996. |
| **Erosion prevention and sediment control field guide**<br>Environmentally Wright. August 2001. Erosion prevention and sediment control field guide. Portland (OR): Environmentally Wright. 25 p. Available from the IECA online bookstore: http://www.ieca.org/Bookstore/bookstore.asp. | **AASHTO guidelines for erosion and sediment control in highway construction**<br>[AASHTO] American Association of State Highway and Transportation officials. 1999. AASHTO guidelines for erosion and sediment control in highway construction. In: Highway drainage guidelines. Volume III. 3rd edition. Washington DC: AASHTO Highway subcommittee on design, Task force on hydrology and hydraulics. |
| **Biotechnical and soil bioengineering slope stabilization**<br>Gray D.H., Sotir R.B. 1996. Biotechnical and soil bioengineering slope stabilization: A practical guide for erosion control. New York: J Wiley. 378 p. | **Best management practices for erosion and sediment control**<br>Roberts B.C. June 1995. Best management practices for erosion and sediment control. Final report. October 1998-June 1995. Washington: FHWA. Report nr FHWA-FLP-94-005. Work unit nr CTIP Study H-12. 187 p. Available from: NTIS, Springfield, VA, 22161. http://www.ntis.gov/. |
| **Erosion Control Handbook for Local Roads**<br>U.S. Department of Transportation, Federal Highway Administration. 2003, Manual No. 2003-08 | **Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects**<br>U.S. Department of Transportation, Federal Highway Administration. 2003, FP-03 (U.S. Customary Units) |
| **Soil Erosion - Process, Prediction, Measurement, and Control**<br>Toy, T.J., Foster, G.R. and Renard, K.G., 2002, John Wiley & Sons | **Engineering Fieldbook**<br>**Chapter 16 – Streambank and Shoreline Protection**<br>**Chapter 18 – Soil Bioengineering for Upland Slope Protection and Erosion Reduction**<br>U.S. Department of Agriculture, Natural Resources Conservation Service, 1996 |

## APPENDIX F—GLOSSARY

**Biotechnical stabilization** – The use of mechanical and biological elements together to prevent mass movement and surface erosion.

**Bonded fiber matrices** – Fiber-mulch material combined with adhesives or gypsum-based compounds and applied as slurry produces a product that is more resistant to water when cured.

**Branchpacking** – Alternating layers of live branch cuttings and compacted fill between wooden stakes.

**Brushlayers** – Crisscross pattern of rootable plant material placed between layers of soil. Modified brushlayers include small logs, short boards, or willow fencing.

**C** – The cover management factor in the USLE and similar equations. Accounts for the effects of surface covers and roughness, soil biomass, and earth moving activity on erosion and sediment yield rates. Values less than one indicate reductions in erosion and sediment yield.

**Channel erosion** – Erosion associated with features that are larger than gullies with low width-to-depth ratios, shallower side slopes than gullies, and typically consistent flow.

**Clay** – Very fine grained soil with particles less than or equal to 0.002 millimeters (USDA soil texture classification) or particles less than 0.075 millimeters that display clay-like characteristics (Unified Soil Classification System). Also a soil texture classification (see Soil Survey Staff 1960).

**Dispersive clay soils** – Clay soils that loose significant cohesive strength when exposed to water of certain chemical composition.

**Dry ravel** – Removal of loose surface particles from an exposed slope by gravity, typically after the soil dries.

**Erosion** – Processes of soil- and rock-particle detachment and transport over an area by wind, water, gravity, ice, and chemical action.

**Erodibility** – A measure of a soil's susceptibility to erosion. Higher erosivity means more soil loss for the same erosive force than a soil with lower erosivity.

**Erosivity** – The potential to produce erosion.

**Erosion-control blanket (ECB)** – A degradable material, made of natural or synthetic materials, manufactured into a rolled erosion-control product (RECP). (ASTM D 6459 2002, Lancaster and Austin 2003).

**Fertilizer** – Any substance applied to the soil for increasing the soil's nutritional content for vegetation establishment.

**Freeze/thaw erosion** – Destruction of soil and rock structure and movement of soil or rock by the actions of freezing and thawing of water.

**Geocellular containment systems (GCS)** – Polyethylene or polyester three dimensional cells up to 8 inches deep filled with soil, sand, or rock and anchored to the slope.

**Gravel** – Coarse-grained soil with particles less than 75 millimeters but greater than or equal to 2 millimeters (USDA soil texture classification) or with particles less than 75 millimeters and greater or equal to 4.75 millimeters (Unified Soil Classification System).

**Gully erosion** – Erosion associated with features that are larger than rills with periodic flow, high width-to-depth ratios, and ‘U’ or ‘V’ shaped cross sections located either in valleys or on hillslopes.

**Hydraulic mulch** – Wood, cellulose, paper pulp, or recycled fibers sprayed on slopes as slurry, typically with seed and fertilizer.

**Infiltration** – The passage of water from the surface to the ground, where it is stored or travels for a relatively long period of time.

**Interrill erosion** – Erosion that occurs primarily from the impact of falling water or from very shallow surface flow not located in easily discernible channels. It is often defined as the erosion that occurs between rills, but may occur on surfaces lacking rills.

**Live fascine** – Stems and branches of rootable plant material tied together in long bundles and secured in shallow trenches.

**Live slope grating** – Array of vertical and horizontal wood members fastened to a slope, filled with soil, and planted with cuttings.

**Live stake** –Live, rootable vegetative cuttings tamped into the ground.

**Loamy soils** – Soils classified by the USDA soil texture classification as sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, and silty clay loam.

**Long term** – An extended duration, typically greater than 1 year.

**Mass-movement erosion** – Erosion associated with movement of a mass of rock, debris, or earth down a slope.

**Mulch** – Organic or inorganic materials placed on or near the ground surface to assist with germination, vegetation establishment, and reduction of erosion and sediment yield. Fiber containing mulches can be lumped into long-fibered or short-fibered mulch. Generally, straw, hay, and shredded hardwood bark are long-fibered mulch while hydromulch, wood fibers, cellulose, and paper are short-fibered mulch.

**Mulch control netting (MCN)** – A planar woven natural fiber or extruded synthetic mesh often used as a component of erosion-control blankets or to anchor mulches. (ASTM D6459 2002, Lancaster and Austin, 2003).

**MUSLE** – Modified universal soil loss equation, a modified version of the USLE for estimating sediment yield.

**Open-weave textile** – A degradable erosion-control blanket composed of natural or synthetic threads woven into a matrix used to provide erosion control and facilitate plant growth. (ASTM D6459 2002).

**Performance objective** – A standard, partially subjective, theoretical value for measuring treatment effectiveness relative to historic conditions.

**Permanent** – Lasting for an exceptionally long period, typically much greater than 2 years.

**Phosphogypsum (PG)** – Chemical compound used as a soil stabilizer or tackifier.

**Pole drain** – Row of live fascines oriented downslope, typically connecting to a central drain.

**Polyacrylamide (PAM)** – Chemical compound used as a soil stabilizer or tackifier.

**Process-based** – Founded on the fundamental, physical, governing laws of nature.

**Polysaccharide (PS)** – Chemical compound used as a soil stabilizer or tackifier.

**Pure live seed (PLS)** – The proportion of seed that is alive and available for germination.

**Rill erosion** – Erosion by water in small microchannels, typically 0.2 to 1.2 inches wide and 0.75 inches deep.

**Riprap** – Rock material used as hard armoring generally less than 4,000 pounds selected and graded that, when properly placed, prevents erosion by wave action, hydraulic currents, seepage when meeting filter criteria, and surface runoff (ASTM D653 2002).

**Rock blankets** – A placement of rock on the ground surface, usually greater than one course thick, to reduce erosion and sediment yield.

**Rolled erosion-control products (RECP)** – Family of materials manufactured or fabricated into rolls, and designed to reduce soil erosion and assist in the germination and establishment or protection of vegetation (ASTM D653 20002).

**RUSLE** – Revised universal soil loss equation, an updated version of the USLE.

**Sand** – Medium-grained soil with particle size less than 2 millimeters and greater than or equal to 0.05 millimeters (USDA soil texture classification) or particles less than 4.75 millimeters but greater than or equal to 0.075 millimeters (Unified Soil Classification System).

**Sediment** – Individual rock or soil particles that are the byproduct of erosion.

**Sediment yield** – The amount of sediment that reaches a particular point of interest.

**Seepage** – Infiltration or percolation of water through rock or soil to-or-from the surface (ASTM D653 2002).

**Seepage erosion** – Removal of soil particles by flowing water, but may also include the increased erodibility of soil associated with subsurface water.

**Shallow mass-movement erosion** – Generally low volume, isolated mass movements that generally occur within the soil’s top 3 feet.

**Short term** – A relatively short duration, typically 1-year or less.

**Silt** – Fine-grained soil with particles less than 0.05 millimeter but greater than 0.002 millimeter (USDA soil texture classification) or particles less than 0.075 millimeter that exhibit characteristics of silt (Unified Soil Classification System).

**Soil amendments** – Any substance applied to a soil, often in a liquid form, for the purpose of altering the soil properties such as permeability, erodibility, chemical composition, or nutrients.

**Soil bioengineering** – A subset of biotechnical stabilization that uses plants as the main structural element.

**Soil stabilizers** – Organic or inorganic products applied in solution to the soil surface to form a protective surface film or that infiltrates and binds the soil particles together.

**Soil tackifier -** Organic or inorganic products applied in solution to the soil surface that binds seed, soil amendments or mulch to the surface.

**Steep** – Slopes with a gradient greater than 50 percent (steeper than 2H:1V).

**Surface erosion** – The combined affects of rill, interrill, dry ravel, and wind erosion.

**Temporary** – A short duration, typically less than a year, but maybe 2 years for exceptionally challenging sites to vegetate.

**Terraces** – Relatively horizontal areas, typically greater than 1-foot wide, placed periodically along a slope.

**Tracking** – Placement of relatively long indentations that are parallel to the horizon in the soil, typically using the cleats of tracked construction equipment.

**Turf Reinforcement Mat (TRM)** – A nondegradable RECP composed of ultraviolet-stabilized materials processed into three-dimensional reinforcement matrices, designed to reduce erosion and permanently reinforce plant roots.

**USCS** – Unified soil classification system. (ASTM 1998).

**USLE** – Universal soil loss equation, a model for estimating relative erosion rates.

**Wattles** – A constructed or manufactured linear feature placed generally on the contour of a slope to break a long slope into a series of shorter slopes.

**Willow fences** – Short retaining walls built of living cuttings placed horizontally behind supporting vertical posts.

**Wind erosion** – Detachment and transport of soil particles by moving air in suspension (particles mostly not in contact with the ground surface), by saltation (bouncing – particles often in contact with the ground surface), or surface creep (rolling).

**WEPP** – Water erosion prediction project, a family of models for estimating soil loss.

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