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CURRENT TECHNOLOGIES FOR EROSION CONTROL ON ARMY TRAINING LANDS

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ENVIRONMENTAL QUALITY

CURRENT TECHNOLOGIES FOR BIOLOGICAL ENGINEERING EROSION CONTROL ON ARMY TRAINING LANDS

1. Purpose. This Public Works Technical Bulletin (PWTB) transmits information on new methods, materials, and structures for erosion control. Military installations use these biological or soft engineering methods in conjunction with Best Management Practice (BMP) for a comprehensive erosion control program.

2. Applicability. This PWTB applies to all U.S. Army facilities.

3. References.

a. Army Regulation (AR) 200-3, Environmental Quality, Natural Resources–Land, Forest and Wildlife Management, 28 February 1995, as modified 20 March 2000.

b. Other references are listed in Appendix D.

4. Discussion.

a. AR 200-3 was implemented in 1995. It requires that installations be good stewards of land resources by controlling sources of windborne and hydrological erosion to prevent damage from facilities to the land, water resources, and equipment. Both hydrologic and wind-driven erosion play into multiple laws and regulations including the Clean Air Act, Clean Water Act, etc. which all affect how Army training lands are managed for erosion. Both historical and current data on biological erosion control and impacts to military lands have been lacking.

b. This PWTB provides information about current biological erosion control technologies and methods used to prevent soil erosion and degradation of environmental resources. Many of these natural resources preservation and conservation rehabilitation technologies are cost-effective and can ensure long-term sustainability of Army training lands. Controlling erosion requires an understanding of military land-use interactions that can damage or alter environmental resources and appropriate rehabilitation technologies that can be applied to sustain training lands.

c. Appendix A provides a simplified definition of erosional processes, erosion impacts, and the importance of erosion control on military lands.

d. Appendix B contains background information on biological and soft erosion control technologies. It also describes methods and issues that are associated with erosion control on military lands. A table comparing all erosion control methods is at the end of the appendix.

e. Appendix C presents case studies and examples of bioengineering erosion control on several military installations.

f. Appendix D lists books, extension services, universities, and companies that will help in the selection of soft erosion control technologies. Appendix D includes a short list of Army regulations, acts, and other laws that apply to erosion and land management on military installations. The final section of Appendix D includes references cited in the previous appendices.

5. Points of Contact. HQUSACE is the proponent for this document. The POC at HQUSACE is Malcolm E. McLeod, CEMP-II, 202-761-0632, or e-mail: malcolm.e.mcleod@usace.army.mil.

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Appendix A: Erosion and Military Land Issues

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Erosion is the translocation or removal of soil particles and aggregates via water, wind, frost, ice and/or extreme sun/heat action (Gray and Sotir 1996, p 19). Primary factors affecting erosion are the climate, topography, and soil texture along with land cover and past and present land use (Gray and Sotir 1996, p 19; Olson 1994; Schwab et al. 1955, p 92). Water erosion is generally caused by raindrop impact and the associated surface runoff (Figure A1). Energy for particle detachment and associated transport of the particles is derived from raindrops striking the soil surface and from the runoff across the soil surface (Agassi 1996, p 239).

The two types of water erosion are natural and accelerated. Bryce Canyon in Utah is an extreme example of natural erosion (Figure A2). The canyon was created over millions of years from natural water flow. Accelerated erosion results from disturbances within the natural system, generally caused by humans and their influences. Accelerated erosion can be subdivided into three categories — sheet, rill, and gully — and can include stream channel erosion, which is soil removal from stream banks and/or sediment scour along the channel bottom. This form of erosion should be considered separately from the rainfall-associated types of erosion listed above (Gray and Sotir 1996, p 28).

Figure A1. Raindrop impact on soil surface (source: USDA).

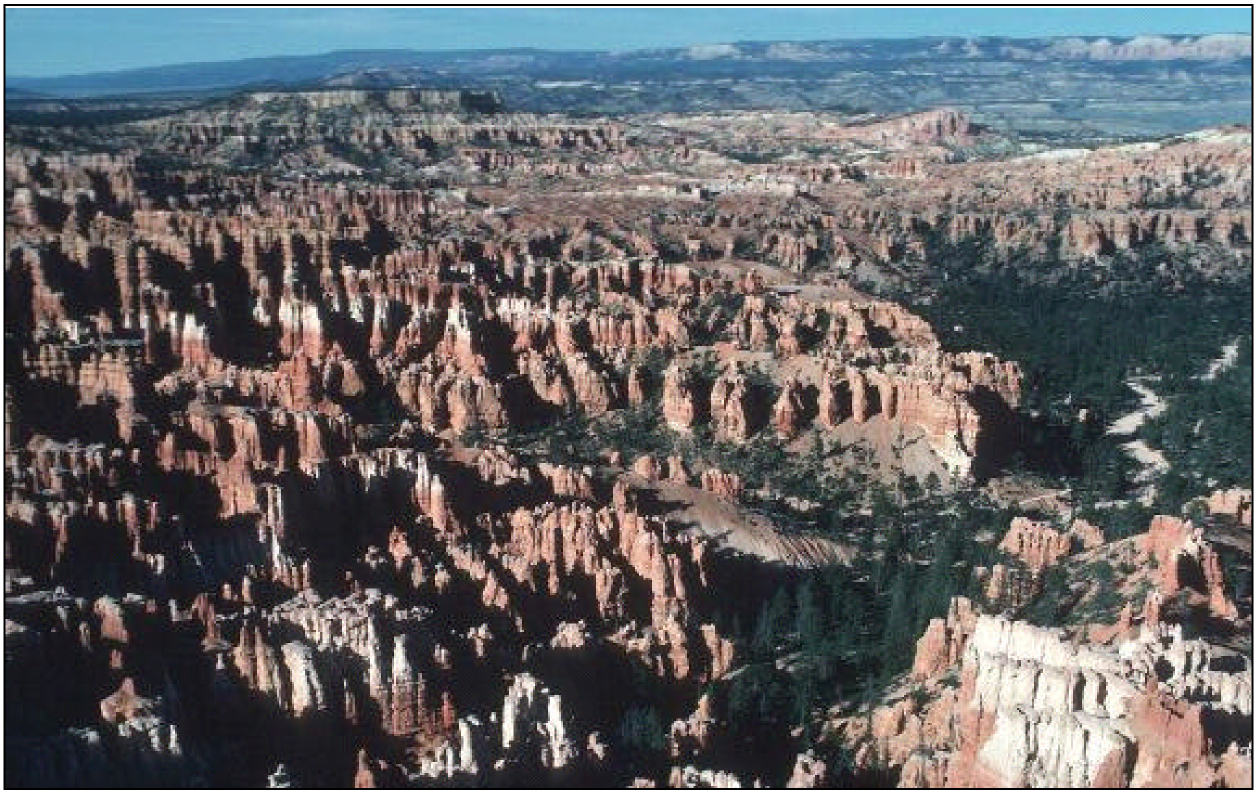


Figure A2. Natural erosion at Bryce Canyon, UT (source: USDA).

Sheet erosion is the result of overland flow or surface runoff of water that occurs when soils reach saturation or when rainfall rates exceed infiltration rates. The water detaches soil particles and removes thin layers in a broad “sheeting” effect. Sheet flow is common in arid and semi-arid lands or in humid areas where vegetation and soil structures have been disturbed or destroyed. The two principal factors governing the erosive force in sheet flow are depth of flow and gradient. To control sheet erosion, therefore, avoiding high concentrations of runoff flow on slopes is critical. Unchecked sheet erosion rapidly becomes rill erosion.

Concentrated or channelized flow, where small rivulets of water cut into the soil surface, will create rills or channels (Toy et al. 2002; White 1997). In rill erosion the water picks up more energy from the concentrated flow and becomes highly erosive. The depth and velocity of channelized flow can increase up to 50 times that of adjacent areas. Once formed, rills can often be difficult to treat. In farming, rills and sheet erosion are often controlled with tillage. Uncontrolled sheet and rill erosion can result in the formation of a gully network (Toy

2001; White 1997). Tillage of training lands is not a common practice and is not conducive to training or land management; this is one reason, therefore, that excessive gullies are found on military training lands.

Uncontrolled rills may grow, or several rills may merge, forming a gully. Erosion enlarges the rill channel until it surpasses the loose definition of size for a rill (can be graded out of existence), thereby forming a gully (Figures A3–A5). If the gully is left untreated, it can grow to hundreds of feet in width, depth, and length (Toy 2001; White 1997). Gully formation is arguably the primary safety hazard on military training lands.

Figure A3. Gully erosion at Fort Bragg, NC.

Unchecked erosion can affect soil properties. Nutrients associated with organic matter and other soil particles can be transported farther downstream or leached from the soil profile. Physically, soil texture and bulk density are more commonly affected. As erosion occurs across a landscape, a cascading event occurs where lighter particles such as clays and organic matter are picked up and carried down the watershed until finally deposited. During this process, a gradated or sorted soil profile occurs. The deposits during the transportation and deposition are sorted with larger and heavier particles falling out before lighter particles (i.e., clay). This process will form horizons of sorted materials (i.e., sand or clay deposits). The new soil has different physical and chemical properties, changing the suitability for plant species composition. Soils may now have a sandy texture, thereby creating a drier environment with faster infiltration rates unsuitable for wetland species.

The shift in the plant community and soil characteristics can make restoration of the impacted areas difficult. Increases in erosion will result in a directional increase in sediments of the impacted watershed. Suspended and depositional sediments have negative effects on primary producers, invertebrates, benthic invertebrates, vertebrates, and associated habitats (Waters 1995; Henly et al. 2000).

Movement of most anything (e.g., cattle, humans, vehicles) across a landscape can cause erosion. Human activities and land use can significantly speed up or slow down natural erosion. Humans modify soil formation processes by altering chemical and physical soil properties such as bulk density, infiltration rates, and productivity (Toy et al. 2002). Sites with high productivity tolerate intensive training; in other words, productivity translates into useable. U.S. Army training activities degrade natural resources much like other activities such as logging, construction, or farming negatively influence erosion, but on a unique scale.

Figure A4. Gully erosion in a Training Area.

Figure A5. Combination of sheet, rill, and gully erosion on military facility.

Tracked and wheeled vehicles, helicopters, foot traffic, ammunition impacts, and other negative influences can decimate the soil structure, increase soil compaction, and eliminate vegetative ground cover, leaving nothing behind to keep erosional processes in check (Goran et al. 1983). Each year Army training lands lose an estimated 3 tons of soil per acre (~6 metric tons per hectare) from erosion.*

Effective land conservation begins with conserving the soil's quality and productivity. Foremost, the native vegetation cover must be preserved, for this is the first line of defense against erosion. Vegetation and its roots provide a physical reinforcement to slope stability, while leaves and stems protect the soil surface from raindrop impact and overland flow. Vegetation also regulates soil moisture via uptake or evapotranspiration. The loss or removal of vegetation on a sloped area can increase erosion, sometimes with tragic results. The U.S. Department of Agriculture (USDA) Soil Conservation Service has estimated that, with effective and dense vegetative covering, soil losses due to rainfall erosion can be decreased a hundredfold. Fiener and Auerswald (2003) found that surface runoff and sediment delivery from a grassed waterway were reduced by 82 percent over an 8-year period.

The removal of vegetative cover and soil during training and other activities leaves the surface of the soil exposed to both water and wind erosion (Figure A6). Vegetation will stabilize and protect the soil surface and subsurface (Abramson 2001). Roots will hold the soil in place while increasing infiltration of water, leaving the surface less susceptible to overland flow (Abramson et al. 2001). The aboveground biomass will also protect the soil surface by decreasing raindrop impact and slowing or retarding overland flow velocity. In the case of some vegetation, it will actually allow the waterborne sediments to settle out and deposit. For these reasons, vegetation is the best frontline defense against soil erosion control. Vegetation is inexpensive, sustainable, and does not disturb military activities like constructed erosion control practices do.

* Helena Mitasova, August 1999, University of Illinois, Department of Geography, personal communication with H. Howard, ERDC-CERL.

Figure A6. Tank and wheeled impacts on Training Area increase erosion at Fort Hood, TX.

Success of the Army's training mission depends on resources required to fight and win effectively. This innately implies that conservation of soil quality and productivity is an essential component of training. Military lands need to be maintained in settings that provide realistic and challenging opportunities to practice individual and battle-focused tasks and missions. In order to improve the ability of military lands to sustain training, soils need to be protected from further degradation via remediation and revegetation. Erosion control is necessary to protect finite military training lands. AR-200-3 mandates that installations are good stewards of land resources and control sources of both aeolian and hydrologic erosion.

As stated earlier, erosion is strongly influenced by climate, land use, vegetative cover and topography (slope). All slopes are impacted or subjected to soil erosion and mass wasting (Gray 1996, p 106). Basically, the control of erosion comes down to decreasing the velocity and amount of overland flow by dissipating the waters energy over surface roughness. Disturbance to the landscape and soil loss need to be minimized with basic erosion control Best Management Practices (BMPs).

BMPs such as reseeding, sediment basins, and grassed waterways help handle increased runoff and sediments. Finally, land managers need to incorporate BMPs into all aspects of land management as early as possible to help control erosion. The need to maintain training land acreage and minimize downtime for lands undergoing rehabilitation requires erosion control practices that are cost effective and military friendly. Erosion control BMPs that concentrate heavily on construction and hard techniques will not meet the needs of land managers, trainers, and soldiers.

Bioengineering and Biotechnical Erosion Control

Living building materials for the protection of structures and crops, and for slope stabilization, have been used for centuries (Norton et al. 2002). With modern technology, man became enamored with physical structures and protection methods, and lost sight of the simpler, effective bioengineering and biotechnical controls. In recent years, many land managers have reverted to these simple technologies for protection and erosion control. Today many bioengineering and biotechnical methods are readily available, effective, and military friendly. Studies have shown that erosion, slope stabilization, and sedimentation can be controlled with quick and cost-effective soil biotechnical and bioengineering methods when combined with the correct physical control materials (Toy 2001; Abramson 2001; Gray 1996; Agassi 1996; Koerner 1998; Samani 2002).

Biotechnical stabilization is generally thought of as a combination of living material incorporated with inert structural or mechanical components such as wood, concrete, stone, rock, geotextiles, and cellular systems. The primary purpose of biotechnical stabilization is to have both living and inert materials work together to reduce erosion and stabilize an area. An example of this is the use of grassed terraces formed by a cellular confinement system such as GeoWeb®.

The definition of *soil bioengineering*, as given by Gray and Sotir (1996), is when plants and plant parts, primarily live cuttings, are imbedded and arranged in the ground in special patterns and configurations. Soil bioengineering is defined in this PWTB as being a living portion of biotechnical stabilization in that the plant materials, such as roots, stems, and leaves serve as the primary structural and mechanical elements in slope protection and erosion control.

Biotechnical and bioengineering methods of stabilization are cost-effective approaches for erosion control on military lands compatible with the training mission. Military training lands pose considerable operations and maintenance issues when dealing with the control of erosion, sedimentation, slope degradation, and vegetation loss. A basic example of such issues would be the requirements of drop zones (DZs).

Safety considerations for paratroopers require that DZs be kept clear of woody vegetation and other materials that may pose safety hazards. Clear cutting to achieve this condition often contributes to concentrated runoff and erosion. Developing sufficient land area for operations often requires extension of drop zone boundaries into areas with steeper slopes. sSuch areas receive concentrated overland flow and are highly susceptible to gully formation. Many times civil engineering structures and techniques are neither safe nor mission enhancing. Riprap or a drop structure could easily injure a paratrooper during landing; a concrete terraced slope may not be visible and may cause an accident during night maneuvers. Solutions to erosion control problems must be carefully selected to be compatible with unique training-related constraints.

Biotechnical and bioengineering methods are generally compatible with military activities. Revegetation, establishment of a grassed waterway, or gentle terracing are all suitable bio-technical and bioengineering methods appropriate for military activities and are effective erosion control BMPs. Establishment of vegetation such as grass, shrubs, and trees is an effective soil stabilization process that also provides a safe training environment and realistic training conditions.

Care in the selection of vegetation species is necessary to ensure that the species selected are compatible to an installation's ecosystem, slopes, and training activities. Locally adapted native species are generally the best for revegetating an area. When constructing a vegetative barrier or mat such as a filter strip, it may be necessary to include species more suited for that process such as a rhizomitous grass. Bermudagrass, for example, is a highly effective filter stripping and grassed waterway species. Utilizing planning tools such as VegSPEC can help with the selection of both native and adapted species that will be compatible to an installation's region and successful for erosion control.

Monitoring and Measurement Methods

Ascertaining the extent of an erosion problem can sometimes be difficult. It is recommended that the land manager contact a local expert, such as a Natural Resources Conservation Service (NRCS) Soil Conservationist, to help estimate soil loss for the site. Numerous erosion assessment models are also available, i.e., USLE (Universal Soil Loss Equation), RUSLE (Revised USLE), WEPP (Water Erosion Prediction Model), Unit Stream Power-based Erosion Deposition (USPED), EROSION 3D, etc. Models such as these will help estimate soil lost per year. The use of erosion, deposition, and sedimentation models may provide justification for the rehabilitation of the site.

Numerous methods are available to measure the extent of erosion and deposition occurring on your land. Methodologies are well documented in books such as Lal (1994) and Toy et al. (2002). Deciding which method to implement is generally determined by cost, labor, and what is best suited for that site. Methods range from inexpensive and fairly accurate, to expensive and highly detailed. Methods include, but are not limited to erosion stakes or pins, digital analysis, and catchments. All methods have good and bad aspects to them and selection of the most appropriate method is generally driven by cost.

Erosion, deposition, and sedimentation analysis will help the land manager determine what erosion control measures are needed, whether the chosen technique is effective, and if it is quantifiable. Results and measurements can be used in defense of a program, mission, or an outside complaint. It is always in the best interest of the land manager to document projects and results for future use.

Appendix B: Bioengineering Techniques for Erosion Control

Bioengineering, or biotechnical stabilization, is a method of erosion control for areas of active erosion using living materials such as shrubs, trees, and grasses to reduce and dissipate overland flow of water. As a result of the interruption and dissipation of water flow, the energy of the water is reduced and allows for deposition and/or the reduction of erosion down slope. Table B1 classifies a variety of bioengineering erosion control techniques into construction types. Table B2 at the end of the appendix compares the benefits and disadvantages of each technique.

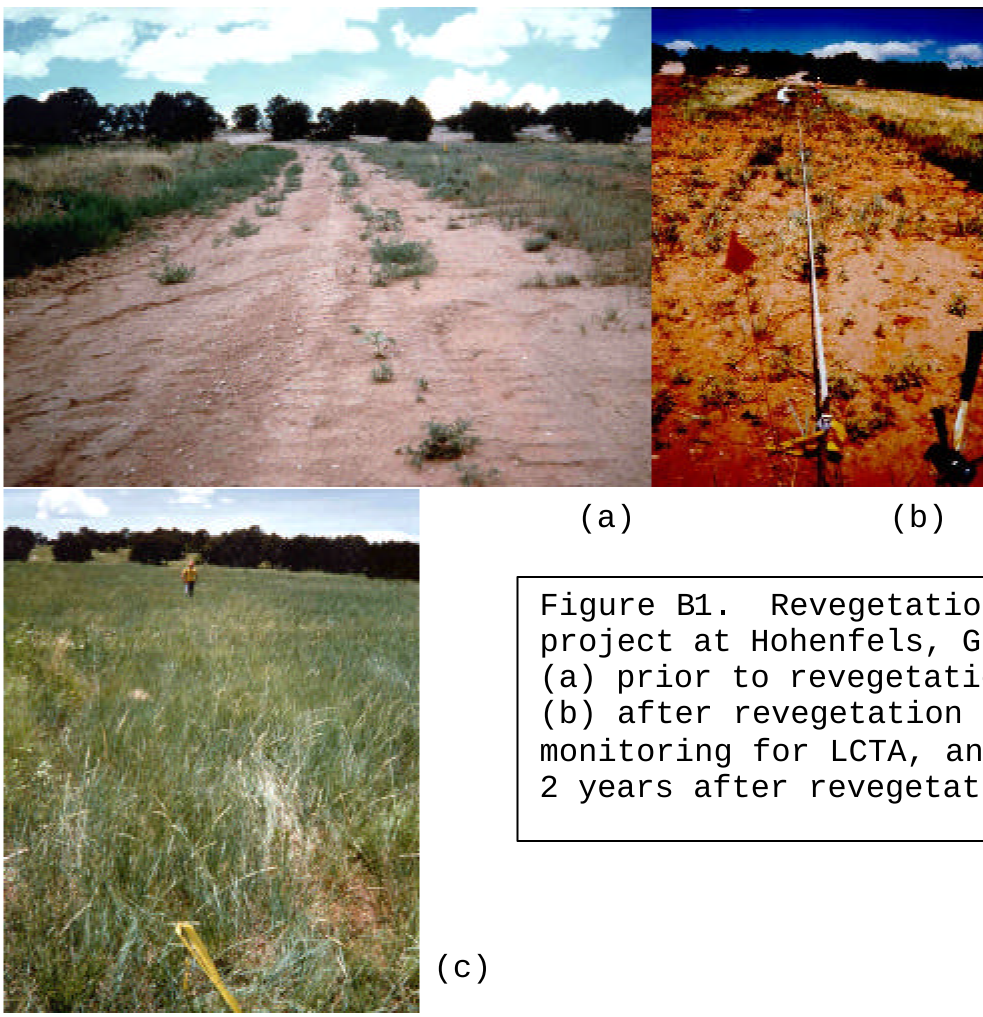
Table B1. Bioengineering erosion control techniques by construction type.

Category	Examples
Live Construction	
Conventional planting	Grass seeding Sodding Transplants
Mixed Construction	
Woody plants used as reinforcements and barriers to soil movement	Live staking Live fascines Brushlayering Branchpacking
Plant/structure associations	Breast walls with slope face plantings Revetments with slope face plantings Tiered structure with bench plantings
Woody plants grown in the frontal openings or interstices of retaining structures	Live crib walls Vegetated rock gabions Vegetated geogrid walls Vegetated breast walls
Woody plants grown in the frontal openings or interstices of porous revetments and ground covers	Joint plantings Staked gabion mattresses Vegetated concrete block revetments Vegetated cellular grids
Inert Construction	
Conventional Structures	Concrete gravity walls Cylinder pile walls Tie-back walls

Source: Gray, Donald H. and Robbin B. Sotir. 1996. *Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control*. This material is used by permission of John Wiley & Sons, Inc.

LIVING CONSTRUCTION – VEGETATION SPECIES (GRASSES)

Vegetation and plantings are the first step in the defense against erosion. Without a vegetative covering, soil erosion exponentially increases. Methods for establishing vegetation are numerous and include conventional seeding, transplanting, sprigging, and sodding. The method chosen for establishment is generally determined by cost, site conditions, and plant species requirements. In the case of large open areas, drilling, broadcasting, or hydroseeding is by far less expensive than establishing vegetation by sodding, sprigging, or transplanting. In cases where the rehabilitation site is either small and or needs quick establishment, it may be more cost and environmentally effective to use sod, sprigs, or live plants. Use locally adapted plants and seeds, when and where possible, and avoid introducing non-native species. Revegetation BMPs should be followed and can be obtained from your local NRCS office of the USDA. **Pros/Cons:** Military friendly and low cost. Maintenance is required after training events to fill in denuded areas to ensure proper erosion control (Figure B1a, b, and c).



(a) (b) (c)

Figure B1. Revegetation project at Hohenfels, Germany (a) prior to revegetation, (b) after revegetation with monitoring for LCTA, and (c) 2 years after revegetation.

Grass mats/filter strips and hedges are planted along the contour on gentle to steep slopes vulnerable to erosion. The living hedges and mats can significantly reduce both erosion and sedimentation (Ghadiri 2001; Rodriquez 1997; Dabney 1997). Grassed filter strips, mats, and hedges can be both labor consuming to plant and maintain and slow to establish. It is critical that the appropriate species of grass be selected to meet the original intent of the bioengineering erosion control practice. Spacing for this process is also critical. Mats are generally 15 feet or wider in width and spaced depending upon the slope. Use locally adapted plants and seeds, when and where possible, and avoid introducing non-native species. Information for suitable species in an installation's area can be found at (http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm). **Pros/Cons:** Military friendly in that vehicles can run over the hedges and mats without complete failure of the system. It is low cost but without proper maintenance can be a short-term solution to erosion. Sediment that collects quickly behind and within the grass can create small, unstable terraces. Significant rain events can occasionally overwhelm the filter strips creating a flush of sediments downstream (Figures B2 and B3).

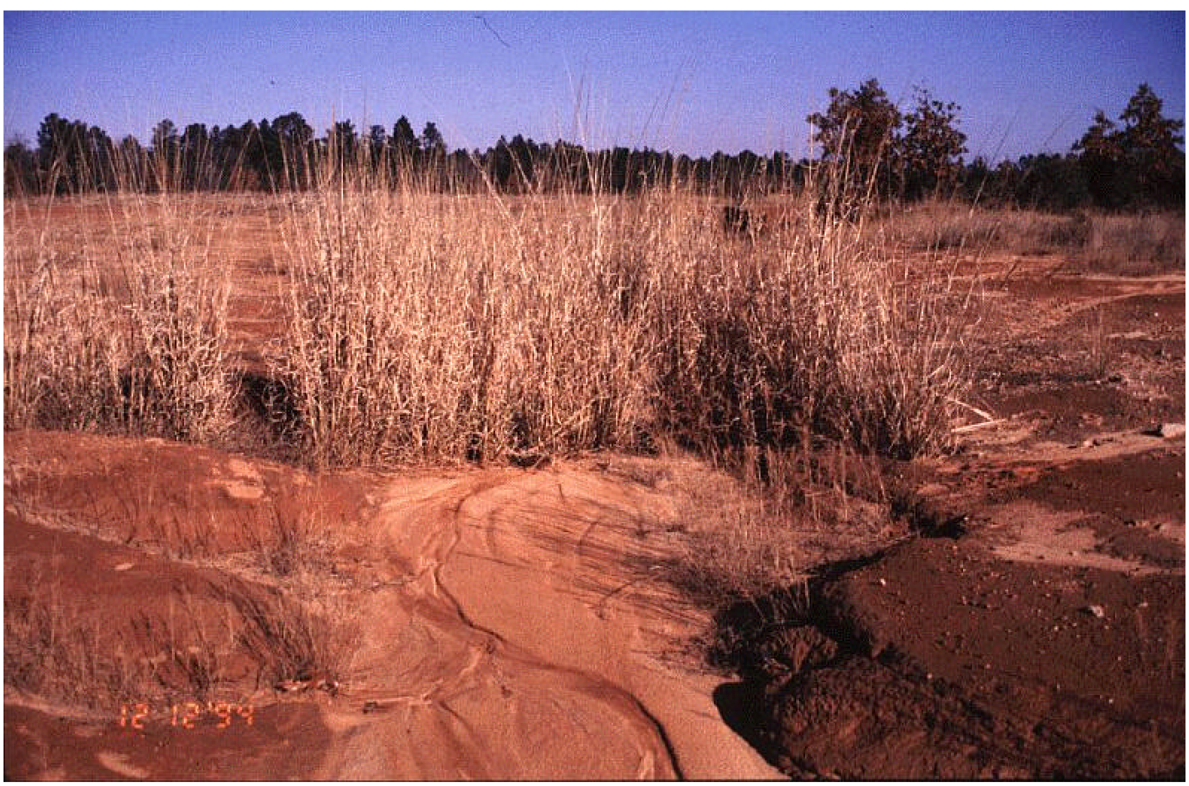


Figure B2. This dormant stiff-grass hedge helps hold training area soil in place and is compatible with military training at Fort Hood.

Figure B3. Grassed filter strips increase infiltration and allow sediments to fall out (source: USDA).

Grassed waterways are shallow watercourses with a width to depth ratio that is usually greater than 5:1, which are used to convey irregular flow and to shelter headwaters from erosion. In some cases, it is necessary to incorporate subterranean pipe drains. Studies have shown that grassed waterways are highly effective in the removal of sediments and the reduction of erosion. (Fiener 2003; Chow 1999; Samani 2002). **Pros/Cons:** Grassed waterways are military friendly, inexpensive to install, and are self-sustaining. Grassed waterways foster infiltration while collecting sediment. Grassed waterways are highly effective in combination with geotextiles. They are susceptible to degradation and scour and new plantings need to be protected from high velocity water flow until well established (Figure B4).

Bio-filters, bioswales, and sediment traps are either grassed strips, riparian vegetation, and/or reedbeds that help prevent sediment translocation. The process allows for rapid infiltration and can help reduce sediment through settlement of sediments. This method also allows for pollutants such as heavy metals to be contained and for phytoaccumulation or phytoremediation. **Pros/Cons:** Cost effective and self-sustainable, but can create undesirable training conditions (low capacity) and take up a high volume of land compared with equivalent engineering techniques. With new regulations pending, installations may be allowed to utilize this approach and “bank” the newly created area as a wetland; if so, that would take the parcel out of training use indefinitely.

Figure B4. Grassed waterways help concentrate runoff while reducing runoff velocity and allowing for infiltration (source: USDA).

MIXED CONSTRUCTION

Woody

Woody live barriers include fences, hedgerows, groynes, sprouting brushwood mattresses, brush grids, and wattles.

Trees and shrubs are placed as hedgerows or fences along the contour. Root development can take place in a short span of time. Fences and hedgerows are generally used in combination with general revegetation efforts and are most effective in areas with gentle slopes. After they are established, they collect sediment that can help form hillsides into a series of terraces that reduce and retain overland flow. **Pros/Cons:** Live fences and hedgerows are more effective and durable than non-living barriers. Can be military friendly if used as a training component (i.e., Tactical Concealment Corridor). Provides realistic training environment. On the other hand, they are slow to establish and can fail when portions do not establish. Living terraces require maintenance, including inspection after every significant storm event for the first year of establishment. They also have a tendency to balance sediment buildup upslope with soil distress directly downslope (Figures B5 and B6).

Figure B5. Gully erosion is shown. Note that the trees in the upper right side have hardened the soil against erosion.

Figure B6. Camp Atterbury used biodegradable erosion control blankets, placed willow wattles as check dams, and planted trees along a disturbed stream bank to help armor the bank against erosion. Note the exposed roots and higher elevation of the mature tree and shrubs.

Brush mattresses, grids, and fascines are formed from sprouting brushwood such as *Salix ssp.* and are effective in stream bank protection. Brush grids are a combination of living and non-living woody materials. A brush grid would include placement of a brushwood mattress and staking at 45^{o} angles to the mattress. Brush grids are commonly used to stabilize a shoreline but can be installed as living terraces on hill slopes. http://www.sf.adfg.state.ak.us/SARR/restoration/techniques/brushmat.cfm **Pros/Cons:** Military friendly for certain areas. All are quick establishers and effective at sediment collection and streambank and slope stabilization. They are more durable than non-living barriers. Maintenance and repair can be required after significant storm events for the first year of establishment. They are labor intensive to install, but supplies are inexpensive if source material is available locally (Figure B7).

Figure B7. Soldiers harvesting *Salix ssp.* for use in wattles.

Live staking and bundling: For successful restoration of an impacted area, it is necessary to set up a restoration project that is both self-sustaining and has a healthy genetic diversity. When using asexual propagation, both sexual and genetic diversity are critical to produce a healthy plant community (Dreesen 2003; Landis et al. 2003). When using a nonrooted cutting for either bundling or staking, consideration for the sex of the donor plant is necessary. Genetic diversification is more at issue when cuttings are taken back to create nursery stock, as nursery stocks tend to be clones of one individual and unisex. Therefore, it is in the best interest of the restoration effort to collect cuttings from several locations and identify the cutting's sex at the time of harvest. **Pros/Cons:** Military friendly for certain areas. All are quick establishers and effective at sediment collection and streambank and slope stabilization. They are more durable than non-living barriers. Maintenance and repair can be required after significant storm events for the first year of establishment. They are labor intensive to install, but supplies are inexpensive if source material is available locally (Figures B8–B10).

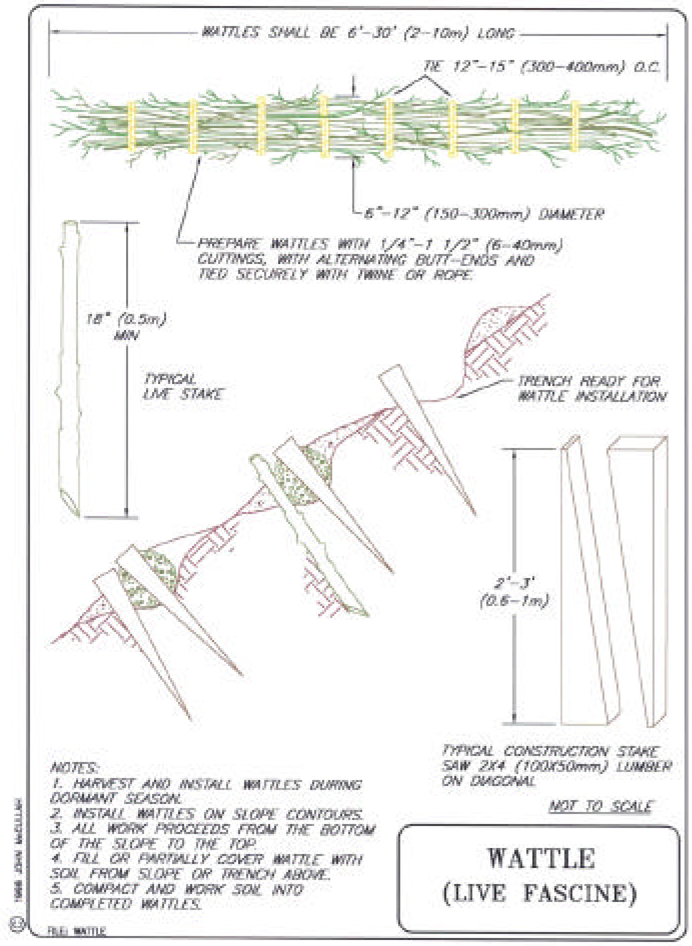


Figure B8. Illustrative diagram of a wattle (BioDRAW®).

Unrooted cuttings are branches generally under one-half inch in diameter and approximately 8 to 12 inches long, planted with two-thirds of the cutting below the soil surface. Cuttings can be trenched, slotted, or even packed by hand if the soil is loamy enough. It is critical that good soil contact is achieved and that cuttings are watered after placement. This method has to be done during dormancy and is generally quick and cost effective.

Rooted cuttings are similar in size to unrooted but have been taken into a nursery and placed in a container to encourage rooting. This method has several cons; primarily the extra labor and space required. If using rooted cuttings, watering is necessary for successful establishment. Pros to this method include a jump on establishment, ensuring rooting success and seasonality is not as critical.

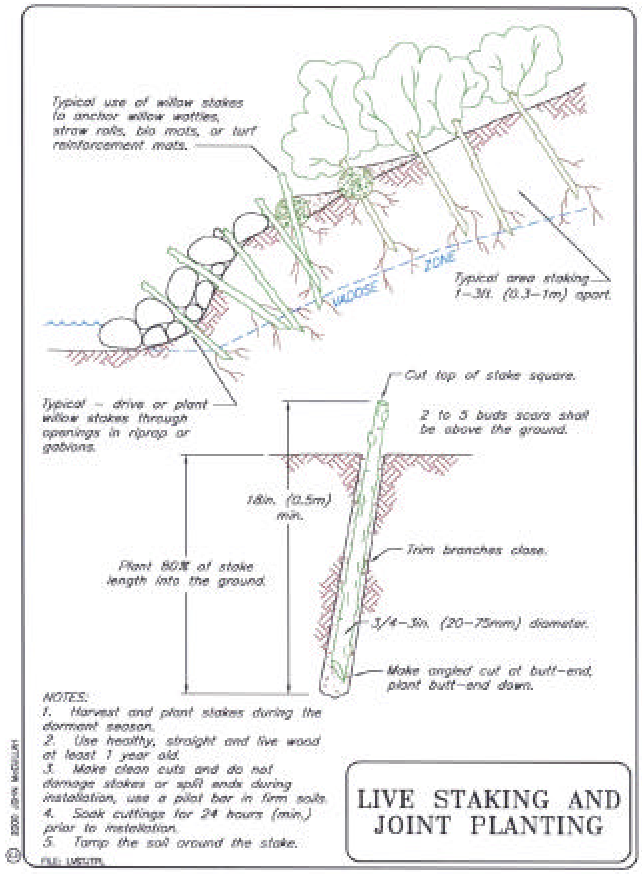


Figure B9. Illustrative diagram of proper live staking and joint planting (BioDRAW®).

Figure B10. Live staking on a hill slope, done during dormancy (BioDRAW®).

Live staking is another common method that is generally combined with wattles. Unrooted live stakes should be between 1 to 3 feet long and of a large diameter so that they can be driven into the ground with a sledgehammer or similar equipment. Rooted stakes are approximately 4 feet long and have been established in the nursery via unrooted stakes. Unrooted stakes are planted during dormancy while rooted stakes can be planted during the summer when rooting becomes difficult. Both methods take longer to establish and form a successful hedge against erosion (Figures B10 and B11).

Whips are unrooted cuttings used for the formation of brush mattresses, live fascines, or branch packing revegetation. Whips are generally 3 to 5 feet in length and should be pliable enough to weave.

Woody wattles are bundles of branches, approximately 4 to 6 inches in diameter and 4 to 10 feet lengths, collected during dormancy. Wattles form a “roll” of branches that can be trenched and staked into the ground and then partially or fully covered by soil. The wattles will form a continuous stand in the spring, effectively creating a living check dam that allows water through and traps soil upslope. Wattles are quick and easy to install and establish very quickly if the proper species are selected and the climatic conditions are favorable (Figure B8).

Figure B11. Live staking in combination with bundles/wattles at Fort Leonard Wood (J. Proffitt, Fort L. Wood).

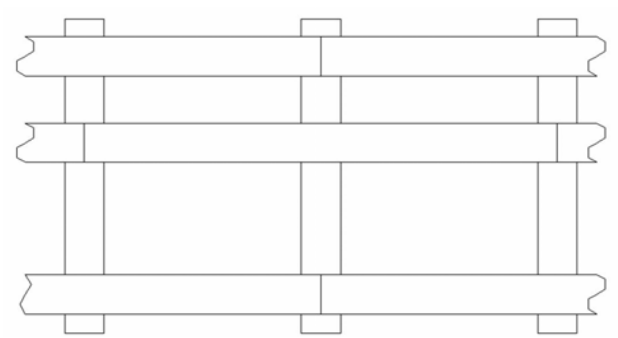
Trees reduce erosion and increase slope stability by protecting and binding the soil. They help to rebuild soils by increasing permeability and infiltration; they reduce runoff and erosion and strengthen the soil with their roots. Trees can help reduce wind erosion and provide a buffer for noise pollution. **Pros/Cons:** Military friendly but expensive and take a long time to establish. Young growth can be inhibited by competition with grass turf and damage from training activities.

Mixed Living and Non-Living

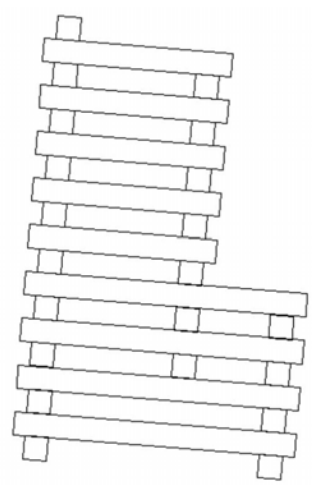
Timber cribs and crib walls are basically a box structure made out of timber, plastic, or concrete logs put together like Lincoln Logs. The forms are filled with soil and or rocks to provide strength. They form walled terraces on the contour and stabilize the back slope. Vegetation easily establishes on and between the logs for an aesthetically pleasing look. This is a long lasting, stable reinforcement mechanism. **Pros/Cons:** Can be military friendly but could pose a significant safety hazard on training areas if troops are unaware of the wall. They are labor intensive, expensive, and can easily blow out if not maintained (Figure B12).

Living timber cribs are basically the same as a regular timber crib except that live branch cuttings are placed between each course of the framing. This lattice-like configuration consists of log frames anchored into the slope, backfilled with soil, topped with a layer of cuttings, and repeated until the desired height is achieved. This process does form walled terraces on the contour and stabilize the back slope. Vegetation easily establishes on and between the logs. Long lasting, stable reinforcement wall. **Pros/Cons:** Can be military friendly but could pose a significant safety hazard on training areas if troops are unaware of the wall. They are labor intensive, expensive and can easily blow out if not maintained (Figure B13).

Groynes (or groins) are small dykes (or dikes) reaching from the bank into the river to create a uniform streambed. The outer end of the groyne is the head, which has to absorb the energy of the flowing water, and the areas between the groynes serve as a sediment basin (Schiechtl and Stern 1997). Groynes are basically long dykes of local materials that are used to decrease bank erosion and slumping. Groynes construction materials can include any combination of stone, riprap, concrete, or living stakes and timbers, felled trees, etc that extends from the shore into the water to prevent beach or bank slopes from washing away. It is imperative that the spacing of groynes along a stream bank not be wider than the distance between two groyne heads on opposite banks (Schiechtl and Stern 1997). **Pros/Cons:** Groynes have a high effectiveness rate when implemented properly, with a long life span, and require little maintenance. Modification during and after construction is easy and can be low cost. During flooding and other high flow periods, cross currents can displace materials, undercut the groyne, or cause erosion of the eddies (Figure B14).



Plan



Side Elevation

Figure B12. Timber cribs should not exceed 10 feet in height.

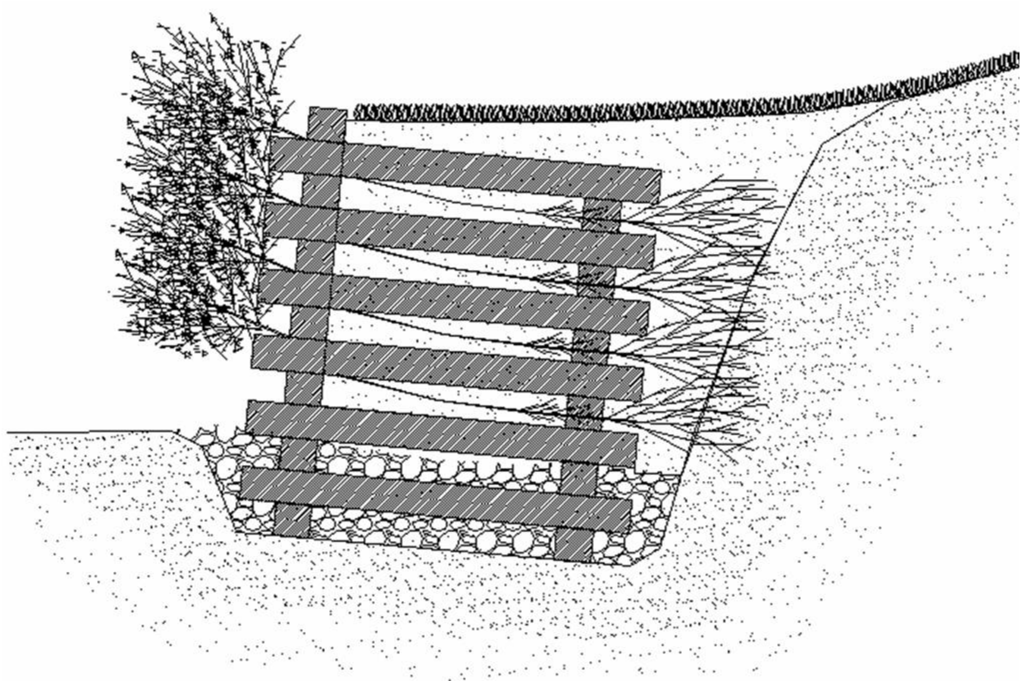


Figure B13. With a living timber crib, it is best to use rock or gravel to help drainage and protect the structure and backslope stability.

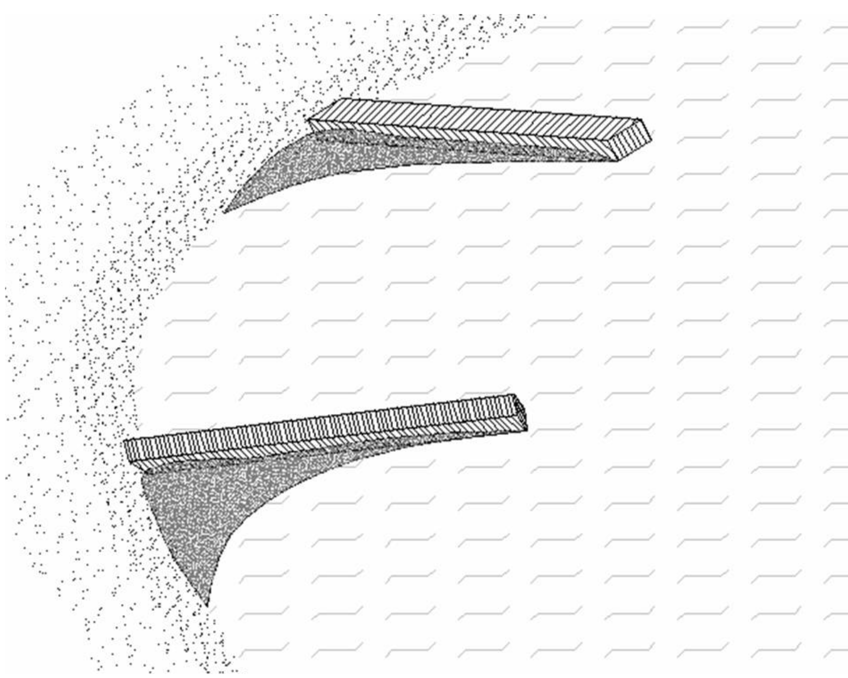


Figure B14. An illustration of groynes placement.

Rolls, Logs, and Coirs

Fiber rolls, logs, or coirs have been developed to reduce overland flow along a slope. They can be made of straw, hay, shredded coconut, and other fibers bundled together with jute, polyethylene, or another pliable binding material. It is common for some companies to offer them with native plants or seeds incorporated into the logs for many wetland remediation efforts. To obtain such materials, it is necessary to go with a local company that can modify or construct the roll, log, or coir with species appropriate for the ecosystem and slopes. General practice guidelines recommend placement of the rolls every 15 feet along the horizontal axis and 30 feet along the vertical axis. Another technique is logs of willow whips or cuttings rolled up in coir mats and secured in place with stakes. **Pros/Cons:** Can be expensive but are highly effective in reducing erosion and stabilization of a slope or stream bank. Cost is generally offset by the quick rate of vegetation establishment and erosion control. Biodegradable materials and soft construction make this suitable for military training (Figures B15–B18).

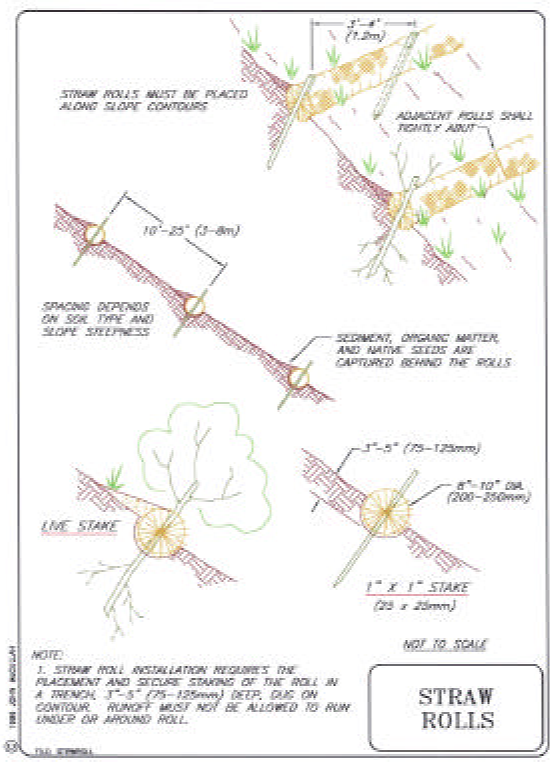


Figure B15. Diagram showning proper installment of fiber log, roll, or coir (BioDRAW®).

Figure B16. Straw log used to control sediments on a construction site in Colorado.

Figure B17. A close view of a coconut fiber log (BioDRAW®).

Figure B18. Coconut fiber log placed on contour with vegetation (BioDRAW®).

Rock

Riprap is coarse cobbles of rock placed to protect a channel bank or to promote infiltration above a drain. Riprap is often stabilized with wire mesh or vegetation. **Pros/Cons:** Military friendly and most commonly used form of erosion control on training lands. The success of riprap relies on it staying in place, which is why mesh, geotextiles, and vegetation are often added to ensure stability. Riprap typically fails because the water runs around the riprap, scouring or undermining it until the riprap is removed (Figure B19).

Vegetated riprap uses vegetation root systems as the structural strength to help bind and stabilize the riprap on the sites that are vulnerable to erosion. **Pros/Cons:** It is a permanent and self-sustaining structure, but may not be as strong as gabions or masonry (Figure B20).

Rock weir structures are designed to serve as grade control and create a diversity of flow velocities, while still maintaining the bed load sediment transport regime of the stream. The rise

Figure B19. Riprap used on military installation to harden crossing and act as a French drain during high flows.

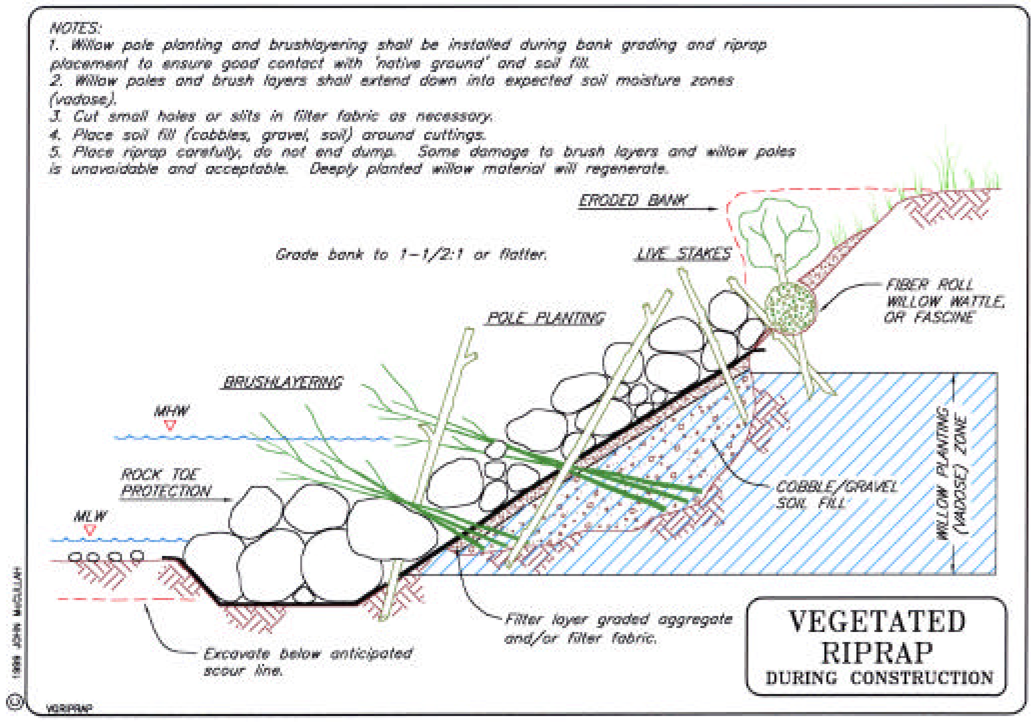


Figure B20. Vegetated riprap diagram (BioDRAW®).

above stream inverts should be no more than 10-15 percent of the full bank height. **Pros/Cons:** It is a permanent and self-sustaining structure, but may not be as strong as gabions or masonry (Figure B21). See (http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Restoration/grade_control.htm) for more information on grade control practices using logs and rocks.

Figure B21. Rock weirs were used to help reduce velocity and cutting for stabilizing a stream in Colorado (source: USDA).

Mulches

Mulching is the application of organic material to the soil surface to protect it from raindrop impact and overland flow. Mulch absorbs the erosive impact of rainfall and reduces the overland flow velocity, significantly reducing soil loss from a site. Mulches can include grass, hay, wood chips, wood fibers, straw, gravel, and compost. Straw is most commonly used as it is cost effective and easy to apply, but it is susceptible to wind displacement, so it must be anchored to the soil by an approved method such as a crimper. Wood chips are often used as landscape mulches and in specialized applications such as when increased water infiltration is desired. Compost mulch can generally be obtained for free from the local landscape-recycling center, but introduction of invasive species or contaminants is an increased risk. Compost does not require anchoring and will increase soil moisture and organic content. For further general information on mulching, visit http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/mulching.pdf.

Pros/Cons: Mulch is generally inexpensive and will help increase organic content of soil. Soil moisture will often increase with mulch application making it suitable for arid areas to help increase and maintain soil moisture. Organic mulches provide a nutrient rich seedbed. Mulch has a limited life span, however, which varies with the material used and site conditions (Figure B22).

Figure B22. Composted mulch prior to application.

Hydraulic mulches are applied directly to an area by a hosepipe from a hydromulcher (Figure B23). Hydraulic mulches are in aqueous solution containing a tacifier that causes it to stick to the applied substrate. This process conserves soil and helps retain moisture. If seed is combined with mulch slurry, the mulch will provide an environment for successful seed germination. **Pros/Cons:** Combined with seed and fertilizer, it can be very effective in establishing vegetation. Wet or hydrolyzed mulch is highly effective on steep slopes. If the work force is available, it could be more economical to apply by hand. Some processed mulches commercially available contain tacifiers such as polyacrylamide (PAM), which help anchor the mulch to the soil surface while increasing the hydrostatic properties of the soil. Such mulches decrease erosion while increasing water available to the plants.

Other mulches such as Straw Net® can be pelletized rather than as a “slurry” solution and can be spread by hand or sprayer. With this type of mulch it is common for PAM to have been incorporated to help in tacification and moisture retention. **Pros/Cons:** Combined with seed and fertilizer, this process can be very effective in establishing vegetation. It is better suited to gentle slopes and during times with slow winds. If the work force is available, it could be more economical to apply by hand. Products with PAM will activate when exposed to moisture, forming fairly uniform netting that protects the soil surface and seeds from eroding away.

Figure B23. Application of hydraulic mulch and seed at Fort Bragg, NC.

Straw checkerboard technique: A recent article in the *Journal of Arid Environments* looked at the use of partially submerged straw for the reduction of wind erosion on sand dunes. Although this technique has been in use for decades, there was little research on the efficacy of this erosion control practice. Researchers found that placing straw vertically into the ground approximately 10-20 cm above and below the surface and in a 1 m x 1 m configuration (or checkerboard) reduced the intensity of sand flux by as much as 99.5 percent (Qiu 2004). **Pros/Cons:** Very labor intensive and expensive. Has not been tested on military lands and no information is available on how suitable this technique is for military training (Figure B24).

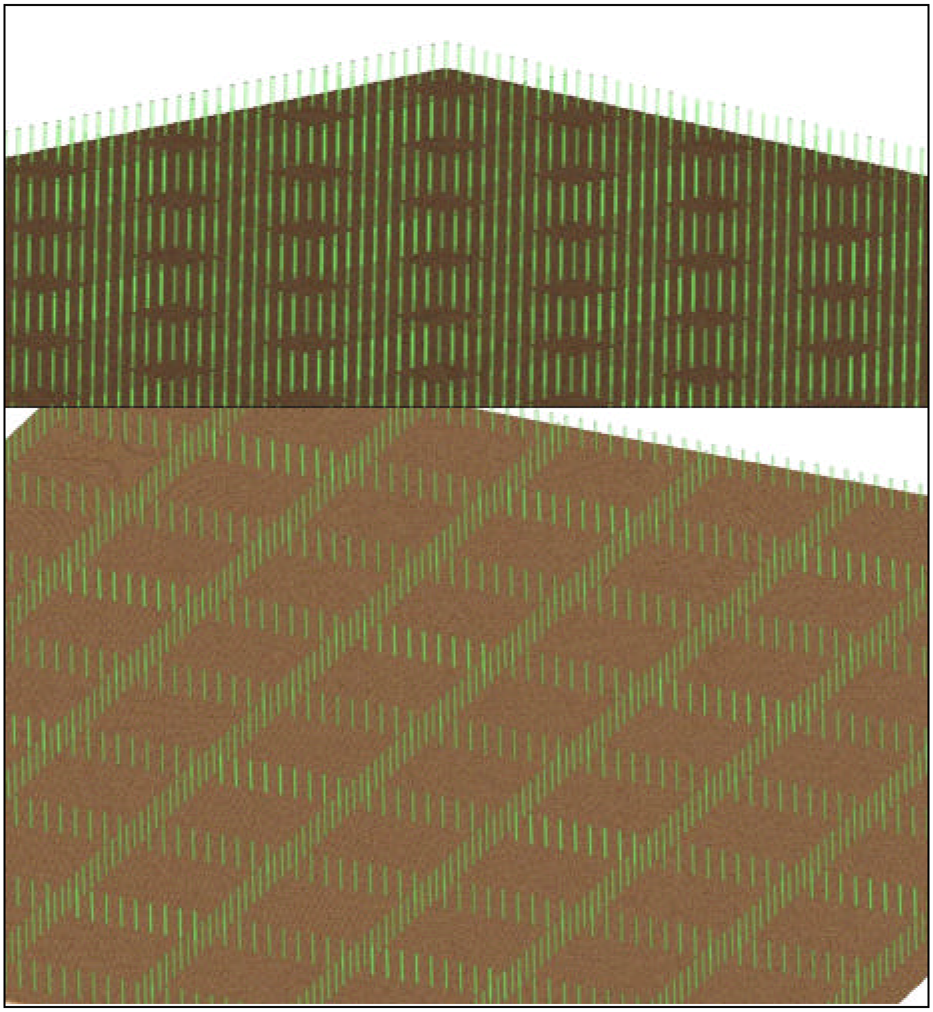


Figure B24. Straw checkboard shown on a 1-m by 1-m layout.

Erosion Control Textiles

Erosion control blankets are permanent or biodegradable mats designed to protect steep slopes that are susceptible to erosion. Woven fibers (e.g., plastic [geocomposites], jute, coconut) are used to reinforce, protect, and stabilize surfaces until vegetation is established. Blankets can include seeds and fertilizer to promote vegetation establishment on the slope. Blankets are not to be confused with geotextiles (i.e., filter fabrics). Made of polymers, geotextiles act as a barrier and filtering system since they can transmit water within the plane of their structure (Koerner 1998). A wide range of blankets is available for most purposes; careful site consideration is necessary when selecting blankets. Contact a local vendor for help. **Pros/Cons:** Can be expensive, but cost is generally offset by the quick rate of vegetation establishment and erosion control. Some installation land managers have had difficulties with tank traffic uprooting or tearing the blankets. Proper anchoring and mulching is necessary to protect blankets until vegetation has established (Figures B25-B27, B29).

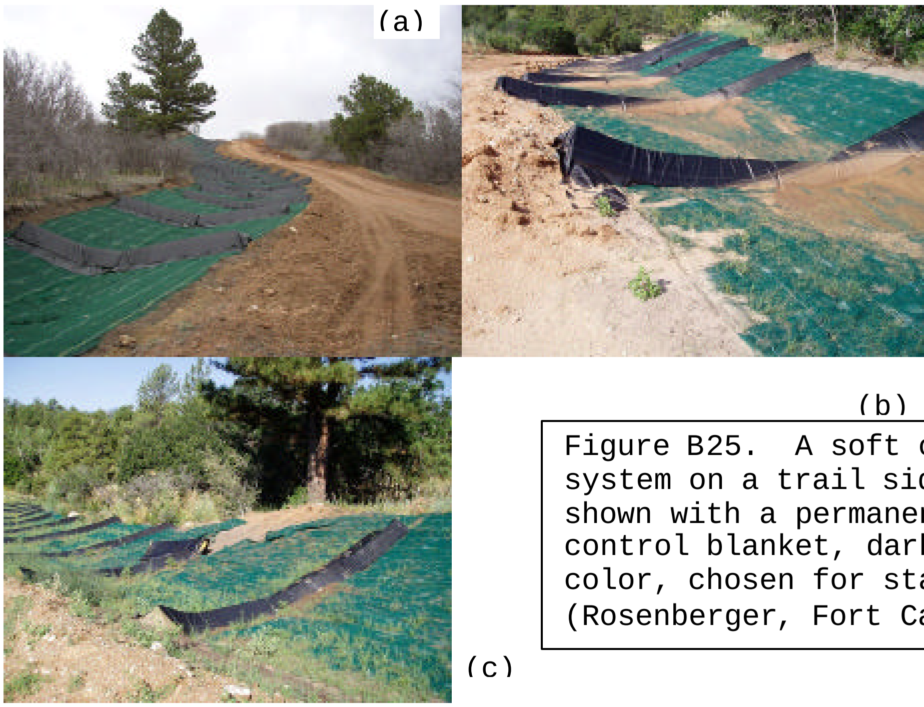


Figure B25. A soft check dam system on a trail sideshoulder is shown with a permanent erosion control blanket, darker teal color, chosen for stability (Rosenberger, Fort Carson, CO).

Figure B26. This nonwoven geotextile fabric was used in a low-water crossing at Fort Carson, CO, for both flow interception and structural reinforcement. Nonwoven geotextiles are used in areas that are generally saturated; consult a local vendor for help.

Figure B27. Improper installation and choice of erosion control blanket resulted in failure.

In-soil structural mats or reinforcement blankets are generally permanent and are applied to either the soil surface or top dressed with soil to reinforce root systems of vegetation on steep slopes or reinforced grass waterways. These systems are generally much more expensive than erosion control blankets but can tolerate higher flow velocities. **Pros/Cons:** Helps protect against problems during the slow re-establishment of vegetation on steep slopes. The blankets hold the slope until woody vegetation becomes established. The blankets can be expensive and not highly effective if improperly installed. Problems occur when the vegetation does not develop, but the blanket will still provide some erosion control. Some installation land managers have had difficulties with tank traffic uprooting or tearing blankets; proper anchoring and mulching are necessary to protect blankets until vegetation has established (Figure B28).

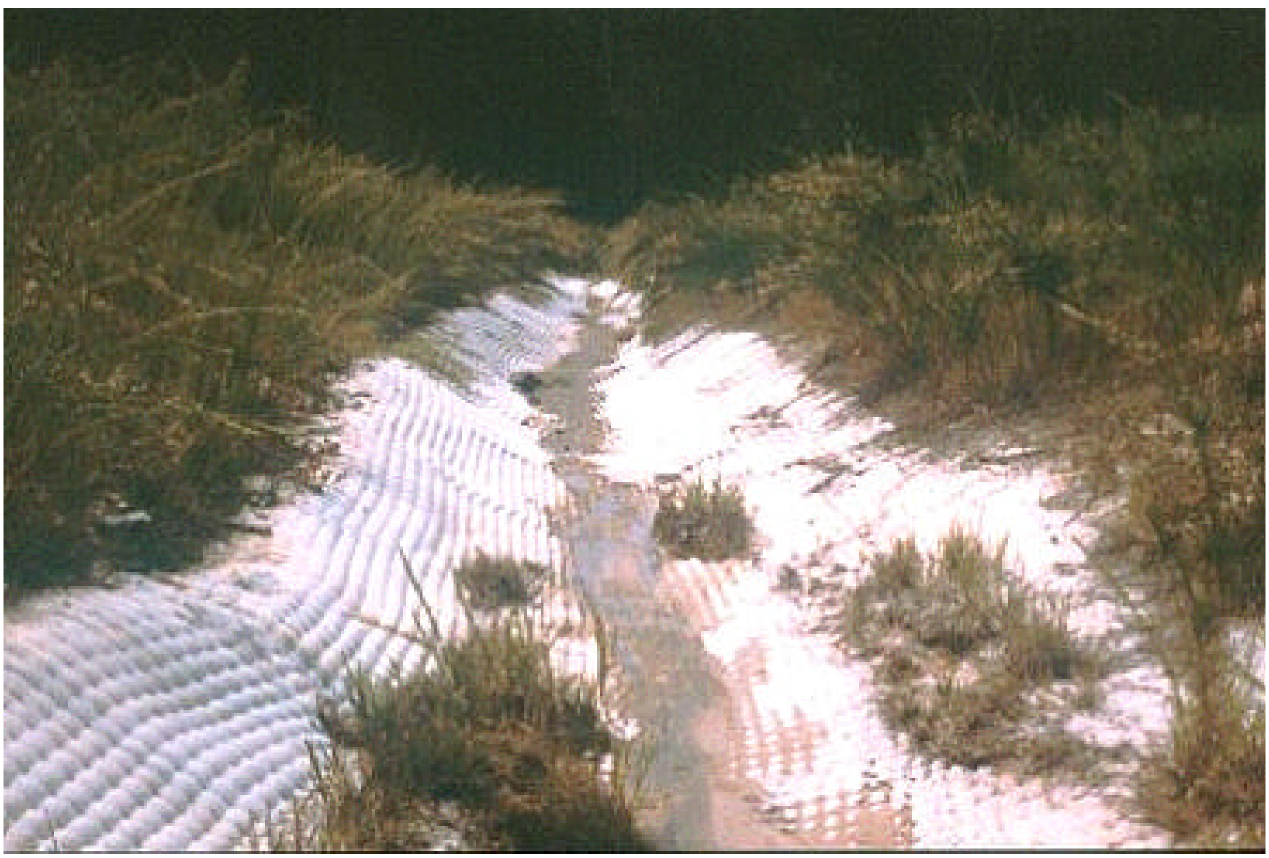


Figure B28. A permanent structural mat was chosen to help stabilize this waterway and increase its longevity (source: USDA).

Figure B29. Demonstration of two different blankets, biodegradable jute and synthetic polymer, indicate that the biodegradable blanket performed better. The synthetic blanket had increased erosion underneath, which could have been a result of poor grading.

Cellular or Soil-Confinement Systems

A Cellular Confinement System (CCS) is a three-dimensional, honeycomb, earth-retaining structure used to mechanically stabilize soil surfaces. A CCS is a permanent erosion control practice intended to stabilize infill materials for slope and channel protection, load support, and earth retention applications. The expandable panel creates a cellular system that confines topsoil infill, protects and reinforces the plant's root zone, and permits natural subsurface drainage. The honeycomb-shaped cells encapsulate and prevent erosion of the infill material. **Pros/Cons:** Can stabilize roads, trails, helipads, slopes, etc. Provides stabilized surface for military training. Reduces erosion and soil compaction for certain soils. A CCS is military friendly and long lasting. Can be expensive to obtain and install. Installation is labor intensive and can be difficult. If not properly installed, the CCS can be torn or ripped out during training activities (Figures B30 and B31).

Figure B30. A cellular confinement system with geotextile is being used to harden a helipad and tank trail at Fort Bragg, NC.

Figure B31. Cellular confinement system used in the construction of a Bradley misfire revetment.

Gabions are baskets or mattresses of wire filled with riprap or stone and used as structural reinforcement on steep slopes or in stream channels. They can be either vegetated or unvegetated. Gabions are practical for many uses but are most effective in the stabilization of a large slope or in cases of high energy overland flow. Buried or toed-in gabions can prevent gully development or create a stabilized crossing. The gabion system allows water to pass through while trapping sediment and other debris. **Pros/Cons:** Gabion systems are a relatively inexpensive, reliable, and well-researched technique. They typically last a few years but, if they are planted with woody vegetation, their lifespan can increase. They are used most often in slope stabilization, large overland flow drop structures. and riverbank stabilization projects. Masonry structures are generally more effective than gabions because of their higher strength, resistance to corrosion, and ability to resist scour in riverbeds (Figures B32 and B33). Further information can be found at: http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/veg_rockgabions.pdf.

Figure B32. Installment of gabions to stabilize firing range backstop.

Figure B33. Gabions were used to develop this drop structure (source: USDA).

Soil-Contouring & Building

Soil-contouring is common in agricultural practices and is defined as a process whereby soil is physically moved or shaped. Common soil-contouring methods include grading, plowing, disking, terracing, chaining, ripping, and pitting.

The most practiced forms of erosion control are *disking and plowing*, which are used to offset and reduce rill and sheet erosion. It is also a typical BMP in any site rehabilitation project where an area is graded or disked to prepare seedbeds or install filter fabrics or blankets. These soil-contouring BMPs can be used to reduce erosion in most areas of the country.

Soil ripping with the contour is another form of soil contouring. This process is generally used in areas with high compaction and gentle slopes. Tractors will rip approximately 6-18 inches deep by 8-16 feet in width along the contour. Ripping of the area increases surface roughness and helps dissipate overland flow and energy. **Pros/Cons:** Quick method for areas with a gentle slope. Must be done in combination with seeding. Can be used quite effectively in conjunction with on-going military training. This process is expensive and requires heavy equipment. If the soil is not properly ripped, the chances for failure substantially increase. Lastly, further soil is made available for erosion, possibly increasing sedimentation (Figure B34).

Figure B34. Deep ripper.

Soil pitting is a mechanical surface modification treatment to improve water infiltration and retention, reduce evaporation, and increase surface storage and the time available for infiltration to occur. Soil pitting can double absorption rates, capture blowing litter, seeds, and fine dust, and protect seedlings from wind and sand blast. The increased availability of water in and around the pits provides suitable niches for plant establishment and stimulates plant growth. For more information on soil pitting for revegetation, see http://www.serg.sdsu.edu/SERG/publications/99bainbridge1.html
Pros/Cons: Quick method for areas with a gentle slope. Can be used quite effectively in conjunction with military training. Requires heavy equipment. Can increase water erosion if not properly vegetated after pitting.

Chain diking involves dragging a chain-like implement, which leaves depressions to collect water. Rainfall or irrigation water is trapped and stored in the depressions so that it soaks into the soil rather than running off. Chain diking has been found to reduce runoff and to increase yields in both dry land and irrigated crops. **Pros/Cons:** Quick method for arid and semi-arid areas with a gentle slope. Can be used quite effectively in conjunction with military training. This process is expensive and requires heavy equipment. Possible increase in both wind and water erosion.

Terracing is formed by collection or cut-and-fill processes. Terraces break a steep slope into small, relatively horizontal benches that can be used for agriculture. Risers separate terrace benches. These are protected from erosion and failure by vegetation or masonry. **Pros/Cons:** Terracing can be very expensive and labor intensive. Gentle terraces are military friendly and have been used extensively at some installation for land management. Terraces have many designs, but each one needs a specialized drainage system and regular riser repair. Terrace risers can be major sources of sediment and can interfere with military training. Maintenance can be expensive and time consuming. Failure of terracing system can have large watershed impacts. Studies have shown that terraces and berms have a tendency to fail due to destruction by animals, trees, vehicles, siltation, overflow, and poor design (Figures B35-B37).

Ancient bench terraces are a type of terrace usually constructed by hand with a rock wall to hold the soil in place. They are difficult to construct and maintain and often impossible to use large equipment on or around.

Figure B35. Newly constructed terrace on farmland (source: USDA).

Figure B36. Terracing system on military drop zone.

Figure B37. Contrasting terracing system with and without vegetation, illustrating the importance that vegetation has in erosion control (source: IECA).

Broad-based terraces are very easy to construct. They are very easy on the landscape. Crops can be grown on the contour right over the terrace. They are effective only on more gentle slopes.

Steep back slope terraces are too steep to cultivate over them. Thus, they are permanently grassed. They often follow the contour. They were the most common type of terrace constructed in Iowa during the middle of the 20th century.

Contour terraces have point rows and grassed waterways and follow the contour. Water tends to collect along the backside of the terrace. In some areas of the world, contour terraces are used to decrease water runoff and to increase water storage in the soil.

Bench/step graded terraces are constructed so that they deviate slowly and continuously from the contour. This allows any water that might accumulate behind the terrace to be gently led away and allows infiltration. Bench/step terraces can be used on slopes of 20-50 percent and convert the land into a series of "steps" separated by nearly vertical risers lined with rocks or vegetation for protection. Though labor requirements are very high, well-constructed bench terraces give excellent erosion control. It is built by digging soil out from the eventual "heel" and using it to fill out the eventual "toe" area. The riser is not vertical but has a backslope of 1/2:1. This slope makes it less likely to cave in. The bench has a gentle backslope to prevent water runoff over the "toe" and to improve saturation.

Ridge terraces are a long, low ridge of earth with gently sloping sides and a shallow channel along the upper side to control erosion by diverting surface runoff across the slope instead of permitting it to flow uninterrupted down the slope. Types of ridge terraces include drainage, narrow-based, and Nichol's terraces. Ridge terraces contrast with bench terraces. *See also* broad-based, graded, and level terraces.

Broad-based terraces are a ridge-type terrace 25–50 cm high and 4–10 m wide with gently sloping sides, a rounded crown and a dish-shaped channel along the upper side, constructed to control erosion by diverting runoff along the contour at a nonscouring velocity. It may be level or have a grade towards one or both ends.

Intermittent terraces or drains are cut at intervals down the slope while retaining the original land slope. The land between terraces must be planted with a cover crop, and the terraces can be constructed on the contour.

Level terraces are constructed on the contour and collect runoff until it can be absorbed into the soil rather than continuing to flow down the hillside or into a waterway.

Contour berms are small embankments constructed across a slope. They run along the contour and are most suitable in arid areas. They are typically protected by vegetation. In areas of heavy to moderate rainfall, berms have a low incline against their upslope side to direct runoff. **Pros/Cons:** Appropriate for lands with grades up to 10 percent. Cannot be used in areas with shallow soils. In India, berms have been successful in all except areas with 2:1 clays.

Table B2. Comparison of erosion control technologies.

Technology	**Pros**	**Cons**
Living Vegetation		
Vegetation	Military friendly and low-cost.	Maintenance is required to ensure proper erosion control.
Grass Mats / Filter Strips / Hedges	Military friendly and low-cost.	Sediment can collect behind and within the grass creating small, unstable terraces. Significant rain events can overwhelm and flush sediments downstream. Short-term solution to erosion without proper maintenance.
Grassed Waterways	Military friendly, inexpensive to install, and self-sustaining. Foster infiltration while collecting sediment. Grassed waterways are highly effective in combination with geotextiles.	Susceptible to degradation and scour, new plantings need protection from high velocity water flow until well established.
Bio-filters & Sediment Traps	Cost effective and self-sustainable. With new regulations pending, installations may be allowed to utilize this approach and “bank” as a wetland.	Can create undesirable training conditions and involve a high land-take and low capacity compared with equivalent engineering techniques. “Banking” would take the parcel out of training indefinitely.
Woody live barriers		
Trees & Shrubs	Live fences and hedgerows are more effective and durable than non-living barriers. Can be military friendly if used as a training component; i.e., Tactical Concealment Corridor. Provides realistic training environment.	Slow to establish, required maintenance of living terrace after every significant storm event for the first year of establishment. Tend towards sediment buildup up-slope with soil distress directly down slope.
Mattresses, Wattles, Brush Grids & Facines	Military friendly, quick establishment and effective at sediment collection, stream bank and slope stabilization. They are more durable than nonliving barriers.	Maintenance and repair required after significant storm events. Labor intensive to install but supplies are inexpensive.
Live Staking and Bundling	Military friendly, quick establishment, durable, effective sediment collection and stream bank and slope stabilization.	Maintenance and repair required after significant storm events. Labor intensive to install but supplies are inexpensive.

Technology	**Pros**	**Cons**
Unrooted cuttings	Military friendly, quick establishment, and cost effective.	This method has to be done during dormancy.
Rooted cuttings	Quick establishment, insurance of rooting success, and seasonality is not as critical.	More costly and labor intensive than unrooted cuttings.
Live Staking	Low cost in labor and supplies, residual benefits from failed stakes.	Slow and unpredictable establishment, high mortality in first two seasons. Potential safety hazard.
Whips	Quick, inexpensive, and military friendly.	Can quickly dry out and have significant undercutting.
Woody Wattles	Military friendly; quick and inexpensive to install.	Can quickly dry out and have significant undercutting.
Trees	Military friendly and long lived.	Expensive and slow to establish. Young growth can be inhibited by competition and damage from training activities.
Mixed Living & Non-Living		
Timber Cribs & Crib Walls	Can be military friendly, long lasting, blends with environment and provides beneficial habitat for vegetation.	Can pose a significant safety hazard on training areas if troops are unaware of the wall. Labor intensive, expensive, and easily blown out if not maintained.
Living Timber Cribs	Can be military friendly, long lasting, blends with environment and provides beneficial habitat for vegetation.	Significant safety hazard on training lands if troops are unaware of the wall. Labor intensive, expensive, and easily blown out if not maintained.
Groynes	High effectiveness rate, long life span, easily modified and require minimal maintenance when implemented properly.	During flooding and other high flow periods cross currents can displace materials, undercut the groyne or cause erosion of the eddies.
Wattles & Logs		
Fiber logs / Wattles / Coirs	Highly effective in reducing erosion and stabilization of a slope or stream bank. Cost is generally offset by the quick rate of vegetation establishment and erosion control. Biodegradable materials and soft construction make this suitable for military training.	Can be expensive and require maintenance and repair after significant storm events.

Technology	**Pros**	**Cons**
Rock		
Riprap	Military friendly, effective and long lived especially in combination with mesh, geotextiles and vegetation.	Can fail due to scouring and/or undermining.
Vegetated riprap	Military friendly, inexpensive, permanent, and self-sustaining structure.	May not be as strong as gabions or masonry.
Rock Weirs	Can be military friendly, inexpensive, permanent, and self-sustaining structure.	May not be as strong as gabions or masonry.
Mulches		
Mulch (Straw, exp)	Generally inexpensive, increases organic content of soil, retain soil moisture, provides nutrients and is military friendly.	Mulch has a limited life span, which varies with the material used and site conditions.
Hydrologic mulch	Military friendly, inexpensive, fast and effective when combined with seed and fertilizer. Can increase soil moisture and decrease wind and water erosion.	Mulch with tackifiers can be difficult to work with, and start-up cost of equipment is expensive.
Other mulch	Military friendly, inexpensive, fast and effective when combined with seed and fertilizer. Can increase soil moisture and decrease wind and water erosion.	This process is better suited to gentle slopes and during times with slow winds.
Straw Checkerboards	Highly effective in arid environments with dune formations.	Very labor intensive and expensive. Has not been tested on military lands and no information on how suitable this technique is for military training.
Erosion Control Textiles		
Erosion control blankets	Can be expensive, but cost is generally offset by the quick rate of vegetation establishment and erosion control.	Some installation land managers have difficulties with tank traffic uprooting or tearing blankets.
In-Soil structural plastic blankets	Long lasting erosion control, military friendly and provides protection during the slow re-establishment of vegetation on steep slopes.	Can be expensive and not highly effective if improperly installed. Problems occur when the vegetation does not develop, but the blanket will still provide some erosion control.

Technology	**Pros**	**Cons**
		Some installation land managers have had difficulties with tank traffic uprooting or tearing blankets.
In-Soil organic fiber blankets	Nonpermanent blanket, biodegradable, effective erosion control, and military friendly.	Temporary structure that can be expensive and not highly effective if improperly installed. Some installation land managers have had difficulties with tank traffic uprooting or tearing blankets.
Cellular or Soil-Confinement Systems		
Cellular Confinement System	Many uses and long lasting. Provides stabilized surface for military training. Reduces erosion and soil compaction for certain soils.	Initially expensive to obtain and install. Installation is labor intensive and can be difficult. If not properly installed, the CCS can be torn or ripped out during training activities
Gabion Systems	Relatively inexpensive, reliable, and well-researched technique. They typically last a few years, but if they are planted with woody vegetation their lifespan can increase.	Masonry structures are generally more effective than gabions because of their higher strength, resistance to corrosion and ability to resist scour in riverbeds.
Soil-Contouring & Building		
Soil Ripping	Quick method for areas with a gentle slope. Must be done in combination with seeding. Can be used quite effectively in conjunction with ongoing military training.	Process is expensive and requires heavy equipment. If not properly ripped failure substantially increase. Makes available soil for erosion, possibly increasing sedimentation.
Soil Pitting	Quick method for areas with a gentle slope. Can be used quite effectively in conjunction with military training.	Requires heavy equipment. Can increase water erosion if not properly vegetated afterwards.
Chain Diking	Quick method for arid and semi arid areas with a gentle slope. Can be used quite effectively in conjunction with military training.	This process is expensive and requires heavy equipment. Possible increase in both wind and water erosion.
Terracing	Gentle terraces are military friendly and have been used	Terracing can be very expensive and labor

Technology	Pros	Cons
	extensively at some installation for land management. Permanent erosion control when maintained. Provides realistic training environment on drop zones.	intensive, require regular maintenance. Terrace risers can be major sources of sediment and can interfere with military training. Tend to fail due to outside impacts. Failure of terracing system can have large watershed impacts.
Contour Berms	Appropriate for lands with grades up to 10%. Highly effective and military friendly.	Not appropriate for areas with 2:1 clays. Cannot be used in areas with shallow soils.

Appendix C: Biological Engineering Lessons Learned

This Appendix highlights just a few of the exceptional and innovative efforts of installation land managers to control erosion with biological engineering techniques.

Most installation land managers have used some form of soft erosion control such as seeding, geotextile fabric, mulches, erosion control blankets, trees, and riprap. Generally, the reason biological engineering techniques were selected for use was due to the cost of conventional construction and/or the unsuitability of conventional methods to the military training mission and troop safety. Many land managers have worked together with the NRCS, U.S. Fish and Wildlife Service (FWS), local universities, and other researchers to develop and implement erosion control plans that incorporate both bioengineering and civil engineering methods that would be suitable for the type of training taking place on that installation.

At Fort Bragg, NC, home of the 108th Airborne Division, the drop zones (DZs) are on highly erodable sandy soils. At both Salerno DZ and Sicily DZ, erosion had produced gullies as large as 30 feet wide by 20 feet deep, with sediment runoff polluting nearby forests and wetlands. These areas were placed off-limits for training due to the dangerous field conditions. Previous land rehabilitation efforts at Sicily DZ followed a traditional hard conservation approach using terraces, riprap in drainage ways, and a downstream sediment basin. This approach, though effect-tive and durable, was cost prohibitive, and the placement of riprap and sediment basins was not compatible with training land use. Fort Bragg then installed a series of terraces and grassed waterways to provide optimal training conditions. The terracing system has ensured troop safety while reducing erosion and sedimentation of the DZs and surrounding sensitive areas. Fort Bragg's soil conservationist Craig Lantz said in a personal conversation, "We gained two advantages. We're able to control the erosion and the design is military friendly. There's nothing to injure soldiers when they drop into the area." Similar approaches have been implemented after the success of the first demonstrations across Fort Bragg to help control and manage erosion (Figures C1 and C2).

Figure C1. Drop zone at Fort Bragg, prior to terracing and seeding.

Terracing and grassed waterways were also successfully used at Fort Leonard Wood in 1998. An old rock quarry had been previously seeded in hopes of stabilizing the side slopes with grades ranging from 10 to 40 percent. Seeding failed and stabilization of this area required a more construction-oriented solution. With help from the local NRCS, the Environment, Energy, and Natural Resources Division of the Directorate of Public Works (DPW) developed a suite of terraces and grassed waterways that reduced the overland flow and speed while providing a stabilized area for training. This approach to erosion control allowed Fort Leonard Wood to get a handle on the area without the use of expensive concrete structures. More information can be found at: http://www.forester.net/ec_0003_profile_demolition.html

Fort McPherson, GA, and the U.S. Army Engineer Research and Development Center's Construction Engineering Research Laboratory (ERDC-CERL) established a combination method utilizing gabions, geotextile fabric, vegetation, and soil to reestablish and stabilize a historical Qualification Training Range (QTR) (Denight et al. 1999). The QTR was situated so that the backstop was actually an eroding hillside, with housing on top. To stabilize the range's backstop, the hill slope face was shored up with a graduated series of gabions filled with 3-6 inch riprap. The gabions were protected from the hill slope soils with various geotextiles so that ERDC-CERL could evaluate performance. A new backstop and impact berm were constructed with local soils of varying clay content, some of which were treated with PAM. The face of the berm was then vegetated with zoysia grass (*Zoysia matrella*) sod. This system has held up very well, and the design has been utilized at other firing ranges. Figures C3 and C4 show the before and after construction progress of the QTR.

Figure C2. Drop zone at Fort Bragg, after terracing and seeding.

Figure C3. Pictures of Fort McPherson backstop from front and side angles prior to stabilization.

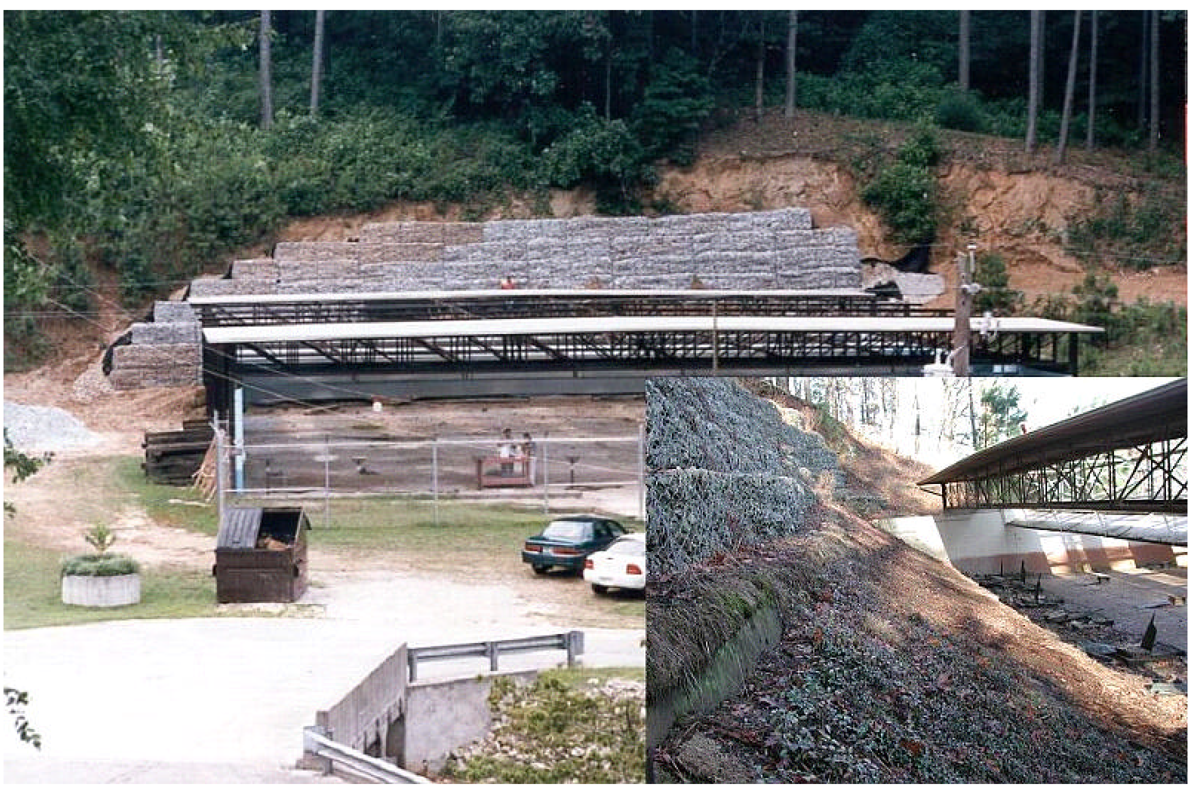


Figure C4. Fort McPherson backstop from front and side angles during and 1 year after stabilization.

At Fort Hood, TX, the Land Rehabilitation and Maintenance (LRAM) Coordinator is addressing an erosion problem through a combination of techniques including deep contour ripping, riprapped checkdams and waterways, grassed waterways, overseeding, and shallow sediment basins within Training Area (TA) 42. These erosion control practices were used not only for their effectiveness in controlling erosion and sediment transport but also for the realistic training opportunities that were provided. Troops can easily and safely maneuver over and around the erosion control applications. Training and other land uses were suspended both prior to and after construction to help facilitate the erosion control plan. This multi-year effort was finished during the summer of 2003 and is still in the young stage, but a marked difference in water quality has been seen. Ongoing water quality research downstream in TA 52, conducted by Texas A&M University, has seen up to a 95 percent decrease in suspended sediments since the placement of the erosion control plan. This research has been insightful and has lead to further investigation of existing erosion control management practices on Fort Hood training lands. Figures C5 and C6 were taken during and after June 2003 construction.

Figure C5. After-construction photograph of check dams in TA 52 that have helped reduce soil erosion while keeping the TA open (D. Jones, Fort Hood).

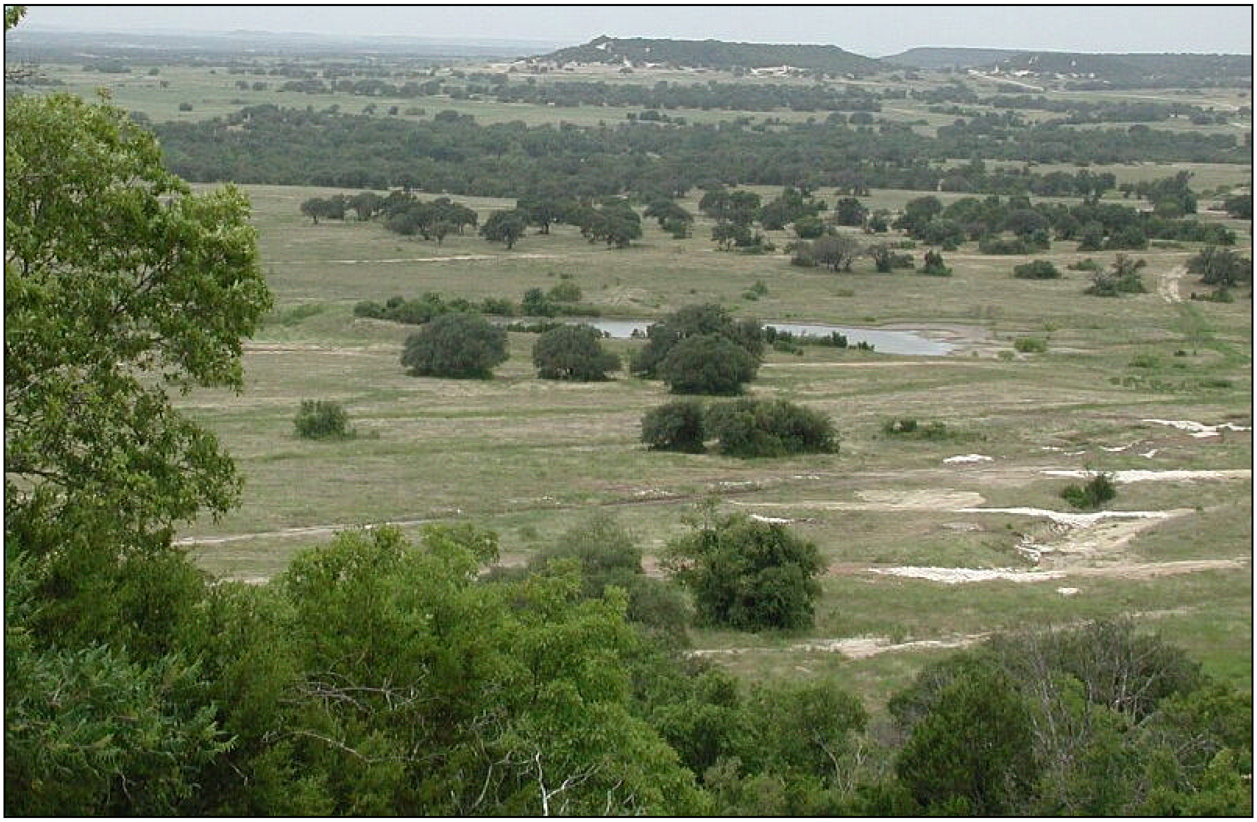


Figure C6. Elevated view of Fort Hood TA after soil contour ripping and after installation of check dam system.

Fort McCoy was the test site in 1995 for a trail stabilization trial that included chunkwood technology from the U.S. Forest Service, various trail stabilization devices available commercially, logging slash, shredded tires, and geotextile fabric. The primary concern was to stabilize thawing roads in the spring. ERDC’s Cold Regions Research and Engineering Laboratory (ERDC-CRREL) oversaw the project, reported on results, and produced a video on the trafficability of the various techniques. After initial testing of trafficability, researchers stabilized the disturbed trails with the chunkwood method, which is simple and highly effective and performs more or less as a temporary French drain. Infiltration was improved and stabilization of the trail was achieved. Fort McCoy has maintained the trail with a top dressing of gravel. This quick and simple method is highly effective, military friendly, inexpensive, and has lasted much longer than originally anticipated.

Installations that have used cellular confinement systems, also known as geogrid, for stabilization of side slopes and/or trail systems include Camp Atterbury, IN; Fort Bragg, NC; Fort Bliss, TX; etc. Camp Atterbury used geogrid to harden helipads, runways, primary and secondary roads, and in the latest project, the construction of a Multi-Purpose Training Range (MPTR). Figures C7 and C8 were taken of the backside of an impact berm at Camp Atterbury. The entire MPTR berm system was constructed out of geogrid. At Fort Bragg, trails within DZs were stabilized by the LRAM group. At Fort Bliss, range trails were also successfully stabilized with geogrid.

Figure C7. MPTR berm constructed entirely out of GeoWeb®. Due to difficulties establishing vegetation, excessive rill and sheet erosion has occurred along the face of the berm.

Figure C8. Backside of the MPTR berm. Many of the berms were composed of over 40 layers of GeoWeb®, obtained by Camp Atterbury after Operation Desert Storm.

Multiple installations such as Leonard Wood, Bragg, Atterbury, Camp McCain, MS, Camp Shelby, AL, etc, have all used one form or another of live posting, wattling, and bundling of various native shrub and tree species for low-lying areas and streambank stabilization. Fort Leonard Wood, with help from the local NRCS, was able to stabilize an area that had caused sediment problems and TA access in the past with placement of woven willow wattles and posts of locally adapted and obtained willows (*Salix ssp*). Figures C9 and C10 demonstrate the installation of both the wattles and live posts. This project was very successful and has been repeated at several other sites within Fort Leonard Wood. Other similar projects at Fort Leonard Wood included stabilization of a gravel bar and streambank with the use of ninebark (*Physocarpus (Camb.)* Raf.) and Ozark witchhazel (*Hamamelis vernalis* Sarg.). All of these projects succeeded and were accomplished with little training, cost, and time.

Figure C9. Installation of wattle and post system along a sediment basin at Fort Leonard Wood (J. Proffit, Fort Leonard Wood).

Figure C10. Sprouting has occurred 45 days after installation of wattle and post system (and 3.5 inches of rain) on Smith Branch TA 244 at Fort Leonard Wood.

Fort Polk, LA, was experiencing heavy erosion and subsequent sedimentation of sensitive areas on and adjacent to training lands. The NRCS established living hedges of *Vetiveria zinzinoides*, Sunshine var., a non-native stiff hedge grass, on several TAs to control runoff and sediments. These hedges have been in place since the early 1990s, are still effectively reducing erosion and sedimentation, and are very compatible with both light and heavy military training. The use of native stiff grass hedges, i.e., switchgrass (*Panicum virgatum*), has also been implemented at other installations with similar results. In conjunction with stiff grass hedges, many installations have installed alternating live grass mats and/or grassed waterways to help reduce flows while capturing sediments. All of these techniques are compatible with most military missions with minor maintenance such as re-seeding after tracked vehicle training.

Beachfront erosion is another problem for one military installation. Fort Story, VA, used native grasses and a sand-filled “geotube” in 1997 to stabilize sensitive sand dunes and beach front that were eroding away due to storms, wave action, and wind erosion. Native grasses such as sea oats (*Uniola* *paniculata* L.) stabilized the back and top slopes of the eroding dunes, while the “geotube” was toed into the dune and has helped preserve the toe of the dunes and build up the beach. The use of soft engineering techniques has enabled the Army to restore the sensitive areas and beach that provide amphibious training for soldiers.

Over 75 percent of Department of Defense (DoD) land is in the arid southwest where wind erosion predominates. At Yuma Proving Ground (YPG), AZ, the Integrated Training Area Management (ITAM) director and local NRCS soil conservationist used straw bales to reduce wind erosion at a critical land reclamation area. Bales were placed on the soil surface in a horseshoe shape, creating a microclimate to help protect and support newly planted vegetation. After 10 years, the bales are still in place and show little signs of degradation or decomposition. Illustrated in Figures C11 and C12 is evidence of deposition in front of the bales, indicating that wind speeds at the surface have slowed enough to allow larger particles to fall out and accumulate. In a more humid environment, soil formation would be an indirect result of this type of deposition. This concept is extensively used in humid regions for both wind and water erosion control, primarily by the state Department of Transportation and by private construction for sediment control. If bales are properly toed into or buried into the soil, the surface water and wind flow will reduce, allowing settling of sediments and wind borne particles.

Figure C11. YPG used straw bales for protection of a critical planting area (Morrill, YPG).

Figure C12. Close-up of bales shows that little degradation has occurred over the years, but sediment has accumulated at the base of the bales (Morrill, YPG).

EROSION CONTROL CHECKLIST

A few things need to be planned for and considered when determining the best course of action for erosion control of a site. Proper planning and implementation will save money, time, and the environment.

- Determine cause of erosion or site failure (e.g., improper road construction, trail placement, vehicles, upstream contributions, etc.)
- Obtain site data: ground survey, topographical maps, aerial photographs, and soil survey.
- Perform a site investigation.
  - Geological and hydrogeological survey
  - Vegetation evaluation, and determine if any species are threatened or endangered.
- Know local, state, and Federal regulations for permitting — engage associated groups and properly budget time for permitting.
  - Obtain legal documents for project:
    - 404 Permits
    - 401 Permits
    - State Erosion/Sediment Control Permit
- Optimize and utilize Engineering, Department of Natural Resources (DNR), and Department of Public Works.
- Involve the Cultural Resources group in initial site inspections and design plans to avoid any disturbance to archeological and other culturally significant sites.
- All sites are characterized by their drainage; a system will revert back to its natural flow or course, and this must be kept in mind when restoring or rehabilitating a site.
  - Try to incorporate the natural water flow within the design to help retain and maintain the natural drainage pattern.
  - Maintain or restore the natural hydrology of the area.
  - Channeling of a natural system will fail; keep within the natural meandering widths of your system.
  - When working in a stream system, always retain the original streambed elevation when and where possible.
- Start rehabilitation of an area, if possible, at the source of the problem.
  - Rehabilitating an area down watershed or downstream may not succeed if the source of the problem is upstream or up watershed.

  - Address first the downcutting before the sidecutting in gully erosion control.
- Fit the design, if possible, to the existing topography, soils, and vegetation.
- Use, when and where possible, locally adapted native vegetation that is suitable for the project.
  - If using non-native species, check to make sure that it is not an invasive species regulated by either state or Federal law.
- If using a biotechnical method, plan for the construction accordingly.
  - Refer to your local nursery, NRCS, DNR manual, etc for appropriate species selection, species requirements, etc.
  - Determine if the conditions of the rehabilitation site are appropriate for the selected vegetation.
    - Sunlight
    - Slope aspect
    - Soil moisture
    - Recovery and establishment time
  - Collect species during dormant periods, keeping in mind male/female ratios.
  - Plant species when optimal.
  - If conditions are unfavorable, plan for supplemental irrigation.
- Minimize disturbance when implementing your design.
  - Do not remove trees, roots, or other forms of vegetation unless absolutely necessary.
- Implement BMPs.
  - Minimize slope steepness.
  - Always reseed and mulch disturbed areas as soon as possible.
  - Use geotextiles and erosion control mats; in the long run the cost is inconsequential.
- Develop an erosion and sediment control plan for during and after construction.
  - Use sediment basins, barriers, or traps (straw bales, mulch, silt fencing, coconut coirs, etc) during and after construction to help keep sediment onsite.
- Set goal for success.
- Develop backup plans for failure or damage of the system.
- Develop post-restoration maintenance and monitoring plans.
- Document design, permits, and surveys along with before and after site rehabilitation photographs or measurements.

Practice the 4 Ds (from BioDraw 2.0):
Decrease (decrease velocity and amount of runoff by reducing gradient and increasing detention)
Detain (decrease flow velocity and amount by temporary storage)
Divert (route flow away from critical areas)
Dissipate (increase sinuosity or channel length, increase channel width, spread flow out, pass flow over baffles or roughened surface)

Appendix D: Resources

General

Erosion Control - magazine website
http://www.forester.net/ec.html

International Erosion Control Association – This organization provide a comprehensive listing of available resources for erosion control.
www.ieca.org

Land and Water: The magazine of natural resource management and restoration
http://www.landandwater.com/

USDA’s Natural Resources Conservation Services –
http://www.nrcs.usda.gov

USDA’s Agricultural Research Services –
http://www.ars.usda.gov/research/programs.htm

Emergency Stabilization Treatments
http://fire.r9.fws.gov/ifcc/Esr/Handbook/default.htm

State websites for erosion and sediment controls and regulations can generally be found under the state Department of Natural Resources, Water Quality, or Department of Transportation. If a state does not have its own handbook for erosion control practices, refer to the general NRCS erosion control practices or the NRCS “Natural Resource Conservation Laws” at:
http://www.nrcs.usda.gov/
http://www.nrcs.usda.gov/technical/references.

Alabama
http://swcc.state.al.us/pdf/ASWCC%20June%202003%20Alabama%20Handbook%20Construction%20E&S%20Control.pdf

Alaska
http://www.dced.state.ak.us/dca/nfip/pub/NFIP_Policy.pdf

Arizona
http://www.water.az.gov/adwr/content/InfoCentral

Arkansas

http://www.swcc.state.al.us/erosion_handbook.htm

California
http://www.swrcb.ca.gov/stormwtr/docs/bmp.pdf

Colorado
http://geosurvey.state.co.us/pubs/geohazards/docs/local.asp

Connecticut
http://dep.state.ct.us/olisp/manual/manualsection1.pdf

Delaware
http://www.dnrec.state.de.us/dnrec2000/Library/NPS/NPSPlan.pdf

Florida
http://www.dep.state.fl.us/water/nonpoint/ero_man.htm

Georgia
http://www.dnr.state.ga.us/dnr/environ/rules_files/exist_files/391-3-7.pdf

Hawaii
http://www.state.hi.us/dlnr/occl/files/coemap.pdf

Idaho (N/A)

Illinois – See Indiana

Indiana
http://www.in.gov/dnr/water/surface_water/DrainageHandbook/load.html

Iowa
http://www.dot.state.ia.us/construction/ctre_erosion_files/frame.htm

Kansas
http://www.lrrb.gen.mn.us/PDF/200308.pdf

Kentucky - Field Handbook Erosion and Sediment Control of Construction Sites Division of Conservation and Division of Water, NREPC – in preparation.
http://www.conservation.ky.gov/education/

Louisiana
http://coastalmanagement.noaa.gov/czm/6217/findla.txt - Under work. http://nonpoint.deq.state.la.us/manage10.html

Maine
http://www.state.me.us/dep/blwq/docstand/escbmps

Maryland
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/publicationsList/index.asp "1994 Maryland Standards & Specifications for Soil Erosion & Sediment Control"

Massachusetts - "Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas" - Massachusetts Association of Conservation Districts - 978-692-9395

Michigan
http://www.michigan.gov/deq/0,1607,7-135-3311_4113---,00.html

Minnesota
http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm

Missouri – County-driven; here are a few examples:
http://www.ci.st-joseph.mo.us/publicworks/erosion_control.pdf
http://www.gocolumbiamo.com/Council/Columbia_Code_of_Ordinances/Chapter_12A/index.html
www.modot.state.mo.us

Mississippi – "Mississippi State Best Management Practices"
http://abe.msstate.edu/csd/NRCS-BMPs/contents.html

Montana – Uses NRCS technical guides

Nebraska
http://www.upperbigblue.org/pages/pdf/Rulebk8.pdf

Nevada – City- and county-driven; this website is for laws, regulations, and acceptable erosion limits for the State of Nevada. http://www.leg.state.nv.us/NRS/NRS-528.html

New Hampshire
http://www.newipswichcc.org/bmp.htm
"Best Management Practices for Erosion Control During Trail Maintenance and Construction". 1994. New Hampshire Department of Resources and Economic Development

"Best Management Practices for Erosion Control on Timber Harvesting Operations in New Hampshire." 1997. New Hampshire Department of Resources and Economic Development, Division of Forests and Lands Society of New Hampshire.

New Jersey
http://www.state.nj.us/agriculture/rural/soilact75.htm

New Mexico
http://www.nm.nacdnet.org/page10.html

New York
http://www.dot.state.ny.us/eab/epm/4-3erosi.pdf

North Carolina
http://www.dlr.enr.state.nc.us/eropubs.html

North Dakota
http://www.ag.ndsu.nodak.edu/abeng/links/soilandwater.htm#Soil%20Erosion

Ohio – County handbooks
http://www.lakecountyohio.org/soil/ESC%20Model%20Ordinance.pdf
http://www.ccao.org/Handbook/hdbkchap092.pdf
http://www.bright.net/~swcd/reg.html

Oklahoma
http://www.okcc.state.ok.us/NPSMP_final_draft.pdf
Michelle Dolan - Oklahoma DOT – Erosion & Sediment Coordinator – 405-521-6771 mdolan@odot.org

Oregon
http://www.odot.state.or.us/contractorplans/ManualSubmitOrder.htm

Pennsylvania
http://www.dep.state.pa.us/dep/subject/rbi/102.htm

Rhode Island - Rhode Island Soil Erosion and Sediment Control Handbook, USDA-SCS. Rhode Island State Conservation Committee. 1989.

South Carolina
http://www.scdhec.gov/water/regs/r72-101.doc

South Dakota – Erosion Control Manual, South Dakota Department of Transportation. 2000.
http://www.sddot.com/docs/manuals/ErosionControlCoverandTableofContents.pdf

http://www.sddot.com/docs/manuals/ErosionControlManual.pdf

South Dakota Codified Laws & Constitution
http://legis.state.sd.us/statutes/index.cfm?FuseAction=DisplayStatute&FindType=Statute&txtStatute=38-8A

Tennessee
http://www.state.tn.us/environment/wpc/
http://www.tennessee.gov/environment/wpc/sed_ero_controlhandbook/

Texas – "Storm Water Management Handbook for Construction Activities". Stormwater Management Joint Task Force, PO Box 131006, Houston TX 77216.
http://www.dot.state.tx.us/env/default.htm

Utah
http://www.ci.west-valley.ut.us/citycode/West_Valley_City_Municipal_Code/Title_18/7/index.html

Vermont
http://www.anr.state.vt.us/dec/waterq/stormwater/htm/sw_erosionhandbk.htm

Virginia
http://www.dcr.state.va.us/sw/e&s-ftp.htm
http://www.vdof.org/wq/index-bmp-fguide.shtml

Washington
http://www.wsdot.wa.gov/eesc/design/designstandards/HTM/TOC.pdf

West Virginia - Best Management Practices for Controlling Soil Erosion & Sedimentation, State of West Virginia Forestry Division. 2001.
http://www.wvforestry.com/%28F%29BMPs.pdf
http://www.wvdot.com/../engineering/files/200/DD204.pdf

Wisconsin
http://clean-water.uwex.edu/pubs/sheets/worksheet.pdf
http://www.dot.wisconsin.gov/business/engrserv/pal.htm

Wyoming – (N/A)

Web-based Resources for Planning:

SedSpec is an expert system that will assist you in analyzing runoff and erosion problems on your site. The analysis will provide information about different types of runoff and erosion control structures. Also, SedSpec will provide customized drawings of the structures, and there is limited interaction, which allows you to determine what size structure fits your needs. Keep in mind that these drawings are rough estimates, and you should contact qualified personnel to determine exact specifications.
http://pasture.ecn.purdue.edu/~sedspec/sedspec/title.shtml

VegSpec is a web-based decision-making tool for the development of site-specific revegetation efforts. It utilizes soil, plant, and climate data to select plant species that are site specific, practical and appropriate for a variety of applications including restoration, erosion control, etc. VegSpec the program can be accessed at the below website.
http://aec.army.mil/usaec/technology/conservation07.html

Statements of Work (SOW) – The Fish and Wildlife Service has developed a practical SOW for general biological engineering. The SOW includes general contractor guidance for construction of riprap, cribs, gabions, etc, and estimation sheets for the Land Manager. This resource could prove useful for a Land Manager to use in the development of a SOW for outsourcing and contracting land rehabilitation work on their installation.
http://www.fs.usda.gov/r9/about/docs/fs-road/250.pdf

Recommended Books on Soil Bioengineering and Erosion

a. Abramson L.W., T.S. Lee, S. Sharma, and G.M. Boyce. 2001. Slope Stability and Stabilization Methods. John Wiley & Sons, Indianapolis, IN, pp 513-582.

b. Agassi, Menachem. 1996. *Soil Erosion, Conservation, and Rehabilitation*. Marcel Dekker, Inc., New York.

c. Charman, P.E.V. and B.W. Murphy. 1991. *Soils Their Properties and Management*, 2nd ed. Oxford University Press.

d. Gray, D.H., and R. Sotir. 1996. Biotechnical and Soil Bioengineering Slope Stabilization. John Wiley & Sons, New York, NY.

e. Haigh, Martin J. 2000. *Reclaimed Land: Erosion Control, Soils and Ecology*. A.A. Balkema Publishers, Brookfield, VT, pp 93-129.

f. Koerner, R.M. 1998. *Designing with Geosynthetics*, 4th ed. Prentice Hall Publishers, Upper Saddle River, NJ.

g. Schwab, G.O., D.D. Fangmeier, W.J. Elliot, and R.K. Frevert. 1955. *Soil and Water Conservation Engineering*, 4th ed. John Wiley and Sons, Inc., New York, NY.

h. Toy, Terrence J., George R. Foster, Kenneth G. Renard. 2002. *Soil Erosion: Process, Prediction, Measurement, and Control*. John Wiley and Sons, Inc., New York.

i. Wittler, R.J., S.D. Keeney, D.R. Eby, and D.L. LaGrone. 1997. "Building Banks on Muddy Creek with Barbs," *Management of Landscapes Disturbed by Channel Incision: Stabilization-Rehabilitation-Restoration*, pp 549-554.

Land Management and Erosion Control Laws and Regulations

NEPA 1969: http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm

Clean Water Act 1972: http://www.epa.gov

Soil and Water Conservation Act 1977:
http://ipl.unm.edu/cwl/fedbook/soilwate.html

Clean Air Act 1990: http://www.epa.gov

Sikes Act: https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Laws/sikes.html

Army Regulation (AR) 200-3:
http://www.usapa.army.mil/pdffiles/r200_3.pdf

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