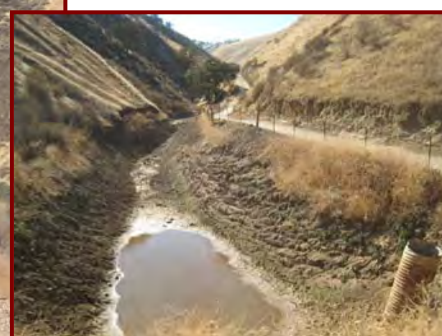
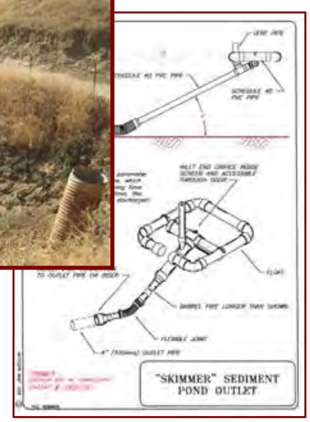
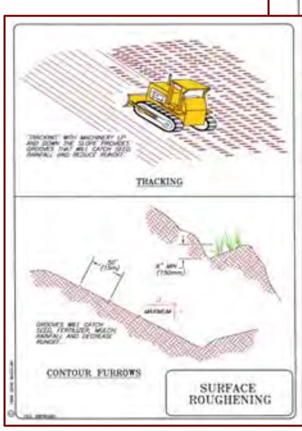
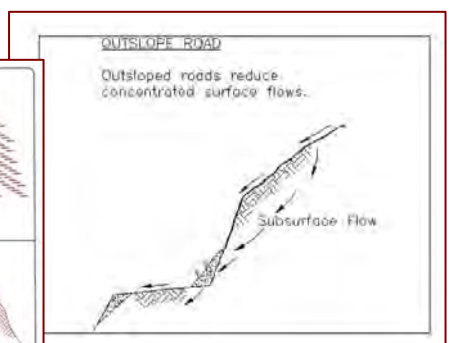
Prepared for:
State of California
Department of Parks and Recreation (DPR)
Off-Highway Motor Vehicle Recreation Division (OHMVRD)
Sacramento, CA

OHV BMP Manual for Erosion and Sediment Control









Prepared by:
Salix Applied Earthcare
Redding, CA

and

Geosyntec Consultants
San Diego, CA

November 2007

Acknowledgements

This Erosion and Sediment Control Manual was prepared by Salix Applied Earthcare (Salix) and Geosyntec Consultants (Geosyntec).

Salix and Geosyntec would like to acknowledge the following members of the CA Department of Parks and Recreation (DPR) for their support of the project, technical review and comments;

Bob Williamson, Bruce Lund, Rick LeFlore, Jennifer Buckingham, Stephanie Buss, Daphne Greene, Damian Jones, Tony Guzman, Terry Harper, Sr., Joe Ramos, Kenney Glaspie, and Randy Caldera.

Salix and GeoSyntec would also like to acknowledge the team members who helped build this BMP Manual, and others outside the core team for their guidance and input;

John McCullah (Author, Salix)*

Rose Sloan (Salix)

Kaila Dettman (Salix)

Nathan Jacobson (Geosyntec)

Chris Dean (Geosyntec)

Carol Forrest (Geosyntec)

The authors would also like to acknowledge the use of illustrations and maps taken from the Caltrans Storm Water Quality Handbooks. A complete list of the reference documents used in completion of this manual is provided in the References section at the end of this document.

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1. INTRODUCTION

Purpose of the OHV BMP Manual

History

In 1972 the Clean Water Act (CWA) was enacted to prohibit discharge of pollutants from any point source. In 1990 the EPA - as part of the National Pollutant Discharge Elimination System (NPDES) - published the final regulations and established permit requirements for Storm Water Discharges associated with industrial (including construction) activities. In California, the NPDES requirements of the CWA are regulated and enforced by the California State Water Board and the Regional Water Quality Control Board. In 1992 California's General Permit was adopted – the permit established requirements for discharges associated with construction activities which had disturbed soil areas greater than 5 acres. The Permit was amended in 1999 and modified in 2001 to also establish sampling and analysis requirements for section 303(d) listed water bodies. 303 (d) listed water bodies are those streams that are already at their total maximum daily load of pollutants, particularly sand and silt. In 2003 the California General Permit was again modified, Phase II, to require permit coverage for construction activities which disturb more than 1 acre.

BMPs and the Storm Water Pollution Prevention Plan

The California General Permit (Permit) now states that any soil disturbing activities exceeding 1 acre, or even areas less than 1 acre that are *part of a larger "planned development"*, require permit coverage. The principle requirement for compliance with NPDES and obtaining permit coverage is the development of a Storm Water Pollution Prevention Plan (SWPPP). The SWPPP is a dynamic adjunct to a construction plan that designates what measures will be employed to eliminate discharges of pollutants. The pollution elimination system is not only for stormwater (stormwater is the runoff related to precipitation and snow-melt) discharges but also non-stormwater discharges of things such as construction wastes, fuel, and litter. The regulations state that the "discharger" shall designate and implement the best available technology (BAT) and Best Management Practices (BMPs) to the maximum extent practicable (MEP).

BMP = Best Management Practice

BMPs then are the measures that minimize or eliminate the effects of soil erosion, sedimentation on stormwater, and the non-stormwater discharges of other possible pollutants. BMPs are the most important elements for compliance. Subsequently, BMPs must be chosen appropriately, implemented correctly and maintained properly in order to achieve compliance. In the current regulatory climate, the inappropriate and ineffective use of BMPs can result in enforcement action similar to those resulting from no BMP implementation. In fact, the improper use of BMPs can actually exacerbate or cause erosion. The regulations are currently performance-based so a working knowledge of BMPs effectiveness, applicability, limitations, installation protocol and maintenance requirements are essential to eliminate stormwater discharges.

BMP Manual

This manual is intended to provide the necessary guidance for selecting and implementing BMPs at Off-Highway Vehicle (OHV) Parks. OHV trail construction projects, the construction and the maintenance of low-volume access roads, the creation of new buildings, campgrounds and other user facilities, special OHV events, and routine park maintenance can all impact the water quality. This BMP Manual was specially compiled and written to be "SVRA-specific" for use by the Carnegie State Vehicular Recreation Area (SVRA) but it should also prove useful to all of California State Parks staff.

Compost berms are relatively new Best Management Practice (BMP) sediment control technology.

The manual is not just a "cut and paste" from old and often outdated BMP manuals. The erosion and sediment control industry has been rapidly adapting and changing - new and better innovations are constantly being developed and assimilated. At the same time old and new BMPs are being scientifically tested and empirically evaluated. The San Diego State University Erosion Control Laboratory, California State University at San Luis Obispo (CalPoly), and the Shasta College Erosion Control Training Facility are locations where development and testing of new BMPs, especially useful in California, is occurring.

This OHV BMP Manual provides the methods necessary for SVRA managers and staff to minimize the impacts of erosion, sedimentation, and other non-stormwater pollutants on water quality. The manual includes all of the new, appropriate, and state-of-the-art BMPs. It also excludes the BMPs that experience and science have proven ineffective. This BMP guide is intended be used by SVRA staff in selecting appropriate BMPs for SWPPPs. The special section on Road and Trail Drainage will be helpful when designing and building future trails and roadways in a manner that will minimize watershed and water quality impacts.

The California State Parks Off-Highway Motor Vehicle Recreation Division (OHMVRD) of California Department of Parks and Recreation (DPR) desire to comply with the CWA and NPDES requirements. Compliance with these laws and regulations will help ensure future OHV opportunities, and the implementation of the BMPs will protect the park, park users, trails, and natural resource values of the Park by:

1. Minimizing soil erosion and compaction of soils resulting in loss of soil productivity and sedimentation to waterways.
2. Minimizing disturbance and sedimentation to riparian areas, wetlands, and waterways adversely impacting amphibians and wildlife.
3. Minimizing spread of invasive, non-native, and noxious weeds along travel routes, and minimize disturbance to botanical resources.

4. Preventing the creation of additional routes in environmentally sensitive areas.

Organization of this Manual

The BMPs presented have been classified and organized to be easily used by those responsible for the management, ecosystem protection, construction, and maintenance of State Parks and SVRAs. The BMP categories are:

- EP – Erosion Prevention
- SS - Surface Stabilization
- TC - Tracking Control
- RC – Runoff Control
- SC – Sediment Control
- RT – Road and Trail Drainage
- RR – Restoration and Rehabilitation
- PO - Park Operations and Maintenance


These gullies will be best treated by diverting (rolling dips) and dispersing (outsloping) the road drainage. See RT-2 Outslope, RT-5 Rolling Dip, and RR-7 Gully Repair. (Tesla Mine area, DPR)

2. GENERAL GUIDANCE FOR EROSION AND SEDIMENT CONTROL, AND SWPPP IMPLEMENTATION

Definitions

Erosion Control/Soil Stabilization

The terms erosion control and soil stabilization are used interchangeably. Both terms refer to the control of raindrop impact erosion and sheet erosion. The primary energy source for the detachment of soil particles (erosion) is the impact of the raindrop on bare soil. Sheet flow, a relatively slow, uniform and shallow form of runoff does not generally have sufficient energy or tractive force necessary to detach soil particles so the detachment is again caused by raindrop impact. BMPs that are employed to address (control) raindrop and sheet erosion are referred to as Erosion Control or Soil Stabilization (SS) BMPs.

Runoff Control

Runoff Control BMPs are those measures intended to control or moderate the for the tractive forces of flowing water. Unlike rain drop impact erosion, concentrated runoff has the energy necessary to both detach and transport soil particles. Runoff Control BMPs address an entirely different erosional process.

An innovative new Runoff Control (RC) BMP is called the "Green Armor System". This system consists of "Enka Mat", which is then seeded and hydromulched with "Flexterra M-BFM". For more information refer to RC-4 Turf Reinforcement Mats / Grass Lined Channels and SS-6 Hydromulching.

Sediment Control

Sediment control is the process of ponding, detaining, or slowing sediment-laden storm water sufficiently to allow the sediment particles to fall out of suspension. Stokes Law describes the physical principles that govern how sediment particles fall out of suspension based on the particle shape, density, and how long they are held in impounded water. Based on this Law, detention time (the length of time sediment laden water can be held in sedentary condition) becomes the critical factor in sediment control effectiveness.

It is a misconception that Sediment Control BMPs can "filter water". Sediment-laden stormwater has never been filtered by a straw bale. In fact water does not flow, except imperceptibly slow, through a straw bale at all. Likewise, proper silt fence implementation is intended to pond water behind the fabric. The filter fabric does not "filter" as it's pore openings rapidly become plugged (blinded) when in contact with silt-laden stormwater.

The following definitions and guidelines are used by Caltrans and adopted by their statewide Stormwater Management Plan (SWMP). These are taken from the Caltrans Construction Site BMP Manual (2003) and Caltrans SWPPP/WPCP Preparation Manual (2007).

Disturbed Soil Area (DSA)

Disturbed Soil Areas (DSAs) are areas of exposed, erodible soil that are within the construction or rehabilitation area limits and that result from these construction/rehabilitation activities. The following are not considered DSAs:

- Areas where soil stabilization, erosion control, or slope protection are applied and associated drainage facilities are in place and functional.
- Roadways, construction roads, access roads or contractor's yards that have been stabilized by the placement of compacted subbase or base material or paved surfacing.
- Areas where construction has been completed in conformance with the contract plans and permanent erosion control is in place and functional.

Erosion control is considered functional when a uniform vegetative cover equivalent to 70 percent of the native background vegetation coverage has been established or equivalent stabilization measures have been employed.

Active and Non-Active Area

Active Areas are construction areas where soil-disturbing activities have already occurred and will continue to occur during the ensuing 21 days.

Non-Active Areas are the construction areas (formerly active areas) that will be idle for at least 21 days.

Non-active areas should be stabilized as soon a practicable and stabilized before the rainy season.

Rainy Season

The average rainfall in California varies greatly from region to region. To account for the various rainfall patterns (including times frames, intensities, and amounts) the state is separated into several rainy seasons. Figure 2-1 identifies those agreed upon rainy seasons throughout the State. These rainy season designations are useful to identify the appropriate timing and level of soil stabilization and sediment control protection. Please note that rainfall can occur at anytime and the Permit requires the elimination of stormwater discharges regardless of the season.

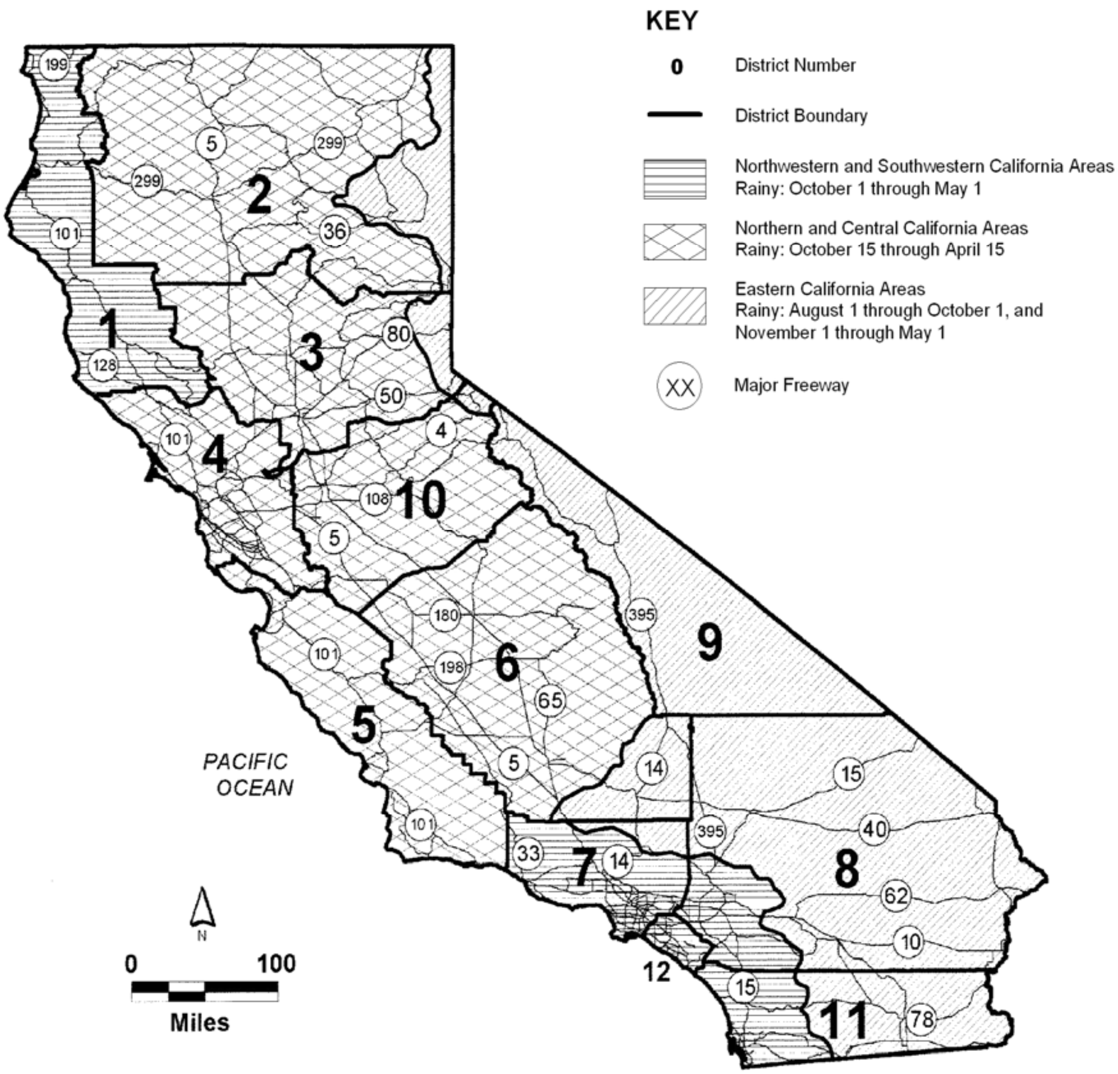


Figure 2-1. DESIGNATION OF RAINY SEASONS - California has three different precipitation zones based on season and variability of rainfall patterns (from Caltrans Construction Site BMP Manual, 2003).

Erosion Control, Sediment Control, and SWPPP Requirements

Storm water pollution control requirements are intended to be implemented on a year-round basis at an appropriate level. The requirements must be implemented in a proactive manner during all seasons while construction is ongoing. California has varied rainfall patterns throughout the state; therefore, the appropriate level of BMP implementation will also vary throughout the state. The temporary sediment controls and erosion controls (soil stabilization) specified in this section are based on rainfall patterns (time frames, intensities, and amounts), general soil types, the seasons, slope inclinations, and slope lengths.

Effective Combination

Appropriate water pollution control includes the implementation of an effective combination of both soil stabilization and sediment controls. Note that the California General Permit specifically requires that construction activities employ an effective combination of BMPs during the rainy season.

Scheduling

Construction scheduling shall consider the amount and duration of soil exposed to erosion by wind, rainfall, runoff, and vehicle tracking and seek to minimize disturbed soil area during the rainy season. A schedule shall be prepared that shows the sequencing of construction activities with the installation and maintenance of soil stabilization and sediment control BMPs. See EP-1 Scheduling and Phasing in this manual for BMP details.

Preserving Existing Vegetation

Preserving existing vegetation to the maximum extent possible and for as long as possible on a construction site reduces or eliminates erosion in those areas. To facilitate this practice, on a year round basis temporary fencing should be provided prior to commencement of clearing and grubbing operations or other soil-disturbing activities in areas where no construction activity is planned or construction will occur at a later date. See BMP EP-3 Minimize Disturbance and Buffer Strip for BMP details.

Control Run-on and Concentrated Flows

The diversion of storm water run-on and conveyance of concentrated flows must be considered in determining the appropriateness of the BMPs chosen. BMPs to divert or manage concentrated flows in a non-erodible fashion may be required on a project-by-project basis to divert off-site drainage through or around the construction site or to properly manage construction site storm water runoff. See the Runoff Control BMPs RC-1 to RC-5 for BMP details.

Disturbed Soil Area Management

The DSA management decisions made by the project manager (PM) are based on considerations of rainfall patterns (time frames, intensities, and amounts), general soil types, the seasons, slope inclinations, and slope lengths. Additionally, minimizing the size of the area disturbed, especially during or near the rainy season is an important DSA management decision. All of these factors are considered in developing the appropriate levels of soil stabilization and sediment control, and will be considered by the PM when directing specific site-by-site actions.

Sediment Basin Management

All sediment basins should be constructed, inspected and certified operational before the rainy season. Sediment basins serving active areas should be inspected before a predicted rainstorm, during a prolonged (24 hours) storm event, and after a runoff-producing storm event. The effectiveness of basins decline as they fill up so basins should be maintained at less than 1/3 full when ever possible. Sediment basins serving the active SVRA areas need clean-out once a year or when 1/3 full, which ever comes first. Sediment basins should have effectiveness monitoring and sampling performed (such as turbidity testing) during storm events to ensure effectiveness or indicate corrective actions that may need to be taken. See SC-1 Sediment Ponds for BMP details.

Wind Erosion Control

Wind erosion controls shall be considered year-round for all disturbed soils on the project site that are subject to wind erosion and when significant wind and dry conditions are anticipated during construction of the project. See SS-11 Dust Control and Tackifiers for BMP details.

Tracking Controls

Tracking control must be implemented year-round, as needed, to reduce tracking sediment and debris from the construction site or the park onto public roads or State Highways. Construction site entrances shall be inspected daily and controls implemented as needed.

Non-Storm Water and Waste Management and Materials Pollution Controls

The objective of the non-stormwater and waste management and materials pollution controls is to reduce the discharge of materials other than stormwater to the stormwater drainage system or to the receiving waters. These controls are usually implemented year-round for all applicable activities, materials usage, and site conditions.

Guidance for Selecting Soil Stabilization (Erosion Control) BMPs

There exists a wide array of measures for reducing raindrop and sheet erosion. Not only are there many BMPs to choose from, such as Erosion Control Blankets and Mats, or Hydromulch, or Straw Mulch, there are also numerous products and formulation available. How does one even begin to select the "best" SS BMP for the site in question?

A group of criteria was developed by Caltrans to allow for comparison and differentiation among the product types that are available. These criteria include installed cost, erosion control effectiveness, drying time, and others. For some criteria, values have been assigned by characteristics: an example would be mode of application (e.g., hydraulic seeder, water truck, and hand labor). For other criteria, actual numeric values should be considered based on available data, such as drying time in hours. Refer to Table 2-1 for a summary of selection criteria information and ratings for temporary soil stabilization BMPs.

The criteria presented here are also provided in Caltrans Stormwater Quality Handbooks, Construction Site BMP Manual (2003).

Antecedent Moisture

This criterion relates to the effect of existing soil moisture on the effectiveness of a soil stabilization method. While antecedent soil moisture conditions can have an effect on the performance of some methods, (e.g., hydraulic soil stabilizers, temporary seeding) other methods, such as erosion control blankets or impervious covers, are not affected – except perhaps in their ease of installation.

Suppliers of manufactured soil stabilization products affected by antecedent soil moisture specify the conditions under which their products are to be applied. For example, some products clearly benefit from having the soil "pre-wetted" before application of the hydraulic soil stabilizer and as a result, some manufacturers recommend application of water by itself as a first step. Conversely, the binding action of some adhesives on soil particles (and thereby their erosion control effectiveness) can be affected by excessive soil moisture. Therefore, some manufacturers recommend that their products not be applied when the soil is visibly saturated or when standing water is present.

Availability

A critical aspect of product specification and use is whether or not a soil stabilization product is readily available. While local sources may be preferable, the seasonal nature of soil stabilization work can create localized shortages of materials. In these cases, usually the material that can be delivered to the job most quickly is the material that is selected for application.

Ease of Clean-Up

This criterion applies primarily to the hydraulically-applied soil stabilization materials, but there may be clean-up issues associated with some of the other categories as well (e.g., packaging materials, disposal of excess product, etc). All of the approved hydraulic soil stabilization products are typically applied using water as a carrier, and to varying degrees, these products can be removed from application machinery and overspray areas with the application of clean water as well. However, cleaning must occur before the material sets or dries, otherwise stronger cleaning solutions of detergent, a strong alkali solution, or a petrochemical solvent must be used. A prudent contractor will take precautions when working with hydraulic products that have some clean-up limitations, and must follow the BMPs in the SWPPP for cleaning of equipment on site (see TC-4 Wash Racks).

Regardless of which approach is used for temporary soil stabilization, site clean-up can be problematic due to the following:

- Added time to dispose of waste materials
- Added time to clean hydraulic equipment before the material sets or dries
- Additional quantities of water needed for cleaning operations
- Impact of quick-setting materials on overspray areas such as roads or vehicles
- Contractor resistance to products that require excessive clean-up
- Additional operation and maintenance costs included in contractor's bid.

Installed Cost

The estimated installed cost (the cost of the material itself, plus the cost associated with its installation) has a value that corresponds to cost in dollars per hectares, which are used for estimating and bidding. This approach allows for the direct comparison of approaches.

Degradability

Degradability relates to the method by which the chemical or structural components of a soil stabilization product are degraded over time. As might be expected, the way in which a product degrades is related to longevity, which is another selection criterion. Both degradability and longevity are sometimes key issues in temporary soil stabilization and long term erosion and sediment control planning. Soil properties, climate, existing vegetation as well as slope aspect contribute to the degradation of soil stabilization materials.

When applying an erosion control blanket, for instance, on a steep slope with rugged conditions, one might chose a product with double-sided netting rather than single-sided.

Length of Drying Time

Not all materials require drying time, and the drying criterion may be used to differentiate categorical approaches as well as a final screen for the various types of materials within a class of approaches. Determining when a soil stabilization material is dry or completely cured is a subjective exercise that relies a great deal on manufacturer-published information. In setting standards for this criteria, where drying or curing time is necessary for a particular method to become erosion control effective, manufacturers' recommendations have been followed.

Time to Effectiveness

Not all soil stabilization products are immediately effective in controlling erosion: some take time to dry (e.g., hydraulic soil stabilizers) and others take time to grow (e.g., temporary seeding). However, when some treatments are applied (e.g., rolled erosion control products and straw mulch) they are immediately effective.

RECPs (Rolled Erosion Control Products) and straw mulch are immediately effective for erosion control.

Erosion Control Effectiveness

This criterion measures the ability of a particular product to reduce soil erosion relative to the amount of erosion measured for bare soil. Erosion control effectiveness is described as a percentage the erosion would be reduced as compared to an untreated or control condition.

Longevity

This criterion simply considers the time that a soil stabilization product maintains its erosion control effectiveness.

Mode of Application

The mode of application criterion refers to the type of labor or equipment that is required to install the product or technique. This is an important consideration when large areas need coverage or time to completion critical or even if labor resources are available. Hydromulching requires the investment for equipment but is less time consuming than installation of erosion control blankets, which requires a significant labor investment.

Residual Impact

This criterion relates to the impact that a particular practice might have on construction activities once they are resumed on the area that was temporarily stabilized. Some examples include:

- Temporary vegetation covers or standard biodegradable mulches might create problems with achieving final slope stability or compaction due to their organic content, and therefore would require removal and disposal.
- Applications of straw or hay fibers might keep soil from drying out as quickly as it might if it was bare.
- Plastic sheeting, netting or materials used in soil stabilization products might persist longer than needed on or in the soil. Loose plastic netting, especially netting that is not stitched together as in an ECB (Erosion Control Blanket), can endanger wildlife by trapping birds, reptiles and small mammals. The selection of netting becomes an important consideration, whether it is highly photodegradable or biodegradable. ECBs, constructed from biodegradable cotton and jute threads are available for sensitive wildlife areas.

Native

This criterion relates primarily to selection of plant materials and is important from the standpoint of environmental compatibility and competitiveness.

Runoff Effect

This criterion measures the effect that a particular soil stabilization product has on the production of storm water runoff. Similar to the erosion control effectiveness criterion, runoff from an area protected by a particular product may be compared to the amount of runoff measured for bare soil and is presented in the matrix as a percentage of the runoff that would occur in an untreated, or control condition.

CLASS	TYPE	Antecedent Moisture	Availability	Ease of Clean-Up	Installed Cost Per Ha	EC Effectiveness (%)	Degradability	Length of Drying Time (hrs)	Time to Effectiveness (days)	Longevity	Mode of Application	Residual Impact	Native	Runoff Effect	Water Quality Impact
		TEMPORARY SOIL STABILIZATION CONTROL CRITERIA													
CATEGORY: STANDARD BIODEGRADABLE MULCHES (SBM)															
Straw Mulch	Wheat Straw	D	S	H	$5,200	90-95	B	0	1	M	L/M	M		+	M
	Rice Straw	D	S	H	$5,200	90-95	B	0	1	M	L/M	M		+	L
Wood Fiber Mulch	Wood Fiber	D	S	H	$2,200	50-60	B	0-4	1	M	H	L		+	M
Recycled Paper Mulch	Cellulose Fiber	D	S	H	$2,100	50-60	B	0-4	1	S	H	L		+	L
Bonded Fiber Matrix	Biodegradable	D	S	H	$13,600	90-95	B	12-18	1	M	H	M		+	H
CATEGORY: ROLLED EROSION CONTROL PRODUCTS (RECP)															
Biodegradable	Jute Mesh	D	S	H	$16,000	65-70	B		1	M	L	M		+	UNK
	Curled Wood Fiber	D	S	H	$26,000	85-90	P/B		1	M	L	M		+	L
	Straw	D	S	H	$22,000	85-90	P/B		1	M	L	M		+	H
	Wood Fiber	D	S	H	$22,000	85-90	P/B		1	M	L	M		+	L
	Coconut Fiber	D	S	H	$32,000	90-95	P/B		1	L	L	M		+	L
	Coconut Fiber Mesh	D	S	H	$77,000	85-90	B		1	L	L	M		+	UNK
	Straw Coconut Fiber	D	S	H	$27,000	90-95	P/B		1	L	L	M		+	M
Non-Biodegradable	Plastic Netting	D	M	H	$5,000	<50	P		1	L	L	H		+	UNK
	Plastic Mesh	D	M	H	$8,000	75-80	P		1	L	L	H		+	UNK
	Synthetic Fiber with Netting	D	M	H	$86,000	90-95	P		1	L	L	H		+	UNK
	Bonded Synthetic Fibers	D	M	H	$121,000	90-95	P		1	L	L	H		+	UNK
	Combination with Biodegradable	D	M	H	$79,000	85-90	P		1	L	L	H		+	UNK
CATEGORY: TEMPORARY SEEDING (TS)															
High-Density	Ornamentals		S-M	H	$1000 - $4000	50-60			28	M-L	H	L-M	N/E	+	UNK
	Turf species		S	H	$900	50-60			28	L	H	M-H	N/E	+	UNK
	Bunch grasses		S-M	H	$750 - $3200	50-60			28	L	H	L-M	N	+	UNK
Fast-Growing	Annual		S	H	$900 - $1,600	50-60			28	L	H	L-H	N/E	+	UNK
	Perennial		S	H	$800 - $2000	50-60			28	L	H	M	N/E	+	UNK
Non-Competing	Native		S-M	H	$700 - $4000	50-60			28	L	H	L-M	N	+	UNK
	Non-Native		S-M	H	$1000 - $1200	50-60			28	L	H	L-H	E	+	UNK
Sterile	Cereal Grain		S	H	$1,200	50-60			28	L	H	L	E	+	UNK
CATEGORY: IMPERVIOUS COVERS (IC)															
Plastic	Rolled Plastic Sheeting		S		$17,000	100	P		1	M	L	H		-	UNK
	Geotextile (Woven)		S		$14,800	90-95	P		1	M	L	H		-	UNK
CATEGORY: HYDRAULIC SOIL STABILIZERS (HSS)															
(PBS) Plant Material Based- Short Lived	Guar	D	S	H	$1,000	80-85	B	12-18	Same as Length of Drying Time.	S	B	L		0/+	M/L
	Psyllium	P	S	H	$1,000	25-35	B	12-18		M	B	L		0	L/H
	Starches	D	S	H	$1,000	25-30	B	9-12		S	H	L		0	L
(PBL) Plant Material Based- Long Lived	Pitch/ Rosin Emulsion	D	S	M	$3,000	60-75	B	19-24		M	B	M		-	H
(PEB) Polymeric Emulsion Blends	Acrylic polymers and copolymers	D	S	M	$3,000	35-70	P/C	19-24		L	B	M		+/-	L/M
	Methacrylates and acrylates	D	M	M	$1,000	35-40	P/C	12-18		S	W	L		0/+	L
	Sodium acrylates and acrylamides	D	M	M	$1,000	20-70	P/C	12-18		S	H	L		+/-	L/M
	Polyacrylamide	D	M	M	$1,000	55-65	P/C	4-8		M	H	L		0/+	L
	Hydro-colloid polymers	D	M	H	$1,000	25-40	P/C	0-4		M	H	L		0/+	L/M
(PRB) Petroleum/ Resin-Based Emulsions	Emulsified Petroleum Resin	D	M	L	$3,000	10-50	P/C	0-4		M	B	M		0/-	H
(CBB) Cementitious Based Binders	Gypsum	D	S	M	$2,000	75-85	P/C	4-8		M	H	L		-	M/H

(hatched) = not applicable for category, class or type
UNK = unknown

Table 2-1. Summary of selection criteria information and ratings for temporary soil stabilization BMPs (URS Greiner Woodward Clyde, 1999).

Antecedent Moisture	**D**	Soil should be relatively dry before application
	P	Soil should be pre-wetted before application
Availability	**S**	A short turn-around time between order and delivery, usually 3-5 days
	M	A moderate turnaround time, between 1-2 weeks
Ease of Clean-Up	**L**	Require pressure washing, a strong alkali solution, or solvent to clean up
	M	Requires cleanup with water while wet; more difficult to clean up once dry
	H	May be easily removed from equipment and overspray areas by a strong stream of water
Installed Cost		Dollars per hectare
Degradability	**C**	Chemically degradable
	P	Photodegradable
	B	Biodegradable
Length of Drying Time		Estimated hours
Time to Effectiveness		Estimated days
Erosion Control Effectiveness		Percent reduction in soil loss over bare soil condition.
Longevity	**S**	1 - 3 months
	M	3 – 12 months
	L	> than 12 months
Application Mode	**L**	Applied by hand labor
	W	Applied by water truck
	H	Applied by hydraulic mulcher
	B	Applied by either water truck or hydraulic mulcher
	M	Applied by a mechanical method other than those listed above (e.g., straw blower)
Residual Impact	**L**	Projected to have a low impact on future construction activities
	M	Projected to have a moderate impact on future construction activities
	H	Projected to have a significant impact on future construction activities
Native	**N**	Plant or plant material native to the State of California
	E	Exotic plant not native to the State of California
Runoff Effect	**+**	Runoff is decreased over baseline (bare soil)
	0	No change in runoff from baseline
	-	Runoff is increased over baseline
Water Quality Impact	**L**	Low potential to impact water quality
	M	Moderate potential to impact water quality
	H	Higher potential to impact water quality

Table 2-2 (Continued from Table 2-1). Temporary Soil Stabilization Criteria Matrix (URS Greiner Woodward Clyde, 1999).

EROSION AND SEDIMENT CONTROL BMPs
INSTALLED COSTS AND EFFECTIVENESS

BMP	Unit Cost Installed	Estimated Relative Erosion/ Sediment Control Effectiveness
Sediment Control		
Silt Fence	$1.50 – 2.00 per lineal foot	UNK
Fiber Rolls	$1.50 – 2.00 per lineal foot	58%
Erosion Control		
Fertilizer	$450 – 550 per acre	N/A
Seeding	$870 – 2,170 per acre	50%
Stolonizing	$2,200 per acre + cost of stolons	90%
Hydraulic Mulching	$900 – 1,200 per acre	50 – 60%
Compost Application	$900 – 1,200 per acre	40 – 50%
Straw Mulching	$1,800 – 2,100 per acre	90 – 95%
Soil Binders		
Plant Material-Based (Short-Term)	$700 – 900 per acre	80 – 85%
Plant Material-Based (Long-Term)	$1,200 – 1,500 per acre	60 – 65%
Polymeric Emulsion Blends	$700 – 1,500 per acre	30 – 70%
Petroleum Resin-Based	$1,200 – 1,500 per acre	25 – 20%
Cementitious Binder-Based	$800 – 1,200 per acre	80 – 85%
Bonded Fiber Matrices	$5,000 – 6,500 per acre	90 – 95%
Rolled Erosion Control Products		
Biodegradable		
Jute	$6,000 – 7,000 per acre	65 – 70%
Curled Wood Fiber	$8,000 – 10,500 per acre	85 – 90%
Straw	$8,000 – 10,500 per acre	85 – 90%
Wood Fiber	$8,000 – 10,500 per acre	85 – 90%
Coconut Fiber	$13,000 – 14,000 per acre	90 – 95%
Coconut Fiber Net	$30,000 – 33,000 per acre	85 – 90%
Straw Coconut	$10,000 – 12,000 per acre	90 – 95%
Non-Biodegradable		
Plastic Netting	$2,000 – 2,200 per acre	< 50%
Plastic Mesh	$3,000 – 3,500 per acre	75 – 80%
Synthetic Fiber w/Netting	$34,000 – 40,000 per acre	90 – 95%
Bonded Synthetic Fibers	$45,000 – 55,000 per acre	90 – 95%
Combination Synthetic and Biodegradable Fibers	$30,000 – 36,000 per acre	85 – 90%

Table 2-3. Unit Costs Imperial Units (URS Greiner Woodward Clyde, 2000).

3. NOTES ON SOIL COMPACTION

Optimizing Soil Compaction and Other Strategies

Vegetation can be grown successfully in compacted soil under less than ideal conditions provided certain limits and precautions are observed. Several approaches can be invoked to make it possible to compact soil to a relatively high density and still allow it to support vegetative cover. In addition, a number of other strategies can be used to allow both engineering and plant growth needs to co-exist with one another.

Compaction can be defined as a process of densification due to the removal of air voids when external stress is applied to a soil. Relevant engineering or physical properties include strength, compressibility, volume stability (shrink-swell potential), hydraulic conductivity, and erodibility.

Key variables affecting engineering soil properties during compaction include the following:

- Density (usually expressed in terms of "dry" unit weight)
- Water content (molding or mix water content during compaction)
- Compactive effort (energy input/unit volume of soil)
- Type of compaction (static, dynamic, or kneading)
- Additives (cement, lime, etc.)

The shearing and pumping actions of wheeled vehicles can reduce soils to a structureless condition. This condition is characterized by the loss of distinguishable soil structure and a reduction in pore space voids, and interped passages (the space between peds) (Meyer, 2002).

The degree of saturation or water content of a clay soil at the time of compaction is perhaps the single most important variable that controls the engineering properties of the compacted material (Lambe, 1958). The influence of molding water content and compactive effort on hydraulic conductivity of compacted silty clay soil (Mitchell et al., 1965) soils is shown in Table 3-1. Soils compacted at water contents less than optimum (dry of optimum) tend to have a relatively high hydraulic conductivity, whereas soils compacted at water contents greater than optimum (wet of optimum) tend to a relatively low hydraulic conductivity. Higher molding water contents also greatly suppress hydraulic conductivity on the wet side of optimum, even offsetting the effect of decreased dry densities (or higher void ratios).

Degree of Compaction (% of max dry density)	"DRY" side compaction		"WET" side compaction	
	Water Content %	Hydraulic Conductivity cms/sec	Water Content %	Hydraulic Conductivity cms/sec
98	13.0	0.5x10-6	16.0	1.0x10-8
96	13.0	1.0x10-6	17.0	0.8x10-8
94	12.3	2.0x10-6	18.5	0.3x10-8
87	12.4	7.2.x10-6	22.5	0.6x10-8

Table 3-1. Influence of Molding Water Content of a Silty Clay Compacted to Different Degrees of Compaction on the "Wet" and "Dry" Side of Optimum. (Note: Modified AASHTO compaction. Maximum dry density = 117.8 lbs/ft3; optimum water content = 15.0 %.)

The results shown in Table 3-1 demonstrate that a soil compacted to the same degree of compaction on the wet side of optimum using the same compaction method but at different molding water contents can have radically different physical properties. This occurs because a soil compacted "wet" versus "dry" of optimum usually has a different texture or internal pore structure and pore size distribution. Soils compacted on the dry side of optimum water content tend to have a more open structure and greater distribution of larger pores. Accordingly, dry side compaction can result in hydraulic conductivities several orders-of-magnitude higher than wet side compaction, even when the soil is compacted to identical densities or degrees of compaction (see Table 3-1). This fact should always be kept in mind when assessing optimal compaction conditions to satisfy plant growth needs vs. engineering requirements, or when rehabilitating compacted slopes on hill climbs, etc.

Influence of Soil Compaction on Plant Growth

Soil compaction can influence plant growth in a variety of ways, both good and bad. Agronomists generally recommend minimal soil compaction so as not to impede growth and development of crops and native plants. Soil must retain enough interconnected void space to allow storage and passage of air and water in the soil. Some degree of compaction is needed after planting or insertion of cuttings to close large voids and to provide suitable soil density for appropriate plant growth. Too much void space can lead to poor contact of a seed or cutting with the surrounding soil, and subsequent desiccation.

The impacts of compaction have been studied extensively by agronomists who are concerned with the decline in soil productivity associated with modern agriculture, forestry practices, and the passage of equipment, which tend to compact soils over time. Goldsmith et al. (2001) provide a good review of these impacts on both conventional plantings and soil bioengineering installations. In general, findings show that high densities specified by engineers for mechanical strength tend to either reduce or effectively stop the development of roots. Depending on the plant species and the soil conditions, Goldsmith et al., (2001) cite evidence of limits to growth that include: 1) restriction in root growth, 2) severe reduction in length of all roots/or primary root 3) absence of root penetration of compacted soils. These authors conclude that a limiting or "threshold" bulk density appears to exist for each soil type or texture above which plant growth is severely curtailed. They further suggest that these limiting densities may be used as a predictive or management tool.

<u>Growth Limiting Bulk Densities for Plants</u>

Several studies appear to support the concept of a growth-limiting bulk density (GLBD) that exists for a given soil texture or type. Daddow and Warrington (1983) computed GLBDs for 80 different soil textures using a regression equation. They next plotted the GLBDs on a USDA soil textural triangle in order to locate the growth-limiting isodensity lines as shown in Figure 3-1.

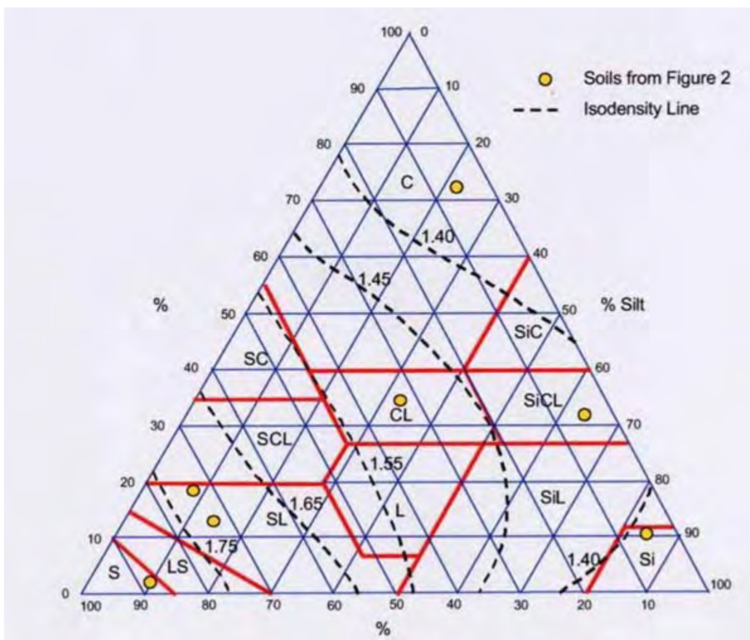


Figure 3-1. Growth-limiting bulk density textural triangle (adapted from Daddow and Warrington, 1983).

Other researchers have tried to relate bulk density to factors such as root penetration, soil strength, and compaction (see Table 3-2). As noted previously, well-graded, non-cohesive soils tend to reach higher maximum dry densities than cohesive soils. Additionally, non-cohesive soils exhibit higher critical dry density than cohesive soils. Coppin and Richards (1990) concur that the critical dry density depends on the soil texture and suggest values of about 1.4 g/cm (87 lb/ft) for clay soils and 1.7 g/cm (106 lb/ft) for sandy soils. These threshold values are within the intervals presented in Table 3-2.

Texture	Critical bulk density for soil resistance gm/cm^3 (lbs/in^3)	
	High	Low
Sandy	1.85 (115.5)	1.60 (99.9)
Coarse-loamy	1.80 (112.4)	1.40 (87.4)
Fine-loamy	1.70 (106.1)	1.40 (87.4)
Coarse-fine silty	1.80 (112.4)	1.30 (81.2)
Clayey	Depends on both clay percent and structure	

Table 3-2. Approximate Bulk Densities That Restrict Root Penetration (Handbook of Soil Science, 1999).

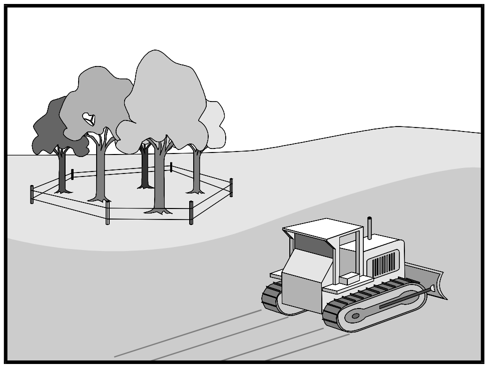
Rehabilitation of slopes may require "ripping" or "trackwalking" the compacted soil with heavy machinery or scarifying the soil by hand. Also see SS-1 Surface Roughening.

Clays contain more pore space than sandy soils, but have a much smaller average pore size. The pore size distribution controls water transmission, not total porosity. Sandy soils have large pores, while clays have small pores, which transmit water slowly. On the other hand, soils with small pores retain and hold moisture more effectively. Optimal conditions occur when there are enough large pores to transmit water readily, but also enough small pores to retain and store water; therefore, plants do better in well compacted, uniform, sandy soils with relatively low porosity (high relative density) or in well graded sands where sufficient fines (silts and clays) are present to provide moisture retention. The converse is true for clays. High porosity (low relative density) clay soils allow better infiltration and water transmission to plants than do highly compacted (high relative density) clay soils while at the same time providing good moisture retention and storage. It is important to emphasize again the importance of compaction on soil structure and pore size distribution in clay soils. Remember that compaction on the wet side of optimum can reduce hydraulic conductivity (and water transmission) of a clay soil by several orders-of-magnitude, even when the soil is compacted to the same dry density or relative degree of compaction (refer to Table 3-1).

4. EROSION PREVENTION (EP)

"Erosion Prevention" is defined here as "The best way to prevent erosion, address sedimentation, and thwart increased runoff in the first place." These preventative techniques should be the top priority for erosion control and include careful and considerate planning, design, scheduling, and environmental sensitivity.

Some examples of Erosion Prevention include:



- Retaining existing vegetation.
- Minimizing disturbance.
- Maintaining buffer strips.
- Scheduling land disturbances during periods of expected dry weather.
- Weather tracking.
- "Wet weather" road or trail closure.

Retaining existing vegetation and preserving a "buffer strip" along Corral Hollow Creek is a Best Management Practice (EP-3 Minimize Disturbance and Buffer Strip). (Carnegie SVRA)

Projects such as new road and trail construction should be phased (EP-1 Scheduling and Phasing) so DSAs don't exceed the ability to apply SS (Surface Stabilization) upon ensuing rainstorms. (Corral Hollow)

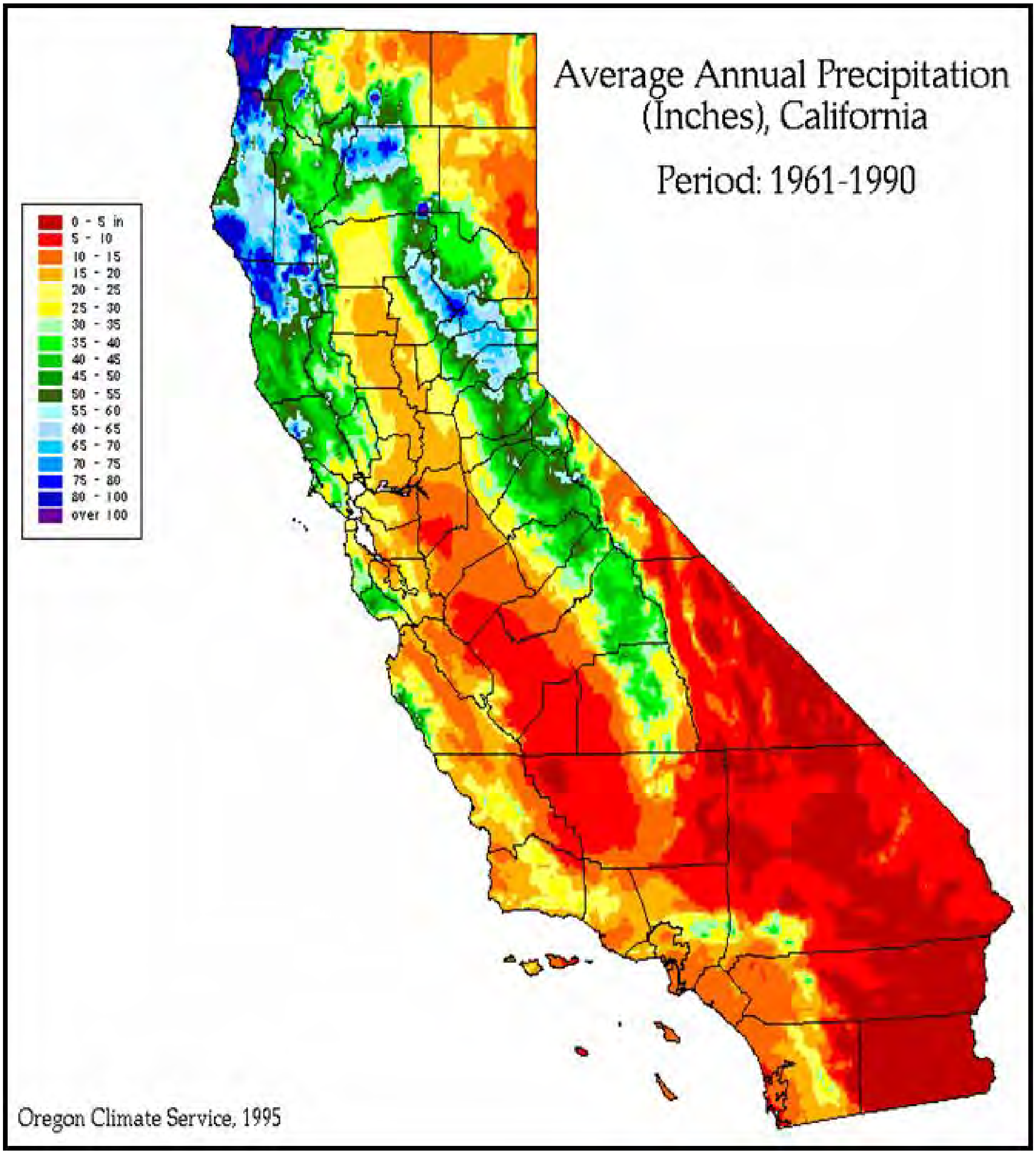
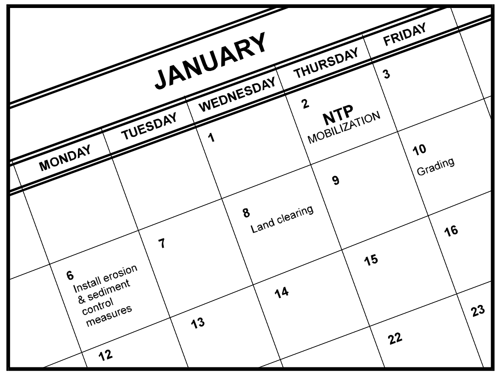


Figure 4-1. Average Annual Precipitation (Inches), California. (Oregon Climate Service, 1995)

EP-1 Scheduling and Phasing

SWPPP Summary



Construction, maintenance, rehabilitation, and restoration projects shall be scheduled and phased to reduce the amount and duration of soil exposed to erosion by wind, rain, runoff, and transport of sediment off-site (vehicle tracking). Project planners shall determine the rainy season and develop a list of candidate BMPs based on that information. Soil disturbing activities shall be phased, if possible, such that critical areas (such as highly erodible soils, areas adjacent to receiving waters, etc.) are not disturbed during the rainy season. If disturbance during the rainy season is unavoidable then the area shall receive an effective combination of soil stabilization and sediment control BMPs. Projects such as new road and trail construction shall be phased so the entire length of area that is disturbed at any one time is kept to a size that can be controlled effectively with appropriate BMPs as necessary. In the rainy season the DSA shall not exceed the Park staff's ability to promptly apply surface stabilization upon the immanent threat of an ensuing rainstorm.

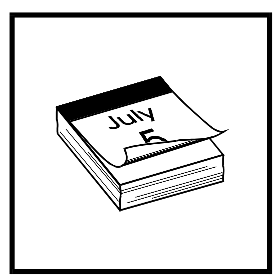
Definition / Purpose

EP-1 Scheduling and Phasing guides the Park on work to be done before other work is started so that serious erosion and sedimentation problems can be avoided. Road and trail projects can be scheduled during the dry season, or constructed in phases during the wet season in order to keep the amount of Disturbed Soil Areas (DSAs) at a minimum.

Following a specified work schedule that coordinates the timing of land-disturbing activities and the installation of control measures is perhaps the most cost-effective way of controlling erosion during construction or other soil-disturbing activities. The removal of surface ground cover leaves a site vulnerable to accelerated erosion.

Planning Considerations

Developing a schedule and planning the project are the very first steps in an effective storm water program. Consider BMPs with regard to rainfall probability, average annual rainfall, the designated rainy season.



For instance, the State of California General Construction Permit requires the use of an "effective combination" of soil stabilization and sediment control BMPs during the rainy season.

Construction Specifications

The construction schedule shall be incorporated into the SWPPP. The schedule shall clearly show how regional precipitation trends relate to soil-disturbing and re-stabilization activities. The schedule shall include detail on the implementation and deployment of BMPs specific to the project. A list of appropriate BMPs shall be designated for the rainy season if applicable.

- The optimum period for road, trail, and other construction projects is during the dry season. For soil-disturbing restoration projects which incorporate native vegetation, bioengineering, and/or biotechnical techniques the optimum time is in the Fall just prior to the wet season.
- If precipitation is likely during construction, maintenance, or restoration activities, minimize the length of time that soils are exposed, and the total area of exposure.
- Materials used for erosion and sediment control shall be on site, in sufficient quantities, at all times during the rainy season.
- Monitor the weather forecast for rainfall.
- Stabilize non-active areas after the cessation of soil-disturbing activities or prior to the onset of precipitation.
- Take the following measures when precipitation is forecast:
    1. Minimize the length of time that the soils are left exposed.
    2. Reduce the total area of exposed soil.
    3. Protect critical areas such as drainage channels, streams, and natural water courses.
    4. Stabilize exposed areas quickly and make sure sediment control measures are in place and functioning properly.
- Incorporate staged seeding and mulching of exposed soil as work progresses. In the rainy season the disturbed soil areas shall receive surface stabilization promptly.
- When the project goals include the establishment nursery-grown native plants or planted cuttings (i.e. restoration), scheduling the work near the beginning of the wet season (or during the wet season) will reduce plant mortality and improve success.
- During the dry season erosion may be caused by "freak" rainfall, wind, and vehicle tracking. Therefore, keep the site stabilized year-round, and maintain wet season sediment trapping devices.

Limitations

Project schedules are often modified due to the vagaries of construction contract bidding, availability of Park staff and equipment, ideal soil conditions for trail maintenance, delays in acquiring environmental permits, etc.

Inspection and Maintenance

Corrective actions will be taken if work does not progress according to the schedule. The schedule shall be amended when changes are warranted.

EP-2 Wet Weather Closure

SWPPP Summary

Wet weather closure is implemented to protect water quality, trail treads, road surfaces, and drainage facilities (rolling dips, outsloped road sections, etc.) from damage during wet weather. EP-2 also reduces maintenance costs and reduces the potential for adverse effects on other resources.

Definition / Purpose

Roads and trails get damaged in wet weather. OHVs can cause deep ruts and permanently damage the trail treads and BMPs, such as climbing turns or rolling dips, when the soils are saturated. OHV impacts during wet weather increases maintenance costs and compounds erosion and sedimentation problems. A Wet Weather Closure Plan will be instituted for OHV use during wet weather periods to reduce damage to roads and trails. The plan will allow for roads and trails to be open when soil conditions permit.

Road Closed

Temporary - Seasonal Closure Necessary to Protect Road and Trail Drainage Measures

The Rain Closure policy of the OHV Division General Plan indicates that temporary closures may be invoked "…during and after periods of significant rainfall." The OHV Rain Closure policy defines "extreme rainfall" as "rainfall in excess of 2 inches in a 24 hour period". The area will be reopened within 24 hours of the end of such a rainfall, unless additional rainfall continues.

Road and trail closures should be respected by park visitors. Closure signs will be placed at the entrance of roads and trails when wet weather closure has been determined. Visitors should be informed that violating these road and trail closure rules contributes to watershed degradation, road and trail damage, and dangerous riding conditions.

Motorized wet weather use can cause public safety and natural resource concerns in OHV parks. Trails may be closed during wet weather if it is determined that the ability of a rider to effectively maneuver is compromised. Trails and roads will also be closed to recreation riding when Park staff, in consultation with a CPESC, or as outlined in the Park Storm Water Management Plan, determine that OHV use will likely result in significant damage to the tread or road surface, threaten and negate drainage facilities, or result in high storm water discharges, sediment pollution, and downstream sedimentation.

Planning Considerations

Wet weather closure will be applied as determined by resource professionals with experience in erosion and sediment control, road and trail maintenance, and law enforcement after considering seasonal rainfall, geology, exposure, drainage patterns, etc.

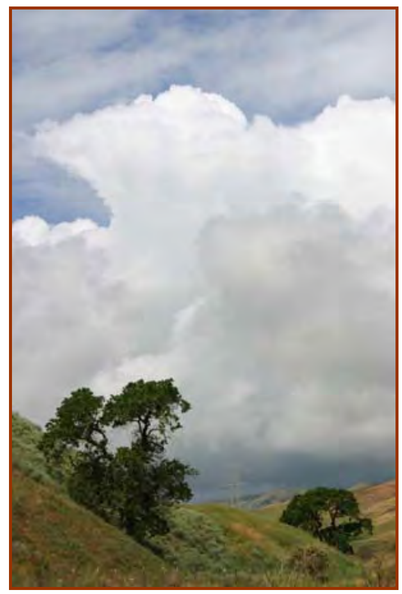
Public awareness and public information programs will be required. Park visitors should be encouraged to check on weather conditions before planning OHV trips.

A road and trail wet weather closure plan should be addressed in the SWMP (Storm Water Management Plan). The closure plan should be reached by the consensus of an interdisciplinary team of resource professionals, some with experience in erosion and sediment control, road and trail maintenance, law enforcement, Park management, etc. The ID team will consider seasonal rainfall, geology, exposure, drainage patterns, and downstream water quality impacts, etc.

Inspection and Maintenance

Park personnel should be on site during Wet Weather Closure to ensure rider compliance. Check closure signs and trail closure barriers to make sure they are not vandalized or damaged by wind. Check roads and trails for tracks and enforce as necessary.

- Inspect "closed areas" after storm events, especially when suspected unauthorized riding or access has occurred.
- Riders must keep out of the creek, especially in the rainy season months.
- The most important impacts that unauthorized seasonal use might cause is damage to the drainage facilities on the access roads, e.g., rolling dips, climbing turns, outsloped roads.
- Personnel should report such damage.



OHV park managers should keep track of storm fronts and implement EP-2 Wet Weather Closure plans when necessary.

EP-3 Minimize Disturbance and Buffer Strip

<u>SWPPP Summary</u>

EP-3 Minimizing Disturbance and Buffer Strip is a planning process which retains natural vegetative cover and also maintains vegetative buffer strips near watercourses. A healthy, dense and vigorous grassed buffer strip can greatly reduce the extent and need for alternative sediment control barriers such as silt fence and fiber rolls.

<u>Definition / Purpose</u>

Grading and other soil disturbance during construction, rehabilitation, or maintenance activities shall be kept to a minimum whenever possible, in order to minimize exposed soils and preserve native vegetative cover. Vegetated buffer strips shall be preserved and maintained in order to treat sheet flow from exposed riding areas, particularly near environmentally sensitive areas such as streams. Buffer strips shall be closed to rider access and riders shall be notified through signage, fencing, and/or rider education.

According to a 2002 Caltrans Study of highway shoulders, a 6 foot-wide grass buffer strip removed approximately 85% of pollutants and suspended sediment from contaminated highway runoff.

Erosion can be reduced 98% by protecting the soil from raindrop impact. Existing native vegetation usually provides the best soil protection. One of the most effective erosion control measures is to only disturb areas immediately needed for construction.

One of the best BMP strategies for OHV parks is maintaining a vegetated buffer between the open riding areas and streams. This buffer area is primarily grasslands with some shrubs and a few trees (Carnegie SVRA).

Water quality and wildlife habitat degradation can be greatly reduced by maintaining streamside buffer strips and riparian corridors. These buffer strips act to filter sediment, hydrocarbons, and other pollutants from the surface runoff before it reaches the watercourse. With preservation and maintenance, buffer strips can provide relatively high pollutant removal.

<u>Planning Considerations</u>

- Existing native vegetation and buffer strips should be incorporated into the project plan. It is adapted to the site, drought tolerant, and will provide shade and erosion protection.
- Existing trees should be protected.
- If the area is not disturbed then it does not require erosion control.

- Vegetated buffer strips around the perimeter of a site can reduce or eliminate off-site sedimentation. However, the composition of buffer strip and species type is important. Sediment and pollutant extraction is most effective when the vegetative buffer is comprised of grasses. Dense, rhizomatous grasses provide the best pollution reduction.

Construction Specifications

- Grading shall be planned so as to minimize the length of time between initial soil exposure and final grading.
- Designate native trees and shrubs that are to be preserved.
- Designate areas of no disturbance. Clearly show on the plans, and flag or fence off areas of no disturbance and construction equipment exclusion.
- Stockpiles, borrow areas and spoil areas shall be shown on the plans and shall be stabilized to prevent erosion and sedimentation.
- All graded or disturbed areas including slopes shall be protected during clearing and construction in accordance with the approved erosion and sediment control plan until they are permanently stabilized.
- All sediment control measures shall be constructed and maintained in accordance with the approved erosion and sediment control plan and according to the standards and specifications for the appropriate erosion control practices.
- Designate watercourse buffer-filter strips on the site design plan.
- Maintain and preserve riparian and naturally vegetated buffer strips along watercourses.
- The width of a buffer strip (i.e., flow path length) shall be maximized to the extent feasible with a 15 ft suggested minimum width. Buffer strips shall be sized in accordance with the site conditions.
- The width of a buffer strip between a road and the stream is recommended to be 50 feet plus four times the slope of the land in percent, measured between the road and the top of stream bank.

Example

For a 10% slope, buffer length is:

50 feet + (4)(10) = 90 feet.

- Buffer width in feet (m) = 50 + 4(% slope).
- Construction materials, equipment storage, and parking areas shall be located where they will not cause root compaction.
- Use mulch to stabilize areas temporarily where final grading must be delayed.
- Keep equipment away from trees to prevent trunk and root damage.
- Park staff, subcontractors, and Park visitors shall be instructed to honor protective devices (such as fencing).

- No heavy equipment, vehicular traffic, or storage piles of any construction materials shall be permitted within the drip line of any tree to be preserved.
- No toxic or construction materials (including paint, acid, nails, chemicals, fuels, or lubricants) shall be stored within 50 ft of the drip line of any preserved trees, nor disposed of in any way which would injure the vegetative buffers.
- Fires shall not be permitted within 100ft of the drip line of any preserved trees.
- Trenching shall be as far away from tree trunks as possible, usually outside of the tree drip line or canopy.

<u>Limitations</u>

- Buffer strips cannot treat a very large drainage area.
- A thick vegetative cover is needed for these practices to function properly.
- Buffer or vegetative filter length must be adequate and flow characteristics acceptable or water quality performance can be severely limited.
- Vegetative buffers may not provide treatment for dissolved constituents except to the extent that flows across the vegetated surface are infiltrated into the soil profile.
- This technology does not provide significant attenuation of the increased volume and flow rate of runoff during intense rain events.

Maintain and preserve riparian and naturally vegetated buffer strips along watercourses. The width of a buffer strip between a road and the stream is recommended to be 50 feet plus four times the slope of the land in percent, measured between the road and the top of stream bank.

<u>Inspection and Maintenance</u>

During construction, the limits of disturbance shall remain clearly marked at all times. Make sure signs and fencing have not become damaged or vandalized. If damage to protected trees still occurs, serious tree injuries shall be attended to by an arborist.

Buffer strips require very little maintenance. Maintenance includes some vegetation management, repair from any OHV damage, and inspection of barriers and signs preventing rider access. Buffers along Corral Hollow Creek should be inspected at least twice annually for erosion or damage to vegetation by OHVs, and the strip should be checked for debris and litter and areas of sediment accumulation.

Sediment and pollutant extraction is most effective when the vegetative buffer is comprised of grasses. Deep, rhizomatous grasses provide the best pollution reduction. (Corral Hollow Creek)

Maintaining buffers year-round is important for water quality. Natural vegetated buffer strips at Carnegie SVRA serve an important role as "bio-filters" and riders should not access buffer areas. (Corral Hollow Creek)

EP-4 Land and Road Grading to Minimize Erosion

SWPPP Summary

These land grading practices are intended to be integrated as construction and land disturbing activities are occurring in order to minimize the erosion potential and facilitate plant establishment. Roadways can be aligned following natural contours rather than up and down steep slopes. Natural drainage patterns shall be noted and maintained as possible. The lay-out of buildings and other Park facilities shall be tailored to fit the topography of the site. All graded or disturbed areas including slopes will be constructed in a manner that will facilitate the establishment of vegetation.

Definition / Purpose

This BMP requires the planners and construction crews to recognize the stable topographic features, long-established drainage patterns, and to establish goals for vegetation establishment. By fitting the new facilities, road, or trail to the existing topography as much as possible then, land disturbance and erosion potential is minimized. By acknowledging that vegetation establishment may be the goal for the critical disturbed soil area, construction techniques can be employed to facilitate, e.g., steps, benches, ripping, or track walking.

Planning Considerations

Design considerations should include the following:

- Existing contours
- Natural drainage patterns
- Land use
- Vegetation
- Soil
- Drainage
- Slope stability
- Slope length
- Slope angle
- Space limitations
- Erosion potential of land disturbance
- Erosion and sediment control measure practicality

Construction of new SVRA trails should cause minimal disturbance by following natural land contours. (Carnegie SVRA)

Slope steepness and excessive slope lengths should be kept to a minimum. Benches, steps, or contour furrows can be installed on long slopes to break up the slope length (see Figure 4-3). Benches, steps, or contour furrows are used, in these instances, to break up slope length, not provide drainage.

However, drainage (run on) from upland areas, roadways, or other facilities must be diverted away from exposed slopes. The use of diversion dikes, fiber rolls, compost berms, and/or temporary overside drains may be necessary during construction.

Construction Specifications

- If the construction area has healthy vegetation, free of noxious weeds, consider the careful removal and set aside of topsoil and duff. Reapplication of these materials can reduce erosion and greatly promote native plant establishment.
- Areas to receive topsoil shall be scarified to a minimum depth of 3 inches (76 mm) prior to placement of topsoil.
- All fill intended to support buildings, structures, conduits, etc., shall be compacted in accordance with local requirements or codes. However, the non-structural outer soil layer should not be compacted greater than 80-90% to encourage vegetation establishment, increase infiltration rates and provide surface roughness.
- The outer face of the fill slope should be allowed to stay loose, not rolled, compacted, or bladed smooth. A bulldozer may run up and down the fill slope so the dozer treads (cleat tracks) create grooves perpendicular to the slope. If the soil is not too moist, excessive compaction will not occur.
- Use slope breaks, such as diversions, benches, or contour furrows as appropriate, to reduce the length of cut-and-fill slopes to limit sheet and rill erosion and prevent gully erosion.
- The unreinforced cut-and-fill slopes, which are to be vegetated with grass, should not be steeper than 2:1. Slopes reinforced with VMSE (*Vegetated Mechanically-Stabilized Earth*) can be built and vegetatively stabilized at a much steeper angle.
- Slopes to be maintained by tractor or other equipment should not be steeper than 3:1.
- Roughen the surface of all slopes during the construction operation to retain water, increase infiltration, and facilitate vegetation establishment (see Figure 4-2). Also refer to SS-1 Surface Roughening.
- Seeps or springs encountered during construction shall be avoided for fill disposal but these areas can provide opportunities for biotechnical erosion control
- Stockpiles, borrow areas and spoil areas shall be shown on the plans and shall be stabilized to prevent erosion and sedimentation.

Inspection and Maintenance

Any sign of rill or gully erosion shall be immediately investigated and repaired as needed.

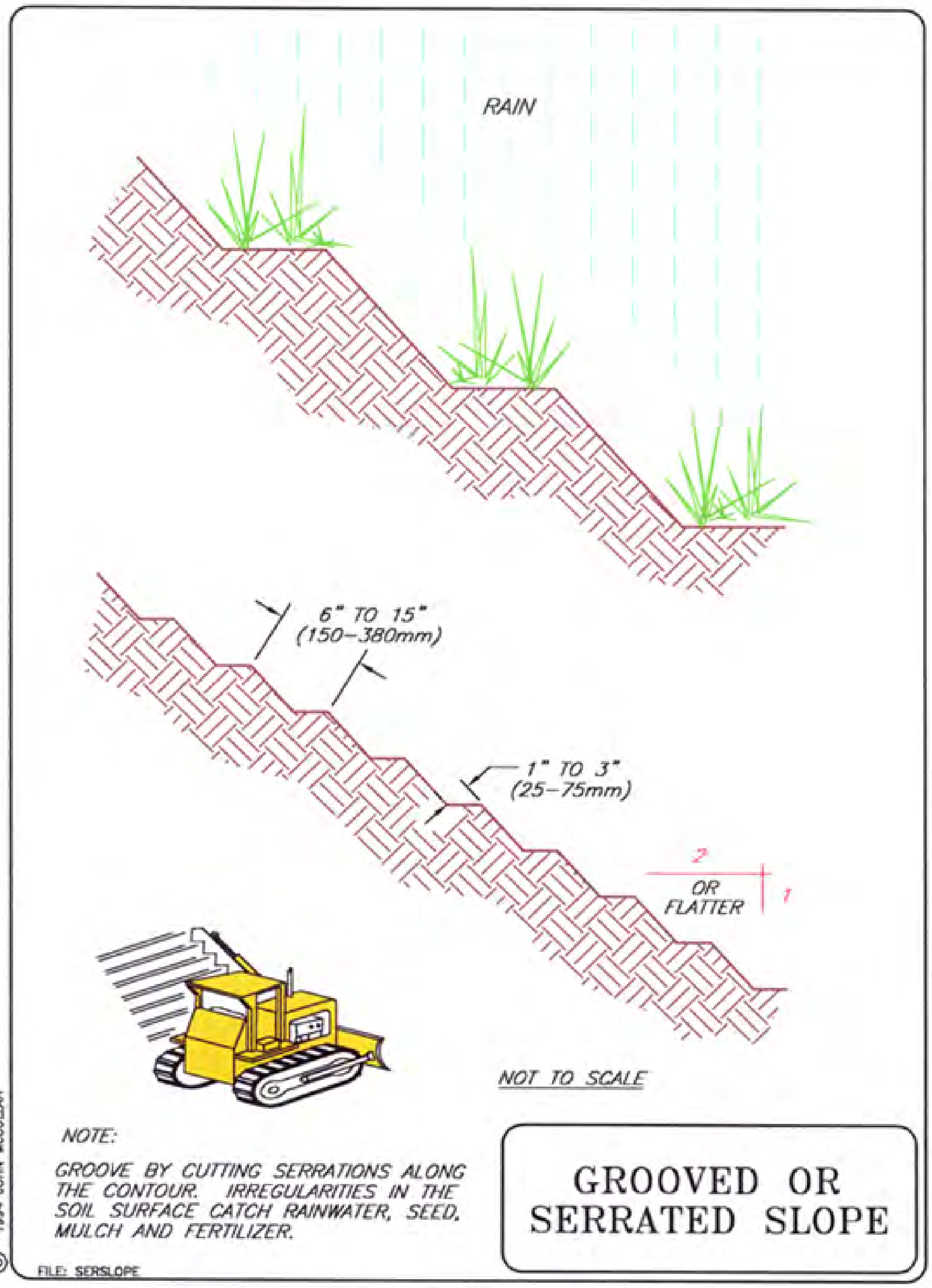


Figure 4-2. Grooved or Serrated Slope.

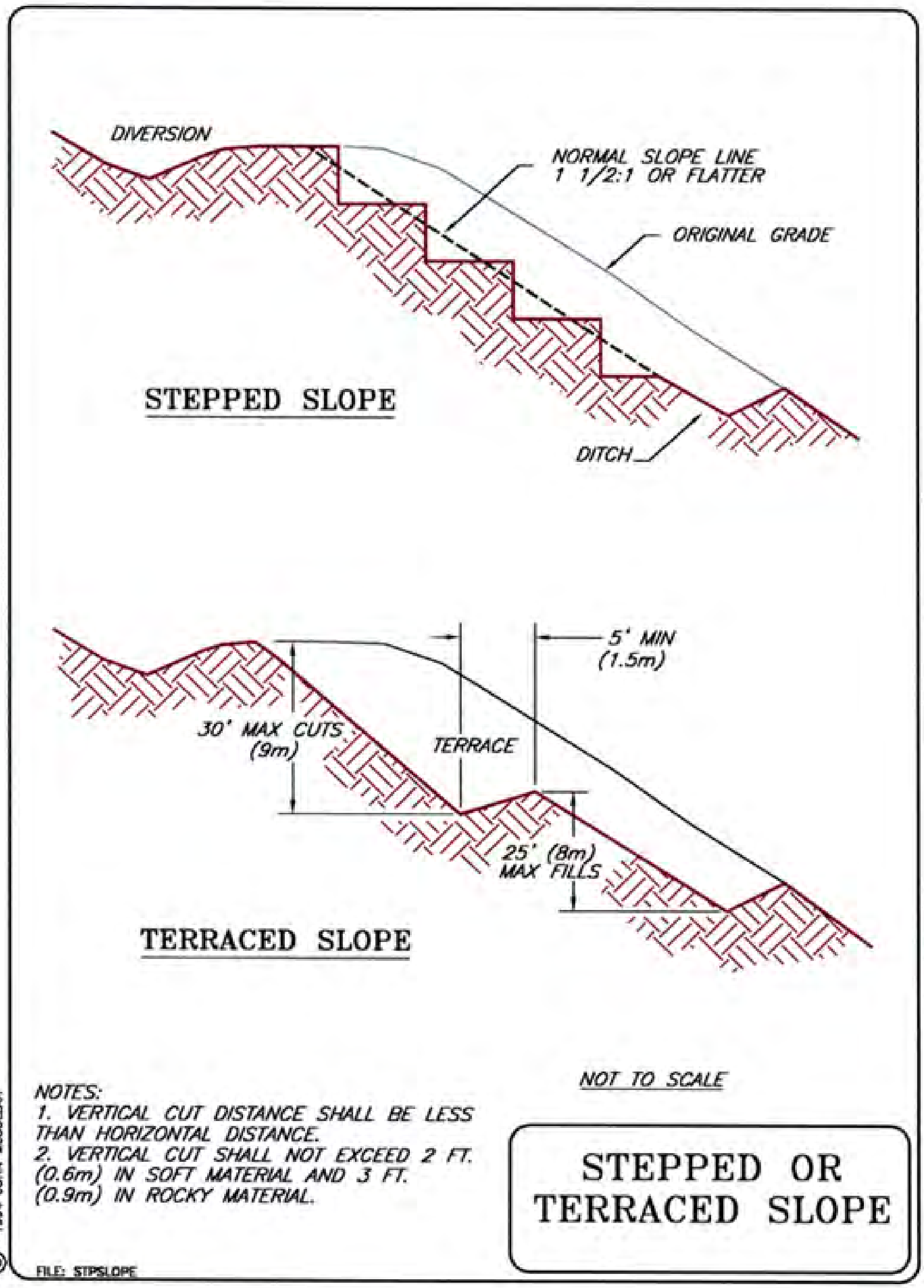


Figure 4-3. Stepped or Terraced Slope.

EP-5 Identify Underlying Geologic Soil Conditions

SWPPP Summary

Soil survey data shall be reviewed and analyzed prior to new construction projects at the park. Erosion control measures will be properly chosen, located, and implemented in accordance with soil types. Roads and trails will be located where soils are the least erosive, whenever possible. Soil maps are useful for planning but not for site-specific purposes, so actual onsite review will also be performed.

Having a broad understanding of the soil attributes will help team members design trails and roads that will incorporate soil resource objectives.

Definition / Purpose

Soil survey data can help with future trail planning and erosion prediction. Soils which contain high proportions of silt and fine sands are more vulnerable to erosion. The most important factors which affect the potential for soil erosion include: soil particle size, soil structure, soil permeability, and percentage of organic content. Vegetation cover, slope, and hydrology are also important considerations which affect the potential erodibility of soil.

Planning Considerations

Soil type, parent material, and underlying geology have a significant influence on erosion. Knowledge of the structural properties of the soil is important for assessment of the global stability, e.g., how steep can the slope be built, or how erosive is it. Cohesive soils can be built steep but may slump and fail if over saturated, whereas granitic soils may have little cohesion and cannot withstand steep angles without reinforcement. The soil properties also ultimately effect the vegetation establishment, thus the ultimate stability of the DSA. Infiltration rates, porosity, cation exchange capacity, water holding capacity are a few important planning considerations effected by the soil conditions.

Some important soil properties and conditions that should be considered:

- Soil texture
- Cohesion
- Infiltration rates
- Porosity
- Water holding capacity
- Cation exchange capacity (fertility)

The use of soil amendments may be required but the amount and type will vary. Consult a knowledgeable soil scientist, CPESC, or native plant specialist for specific recommendations prior to construction.

The addition of composted materials to adverse soils has had measured success on difficult soils (decomposed granite, serpentine, etc.) in California. Refer to "Effective Compost and Bioengineering Techniques for Adverse Soil Conditions", *IECA-EC05 Proceedings* (2005), McCullah, J., Dettman, K., & Claassen, V., and also "Compost and Vegetation Applications to Stabilize a City Burn Dump", *IECA-EC06 Proceedings* (2006), Dettman, K., & McCullah, J.

The adverse soil on this decomposed granite slope was stabilized by using a 25% compost mix.

Construction Specifications

- Discuss and understand the underlying soil conditions before beginning construction.
- Consult known geologic and soils maps and references (for more information refer to the Corral Hollow Watershed Assessment, Section 9 "Soils and Geology" (2007), the CARC Draft of the Soil Conservation Guidelines/Standards for OHV Recreation Management (2005), and the Geology and Soils Index (compiled by CGS). The Natural Resources Conservation Service (NRCS) has established a classification system to describe the potential hazard for off-road or off-trail erosion for specific soil types. However, this system does not take into consideration compaction and surfacing of trails, or many of the Best Management Practices in this Manual, and should be used cautiously as it represents the worst-case scenario for hazard ratings.
- Avoid construction of roads, trails, and facilities on unstable areas and in areas of very high erosion hazard ratings, especially those adjacent to watercourses.

Limitations

If sensitive areas cannot be avoided, seek technical input from qualified technical experts. Develop specific measures to minimize the effects of operations on slope stability and erosion. Explain and justify these measures in the project plan and SWPPP.

5. SURFACE STABILIZATION (SS)

"Surface Stabilization" (aka Erosion Control) as described here is any practice that protects the soil from raindrop impact, enriches, or establishes vegetation on disturbed soil surfaces and prevents the exposed soil particles from being detached by rainfall or wind. Surface Stabilization, therefore, is a source control that treats the soil as a resource that has value and should be kept in place.

The most efficient and economical method of controlling sheet, rill and raindrop impact erosion is to establish vegetative cover from seed. Vegetation can reduce erosion by more than 90% by protecting the soil from raindrop impact and sheet erosion.

Raindrop impact.

When Surface Stabilization BMPs are implemented and maintained, the amount of sediment associated with runoff waters can be dramatically reduced. *Whenever possible do Erosion Prevention first, Surface Stabilization second, and Sediment Control third, if needed.* Some important points to remember:

- Re-establishing vegetative cover is the primary surface stabilization practice.
- Establishing cover immediately after disturbance (staging) is important.
- Temporary erosion control is usually achieved by seeding with fast growing annual grasses, or planting native grasses with the appropriate Surface Stabilization, and/or just protecting the soil with mulch (SS-5 Straw Mulching).
- Permanent erosion control usually involves planting native grasses, native plants, and trees.

Raindrop impact on unprotected surfaces detaches soil particles, making them more susceptible to erosion and transport off-site (and into waterways).

SS-1 Surface Roughening

SWPPP Summary

After final grading of all construction, rehabilitation, and restoration projects, a rough texture shall be applied to the disturbed soils to prevent erosion, decrease runoff, increase infiltration, and aid in vegetation establishment. SS-1 Surface Roughening is a technique for roughening a bare soil surface with furrows running across the slope, stair stepping, or tracking with construction equipment.

Definition / Purpose

Surface roughening is intended to aid the establishment of vegetative cover from seed, to reduce runoff velocity and increase infiltration, and to reduce erosion and provide for sediment trapping.

Planning Considerations

All constructed slopes require surface roughening to facilitate long-term stabilization with vegetation, particularly slopes steeper than 3:1. Graded areas with smooth, hard surfaces may be initially attractive, but such surfaces increase the potential for erosion. A rough, loose soil surface gives a mulching effect that provides more favorable moisture conditions than hard, smooth surfaces; this aids seed germination.

There are different methods for achieving a roughened soil surface on a slope, and the selection of an appropriate method depends upon the type of slope. Roughening methods include stair-step grading, furrowing, and tracking. Factors to be considered in choosing a method are slope steepness and whether the slope is formed by cutting or filling.

Construction Specifications

Trackwalking has been proven to be 52% effective in reducing surface erosion!

- SDSU Erosion Control Laboratory

Cut Slope Roughening:

- Stair-step grade or groove the cut slopes that are steeper than 3:1.
- Use stair-step grading on any erodible material soft enough to be ripped with a bulldozer. Slopes consisting of soft rock with some subsoil are particularly suited to stair-step grading.
- Make the vertical cut distance less than the horizontal distance, and slightly slope the horizontal position of the "step" in toward the vertical wall.
- Do not make individual vertical cuts more than 2 feet high in soft materials or more than 3 feet high in rocky materials.
- Groove the slope using machinery to create a series of ridges and depressions that run across the slope, on the contour.

Fill Slope Roughening:

- Place fill slopes with a gradient steeper than 3:1 in lifts not to exceed 8 inches, and make sure each lift is properly compacted.
- Ensure that the face of the slope consists of loose, uncompacted fill 4-6 inches deep.
- Use grooving or tracking to roughen the face of the slopes, if necessary.
- Apply seed, fertilizer and straw mulch then track or punch in the mulch with the bulldozer.
- Do not blade or scrape the final slope face.

Tracking (also referred to as "trackwalking") creates horizontal depressions in the soil which catch seed, rainfall, and reduce runoff.

Cuts, Fills, and Graded Areas:

- Roughen these areas to shallow grooves by normal tilling, disking, or harrowing. Make the final pass of any such tillage on the contour.
- Make grooves formed by such implements close together (less than 10 inches, and not less than 1 inch deep).

Roughening With Tracked Machinery:

- Operate tracked machinery up and down the slope to leave horizontal depressions in the soil. Do not back-blade during the final grading operation.
- Immediately seed and mulch roughened areas to obtain optimum seed germination and growth.

<u>Limitations</u>

SS-1 Surface Roughening is not a stand-alone practice – it must be used in conjunction with other erosion and sediment control measures, such as seeding and mulching.

<u>Inspection and Maintenance</u>

Periodically check the seeded slopes for rills and washes. Fill these areas slightly above the original grade, then reseed and mulch as soon as possible. Maintenance needs identified in inspections or by other means should be accomplished before the next storm event, if possible, but in no case more than seven days after the need is identified.

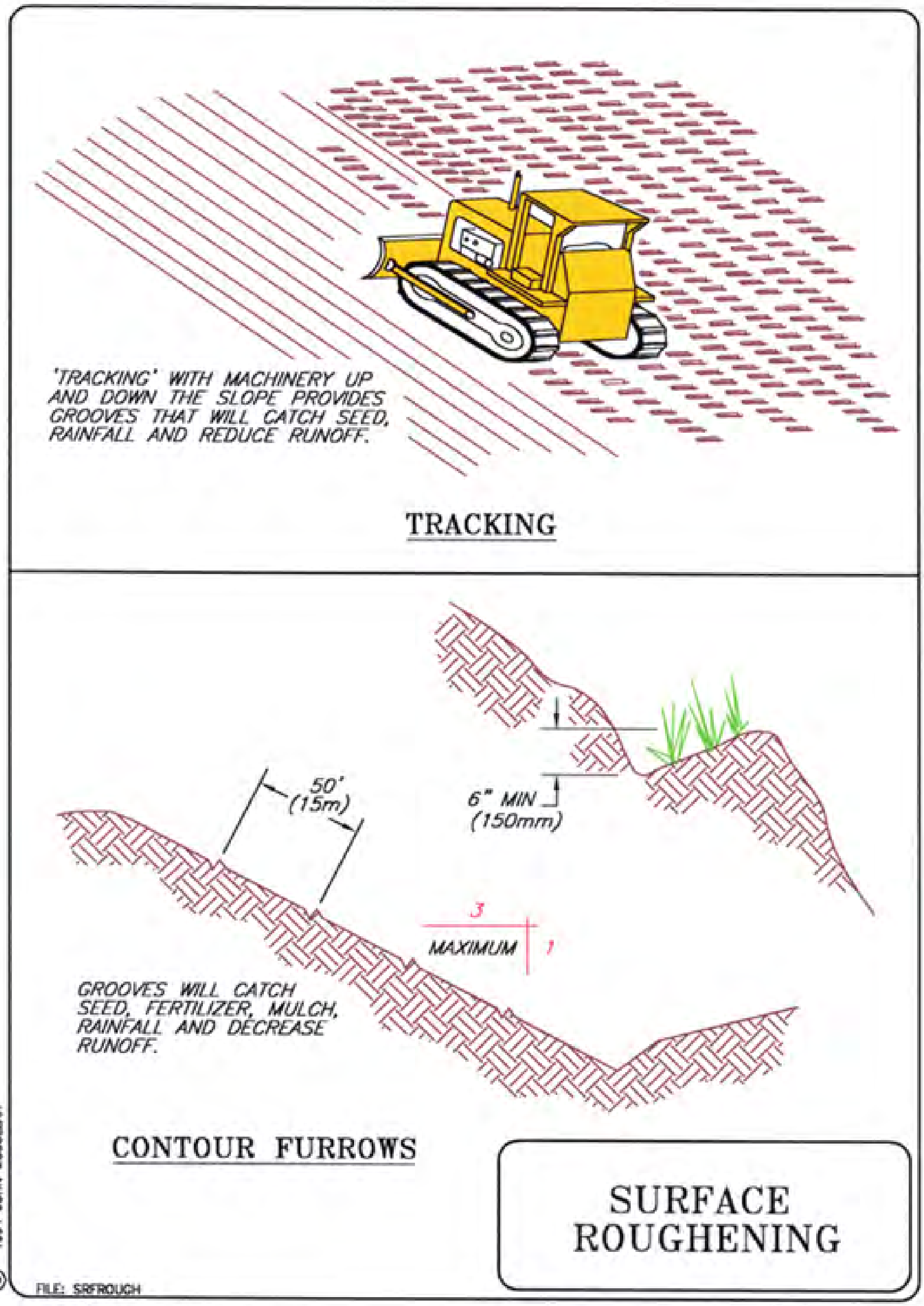


Figure 5-1. Surface Roughening.

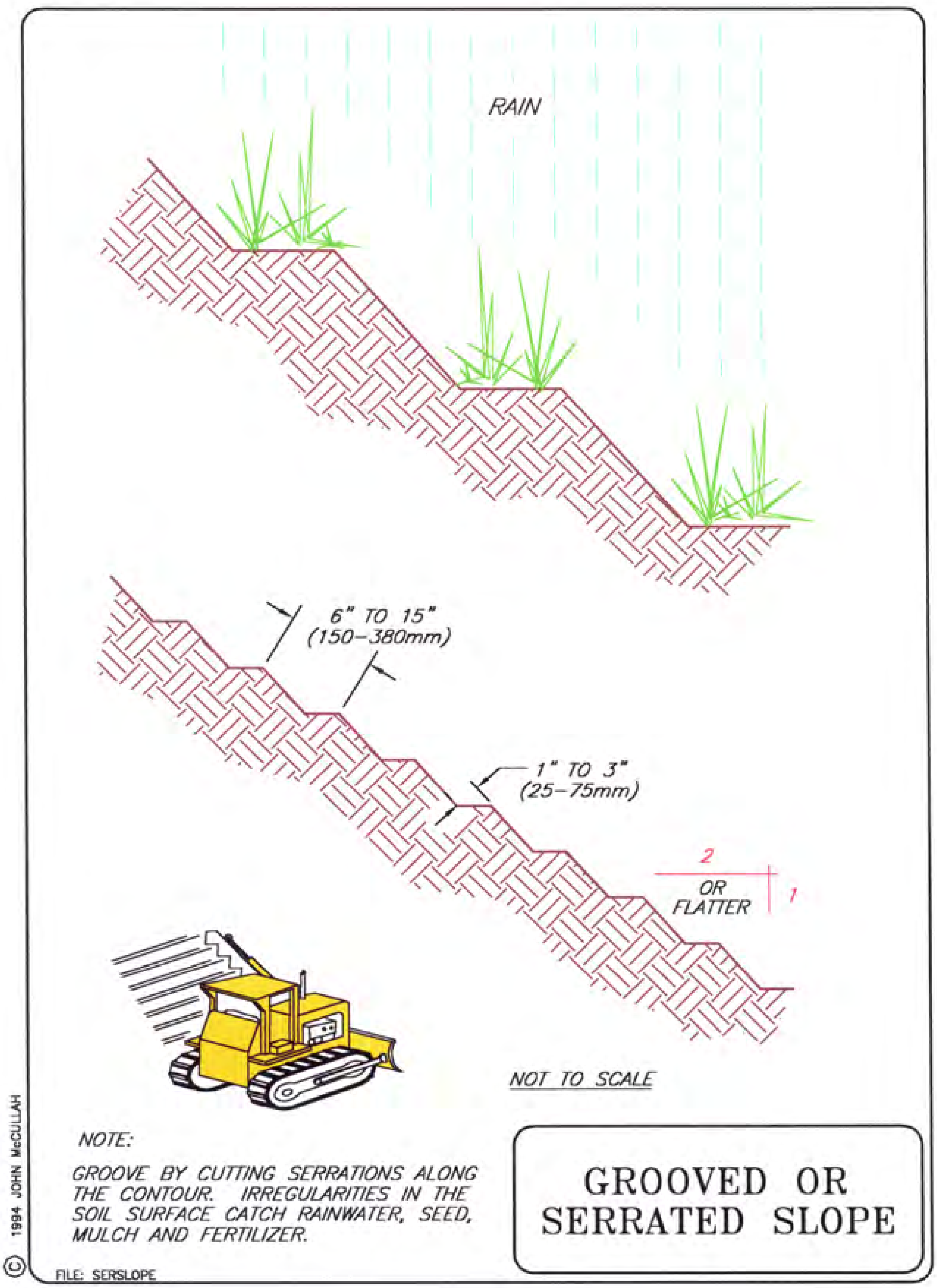


Figure 5-2. Grooved or Serrated Slope.

SS-2 Topsoiling

SWPPP Summary

Topsoil shall be preserved to help provide a suitable growth medium for final site stabilization with vegetation. Topsoil shall be preserved in the Park by stripping the topsoil during facilities development and road and trail-building activities and setting aside in stockpiles for later re-application.

Topsoil is enriched with organic matter and makes an excellent growth medium. It should be set aside during ground-disturbing projects whenever possible and saved for later soil stabilization applications.

Definition / Purpose

Topsoiling is the placement of topsoil over disturbed lands to provide a suitable soil medium for vegetative growth and a supply of native or locally occurring seeds. Topsoil is the surface layer of the soil profile, generally characterized as darker than the subsoil due to enrichment with organic matter. It is the major zone of root development and biological activity. Microorganisms that enhance plant growth thrive in this layer. Topsoil can usually be differentiated from subsoil by texture as well as color. Clay content usually increases in the subsoil. The depth of topsoil may be quite variable. On severely eroded sites it may be gone entirely.

Advantages of topsoil include its high organic-matter content and friable consistency (soil-aggregates can be crushed with only moderate pressure), and its available water-holding capacity and nutrient content. Most often it is superior to subsoil in these characteristics. The texture and friability of topsoil are usually much more conducive to seedling emergence and root growth.

In addition to being a better growth medium, topsoil is often less erodible than subsoils, and the coarser texture of topsoil increases infiltration capacity and reduces runoff. It may also be required to establish vegetation on shallow soils, soils containing potentially toxic materials, stony soils, and soils of critically low pH (high acidity).

Planning Considerations

Topsoiling is applicable where a sufficient supply of quality topsoil is available, and where the subsoil or areas of existing surface soil present the following problems:

- The structure, pH, or nutrient balance of the available soil cannot be amended by reasonable means to provide an adequate growth medium for the desired vegetation;
- The soil is too shallow to provide adequate rooting depth or will not supply necessary moisture and nutrients for growth of desired vegetation;
- Existing soil contains substances toxic to the desired vegetation.

- Where it may be desirable to try to establish native, indigenous grasses, and shrubs from the seeds "banked" in the topsoil.
- Where slopes are 2:1 or flatter.

If topsoiling is to be used, also consider the following:

- Quality of topsoil available and amount of topsoil needed.
- Location for a stabilized stockpile site that will not erode, block drainage, or interfere with work on the site.

Do not apply topsoil to slopes steeper than 2:1 to avoid slippage, nor to a subsoil of highly contrasting texture. Sandy topsoil over clay subsoil is a particularly poor combination, especially on steep slopes. Water may creep along the junction between the soil layers and cause the topsoil to slough.


Whiskeytown NRA staff collected duff (decaying leaves covering the forest floor) to help stabilize and revegetate slopes along a rehabilitated access road. Utilizing topsoil and duff from the project area helps reestablish native plants because the organic matter contains native seeds. (Whiskeytown National Recreation Area, 2007)

Construction Specifications

Scarify subsoil to a minimum depth of 3 inches before placing topsoil. If topsoil and subsoil are not properly bonded, water will not infiltrate the soil profile evenly, and it will be difficult to establish vegetation.

- Determine whether the quality and quantity of available topsoil justifies selective handling.
- Soils of the textural class of loam, sandy loam, and silt loam are best; sandy clay loam, silty clay loam, clay loam, and loamy sand are fair. Do not use heavy clay and organic soils such as peat or muck as topsoil.
- Strip topsoil only from those areas that will be disturbed by excavation, filling, road building, or compacting by equipment. A 4-6 inch stripping depth is common, but depth varies depending on the site.

- Determine depth of stripping by taking soil cores at several locations within each area to be stripped. Topsoil depth generally varies along a gradient from hilltop to toe of the slope.
- Put sediment traps, diversions, and other controls into place before stripping.
- Select stockpile location to avoid slopes, natural drainage ways, and traffic routes. On large sites, re-spreading is easier and more economical when topsoil is stockpiled in small piles located near areas where they will be used.
- Use silt fences, fiber rolls, or other barriers where necessary to retain sediment.
- Protect topsoil stockpiles by temporarily seeding and/or mulching as soon as possible to assure the stored material is not exposed and allowed to erode.
- If stockpiles will not be used within 12 months they must be stabilized with permanent vegetation to control erosion and weed growth.
- Before spreading topsoil, establish erosion and sedimentation control practices such as diversions, berms, dikes, waterways, and sediment basins.
- Where the pH of the existing subsoil is 6.0 or less, or the soil is composed of heavy clays, incorporate agricultural limestone in amounts recommended by soil tests or specified for the seeding mixture to be used. Incorporate lime to a depth of at least 2 inches by disking.
- Immediately prior to spreading the topsoil, loosen the subgrade by disking or scarifying to a depth of at least 3 inches, to ensure bonding of the topsoil and subsoil. If no amendments have been incorporated, loosen the soil to a depth of at least 6 inches before spreading topsoil.
- Uniformly distribute topsoil to a minimum compacted depth of 2 inches on 3:1 slopes and 4 inches on flatter slopes.
- Do not spread topsoil while it is muddy or when the subgrade is wet.
- Correct any irregularities in the surface that result from topsoiling or other operations to prevent the formation of depressions or water pockets.
- Compact the topsoil enough to ensure good contact with the underlying soil, but avoid excessive compacting, as it increases runoff and inhibits seed germination.
- The surface may be left rough after spreading topsoil. A disk may be used to promote bonding at the interface between the topsoil and subsoil.

Limitations

Although topsoil may provide an improved growth medium, there may be disadvantages, too. Stripping, stockpiling, hauling, and spreading topsoil, or importing topsoil may not be cost-effective. Handling may be difficult if large amounts of branches or rocks are present, or if the terrain is too rough.

Be careful not to apply topsoil over a subsoil of contrasting texture. For instance, a clay-like topsoil placed over a sandy soil may cause the topsoil to slough as water flows between the two soil layers of different permeability.

Inspection and Maintenance

Periodically and after major storm events, inspect, repair, and reseed as necessary to control slope erosion and subsequent topsoil losses.

SS-3 Mycorrhizae Inoculation

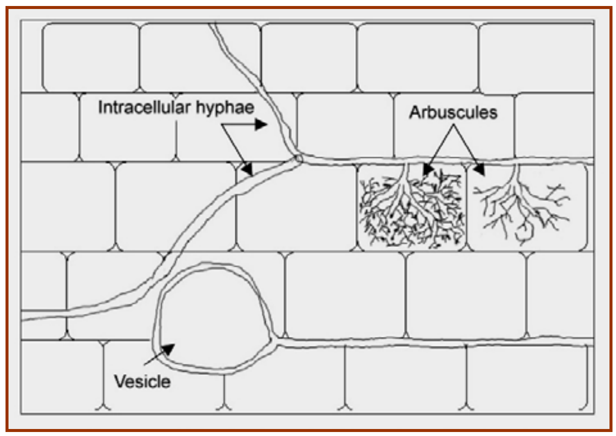
SWPPP Summary

Mycorrhizal fungi and "biofertilizers" shall be used in construction and revegetation projects in order to enhance soil nutrient availability and biological soil structure, encourage native plant succession, reduce erosion, and discourage invasive plant species. Inoculation of soils with mycorrhizal fungi or the presence of pre-existing soil microbes is essential for the stabilization of adverse soils, establishment of native grasses, and the exclusion of non-native "annuals" and noxious weeds.

Definition / Purpose

Mycorrhizae means "fungus root." The most common mycorrhizae grow inside the cells of roots. These are called endomycorrhizae ("endo" means inside). Many of these endomycorrhizae form tiny trees and little sacs inside root cells. These tiny trees, called *arbuscules* (Latin for "tree") and tiny sacs, called *vesicles* ("little sacs") are connected to long threads of the mycorrhizae that lead out into the soil. These long threads, called *hyphae*, are analogous to the roots of plants. These hyphae extend beyond the length of roots, and allow the roots to absorb more nutrients than they would without the help of the fungus.

Mycorrhizae then have *symbiotic* associations between native plants and soil fungus. In this association, the fungus extends itself into the soil and helps the plant by gathering water and nutrients, such as phosphorus and nitrogen. In return, the plant helps the fungus by giving it sugar produced by photosynthesis. This is an example of symbiosis, a win-win association.



The endomycorrhizae, arbuscular mycorrhizae (AM), form little sacs, tree roots, and hyphae inside the plant root cells. The hyphae extend outside into the soil, which conducts nutrients and provides soil stability.

Biofertilizers and mycorrhizae are very important to any revegetation effort, as they help to rebuild the living soil that can get damaged by any earthwork or OHV impacts. Most desirable species will have a very difficult time out-competing weeds without mycorrhizae, or the slowly released nutrients provided by biofertilizers.

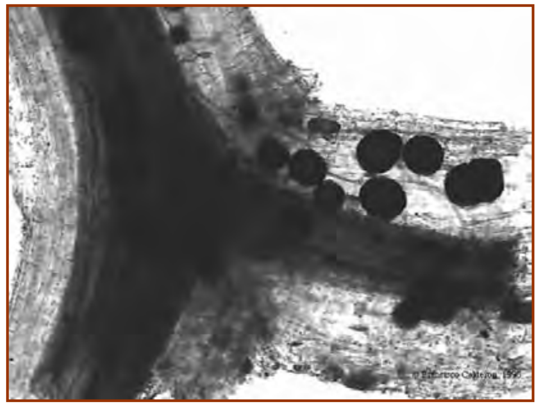
Planning Considerations

Mycorrhizae allow plants to live in harsh and adverse sites that are poor in nutrients, such as disturbed soil areas associated with road-sides, off-highway recreation, or mining operations. In these nutrient-poor soils, mycorrhizae can help plants to live where they otherwise might die.

Construction or repetitive soil disturbance can degrade the soil's physical structure along with the biotic function of the vegetative and microbial community (Vogelsang et al., 2004).

Arbuscular mycorrhizal (AM) fungi represent a major component of the soil biota thought to be lost as a direct consequence of various road construction activities. AM fungi are soil-dwelling organisms that form obligate symbiotic relationships with plants, and generally improve plant performance by providing greater access to limiting soil nutrients such as phosphorus.

Additionally, research indicates that the lack of mycorrhizae and other natural soil microbes is one of the major reasons for the invasion of non-native exotic annuals and weeds. Native plants have a much stronger relationship with mycorrhizae ("mycorrhizal obligate") than weedy exotic plants. Reintroducing lost or missing soil microorganisms is increasingly recognized as an effective strategy for promoting cover of desirable plant species.



This micrograph shows arbuscules as they appear in the plant roots of California sagebrush.

The best way to be sure that you have appropriate mycorrhizal levels in your soil is to get a soil sample analyzed for mycorrhizal presence.

Moreover, the establishment of both AM fungi and native plants acts synergistically to stabilize the soil. Studies have found that AM fungi, in association with a native host, can significantly increase the proportion of water-stable soil aggregates. After the establishment of soil cover, a major determinant of the erodability of soil is the stability of soil aggregates to wetting.

The greater the proportion of the soil held with water-stable aggregates (WSA), the more resistant soil is to erosion (Lundekvam and Skoien, 1998). Soil particles are formed into WSA through the combined effects of entanglement by roots and fungal hyphae and the cementing effect of plant and fungal exudates. Mycorrhizal fungi can be particularly important to this process because AM fungal hyphae are abundant in California grasslands and shrublands (Klironomos et al., 1996, Rillig et al., 1999), and because AM fungi secrete a sticky and highly resistant substance (a glycoprotein) known as glomalin. This chemical has been shown to be very important in soil aggregation (Wright and Upadhyaya, 1998). Because of these processes, AM fungi have been shown to be at least as important, if not more important to WSA formation than other soil properties.

The Use of Mycorrhizal Fungi in Erosion Control Applications (Vogelsang et al., 2004) disclosed three major findings:

- Native plant species tended to have higher cover with mycorrhizal inoculation.
- Soil aggregate stability also increased with mycorrhizal inoculation.
- Soil aggregate stability also increased with the establishment of native plant species.

Biofertilizers:

Commercial chemical fertilizes can favor the establishment of annual and non-native species of grasses. This advantage comes at the cost of the establishment of the native perennial species so desired. Native grasses, especially in California, have adapted to low concentrations of nutrients. Because of their symbiotic relationship with mycorrhizal fungi, native grasses can extract nutrients from the soil very efficiently. In fact, if there are sufficient carbon content and appropriate soil microorganisms available in the soil, the native grasses could very likely establish without having to give advantage to the noxious weeds – by adding chemical fertilizers. If fertilizers are added, they should be in the form of "biofertilizers" or certified compost (see SS-7 Compost Blankets).

These native seeds were coated with mycorrhizae (an alternative to applying mycorrhizae directly to the soil).

Biofertilizers are fertilizers containing living microorganisms, which increase microbial activity in the soil. They also contain low concentrations of soluble nutrients, especially N. So, organic food is often included to help the microbes get established.

Important functions of soil microbes:

- Convert ambient nitrogen into forms that the plants can use (Nitrate and Ammonia),
- Increase soil porosity by gluing soil particles together.
- Defend plants against pathogens by out-competing pathogens for food.
- Saprophytic fungi in the soil break leaf litter down into usable nutrients.

The high soil porosity (large spaces between soil particles) caused by microbes is important, because it aids water infiltration. If pore spaces are too small, they cannot break the surface tension of a water droplet, and water will run off, instead of saturating the soil, where it can be taken up by plant roots.

Chemical fertilizers are often over-applied, and end up polluting the water because they are not used up. The chemicals are less expensive in the short term, but must be continuously reapplied, and are therefore more expensive over the long-term.

Relationships Between Biofertilizers and Mycorrhizal Fungi:

For the establishment of California native grasses and shrubs in adverse soil conditions, it is necessary that the appropriate mycorrhizal fungi be present in the soil, or commercial mycorrhizal fungi should be added live at the time of construction.

Plant roots secrete "food" for bacteria and fungi, which attracts nematodes (worms) to the roots, because nematodes eat bacteria and fungi, and excrete Nitrogen, Sulphur and Phosphorus in a form that the plants can use (URS, 2001). The nematodes only keep 1/6 of the nitrogen that they process – 5/6 is excreted to the plant. Once the nematodes have excreted the nutrients, the hyphae of the mycorrhizal fungi pick them up and transfer them into the plant. Because of this symbiotic relationship, the least-leachable form of Nitrogen you can apply is bacteria and fungi, and bacteria are the most Nitrogen-rich organisms on earth (URS, 2001).

AM hyphae pick up more nutrients than just those excreted by nematodes, however. One of the most beneficial properties of AM mycorrhizae is its ability to "mine" the soil great distances from the roots for nutrients, especially those, such as Phosphorus, that are poorly mobile in the soil. AM Mycorrhizae also assist in picking up water further away from the roots, and block pest access to roots (Peters, 2002).

Construction Specifications

Endomycorrhizae should be applied at a rate of 3,600,000 propagules per acre (8,900,000 propagules per hectare), which equates to 60 lbs per acre or 1.4 lbs/1000 ft2 , assuming the standard 120 propagules/cc. Mycorrhizae is most frequently applied via hand seeding, seed drilling, hydroseeding, broadcast and till, planting, or as a nursery medium. AM-120 is a commercial product where the fungal spores are attached to a "kitty litter" type medium for easy broadcasting. It is a good idea to get the mycorrhizal spores into the soil so plant roots can contact them. Shallow tilling or broadcasting while the soil surface is loose and friable has worked successfully (McCullah, 2007). Grass seeds pre-coated with mycorrhizae have also been applied successfully.

If installing container plants, packets of mycorrhizae (such as RTI's MycoPaks) may be planted along with the plant, at a rate of 1 packet per foot of plant height or container width (RTI, 2003).

Inspection and Maintenance

No maintenance should be necessary, although if plants do not appear to be growing vigorously, analysis of mycorrhizal density in the soil can help to determine if you need to apply more.

SS-3 Mycorrhizae Inoculation was important for revegetation on the Old Hwy 99 Road to Trail Project (Redding, CA, December 2002). Mycorrhizae-inoculated native grass seeds were used for the Vegetated MRE (Mechanically-Reinforced Earth) trail construction.

SS-3 Mycorrhizae Inoculation aided in vegetation establishment for adverse soils on the Old Hwy 99 Road to Trail Project. The photo on right shows the Vegetated MRE after 5 months (Redding, CA, May 2003).

SS-4 Seeding

SWPPP Summary

Seeding involves the establishment of a permanent, perennial vegetative cover on disturbed areas from seed. Native, indigenous, or naturally-occurring species (particularly grasses) will be used for seeding. These "native" species have evolved in a manner that will not compete with or preclude the establishment, or natural recruitment, of naturally-occurring woody vegetation.

Nassella pulchra (Purple Needlegrass) is the official California State Grass. The deep root systems (6-15 feet) of the grass support the survival of oak seedlings, especially in warmer areas of the state, by maintaining moisture in the soil for the seedlings and by promoting the growth of mycorrhizal fungi, which are important to the health of oaks. Purple Needlegrass is very well suited for restoration and rehabilitation projects at Carnegie SVRA. (Photo from Alameda property, DPR)

Definition / Purpose

Seeding stabilizes the soil and reduces damage from wind and/or water erosion. The cover protects the soil surface from rain drop, sheet and rill erosion. Vegetative ground cover also increases infiltration rates, thus reducing runoff.

Planning Considerations

Temporary seeding is an important component if any large-scale "phased" construction activities are planned at the Park. Permanent seeding shall be applied to areas intended to be left dormant for a year or more, and restoration and rehabilitation areas.

- Prior to seeding, install necessary erosion control practices such as fiber rolls.
- Proper seedbed preparation and the use of quality seed are important in this practice. Failure to carefully follow sound agronomic recommendations will often result in an inadequate stand of vegetation that provides little or no erosion control.
- Annual plants which sprout rapidly and survive for only one growing season are suitable for establishing temporary vegetative cover. Consider mixes because they are more adaptable than single species.
- For permanent vegetative cover, choose climatically adapted perennial species that are long-lived, hearty, require low inputs of fertilizer, and adapt to dry conditions, such as native grasses.
- Mulching is commonly used with seeding practices for temporary cover and to aid in the establishment of vegetation.
- To reduce the amount of fertilizer, pesticides and other inputs needed, choose adapted varieties based on environmental conditions, management level desired, and the intended use.

Construction Specifications:

Timing:

The proper time to seed is dependent upon the climate of the area. In most areas of California the ideal time is just before the rainy season.

Seed Mixes:

Scientific Name	Common Name	Erosion Control Value	Growth	Native or Non-Native	Habitat	Seeding Rate** (lbs/acre)
Bromus carinatus	California Brome*	Very High	Fast	Yes	Grass	10-15
Melica californica	California Oniongrass	High	Slow	Yes	Grass	5-7
Vulpia microstachys	Three Weeks Fescue	Very High	Medium	Yes	Grass	2-3
Elymus glaucus	Blue Wild Rye	High	Medium	Yes	Grass	6-10
Festuca idahoensis	Idaho Fescue	High	Slow	Yes	Grass	4-6
Nassella pulchra	Purple Needlegrass	Very High	Slow	Yes	Grass	5-10
Trifolium wildenovii	Tomcat Clover	High	Medium	Yes	Legume	3-4
Achillea millefolium	Common Yarrow	Very High	Medium	Yes	Forb	2-4
Triticum	Common Wheat***	Medium	Fast	No	Grass	10-12
Trifolium gracilentum	Pinpoint Clover	High	Medium	Yes	Legume	3-4

**Not to be confused with "Cucamonga"*
***Varies depending on the number of other species being used*
****This species should be used cautiously since it is a short-lived annual cereal grain. It is an appropriate species for fast, short-term erosion control, but not for rehabilitation.*

Table 5-1. Recommended Grasses and Forb Species for Erosion Control, Restoration, and Rehabilitation at Carnegie SVRA and adjacent properties.

Select plants appropriate to the season and site conditions.

- The seeding rates should be based on acceptable pure live seed (PLS) of 80%. When PLS is below 80%, adjust rates accordingly.

- Legumes should be inoculated with the proper rhizobium bacteria before planting. Pellet inoculated seed can be purchased or inoculation can be done in the field. Use only fresh, age-dated inoculate specifically labeled for use with the legume you are using.

Site Preparation:

- Grade as needed and feasible to permit the use of equipment for seedbed preparation.
- Divert concentrated flows away from seeded areas.
- Soil tests should be done to determine the nutrient and pH content of soil. Depending on the results of soil tests, soil management may be necessary to adjust the pH to between 6.5 and 7.0 (for most conditions). All lime, fertilizer and other soil amendments should be added following sound soil management practices.
- Surface roughening: If the area has been recently loosened or disturbed, no further roughening is required. When the area is compacted, crusted or hardened the soil should be loosened with discing, raking or harrowing. Tracking with bulldozer cleats is very effective on sandy soils (see SS-1 Surface Roughening).
- Hydroseeding and hydraulic planting generally require less seedbed prep.
- Generally, slopes steeper than 2:1 that cannot have good seedbed preparations with equipment will require hydraulic planting techniques.
- Seed to soil contact is the key to good germination. Prepare a 3-5 inch deep seedbed, with the top 3-4 inches consisting of topsoil, if possible.
- The seedbed should be firm but not compact. The top 3 inches of soil should be loose, moist and free of large clods and stones. For most applications, all stones larger than 2 inches in diameter, roots, litter and any foreign matter should be raked and removed.

Seed to soil contact is the key to good germination!

Planting:

- Seed should be applied as soon after seedbed preparation as possible, when the soil is loose and moist.
- Always apply seed before mulch.
- Apply seed at the recommended rates using calibrated spreaders, cyclone seeders, mechanical drills, or hydroseeders so the seed is applied uniformly on the site.
- Apply fertilizer if needed. Seed and fertilizer should be incorporated into the soil by raking, then lightly compacted to provide good seed-soil contact.

- Straw mulch, erosion control blankets or mulch and tackifiers/soil binders should be applied over the seeded areas.

Inspection and Maintenance

- Newly seeded areas need to be inspected frequently to ensure the grass is growing. Areas which fail to establish cover adequate to prevent sheet and rill erosion will be reseeded as soon as such areas are identified. Spot seeding can be done on small areas to fill in bare spots where grass did not grow properly.
- If the seeded area is damaged due to concentrated runoff, additional practices may be needed.
- Temporary vegetated areas will be maintained until permanent vegetation or other erosion control practices can be established.

SS-5 Straw Mulching

SWPPP Summary

All disturbed soil areas shall be protected with straw mulch. Mulching is the application of a protective layer of straw or other suitable material to the soil surface. Straw mulch and/or hydromulch shall be used in conjunction with seeding and hydroseeding of critical areas for the establishment of vegetation. Mulching with straw (or fiber mulches) is commonly used as a temporary measure to protect bare or disturbed soil areas that have not been seeded, until native vegetation regrows. Certified weed-free or rice straw mulch shall be used to prevent the introduction of undesired plant species.

SS-5 Straw Mulching BMP used to rehabilitate a hill climb at Carnegie SVRA.

Definition / Purpose

Straw mulch is used to stabilize bare and disturbed soils, to protect the soil surface from raindrop impact, to increase infiltration, to conserve moisture, to prevent soil compaction or crusting, and to decrease runoff. Mulching also fosters growth of vegetation by protecting the seeds from predators, reducing evaporation, and insulating the soil.

Planning Considerations

Straw mulch can be applied to any site where soil has been disturbed and the protective vegetation has been removed. The most common use of a mulch is to provide temporary stabilization of soil, usually until permanent stabilizing vegetation is established. Where mulches are used to compliment vegetation establishment, they should be designed to last as long as it takes to establish effective vegetative erosion control.

Where mulches are used as surface cover only (i.e. bark, wood chips, or straw mulch cover) the serviceable duration of the application and maintenance requirements, including augmentation or replication should be specified.

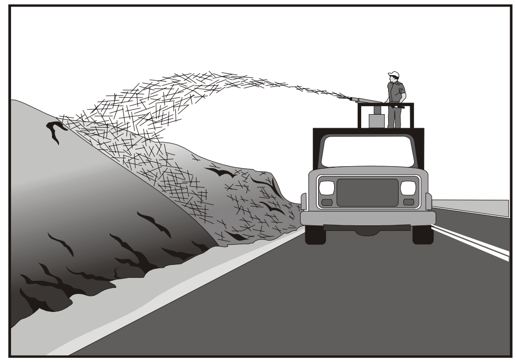
On steep slopes, greater than 2.5:1, or where straw mulch is susceptible to movement by wind or water, fiber mulch should be hydraulically applied or the straw mulch should be appropriately anchored. Hydraulic fiber mulches and/or tackifying agents are used effectively to bind the straw together and prevent displacement by wind or rain (see SS-6 Hydromulching).

Construction Specifications

Straw is an excellent mulch material. Because of its length and bulk, it is highly effective in reducing the impact of raindrops and in moderating the microclimate of the soil surface. Straw mulch can be applied by hand on small sites and blown on by machine on large sites.

Straw blowers have a range of about 50 feet. Some commercial models advertise a range up to 85 feet and a capacity of 15 tons/hr.

Mulch should not be applied more than 2 inches deep on seeded sites, unless it is incorporated into the soil by tracking, discing, or other 'punching in' techniques (see Figure 5-3). If the straw is applied at rates higher than 3 tons/acre, the mulch may be too dense for the sunlight and seedlings to penetrate.



Straw mulch can be applied by using a straw blower, or spread by hand.

Prior to mulching, install any needed erosion and sediment control practices such as diversions, grade stabilization structures, diversion dikes, and sediment traps.

- Obtain certified weed-free or rice straw in order to prevent the spread of noxious weeds. Avoid moldy, compacted straw because it tends to clump and is not distributed evenly.
- The straw shall be evenly distributed by hand or machine to the desired depth of 2-4 inches and should cover the exposed area to a uniform depth.
- Approximately one bale (approximately 80 lbs) of straw covers 1000 ft^2 adequately. The soil surface should be barely visible through the straw mulch. On steep or high wind sites, straw must be anchored to keep it from blowing away.
- For seeded sites apply: 1.5-2 tons/acre, 1-2 inches deep, covering 80% of the soil surface.
- For unseeded sites: 2-3 tons/acre, 2-4 inches deep, covering 90% of the soil surface.

One (80 lb) straw bale covers approximately 1000 square feet.

Anchoring:

Mulch must be anchored immediately to minimize loss by wind or water. Straw mulch is commonly anchored by:

- Crimping, tracking, disking, or punching into the soil.
- Covering with a netting.
- Spraying with asphaltic or organic tackifier.
- Tacking with cellulose fiber mulch at a rate of 750 lbs/ac.

Crimping:

- On small sites, where straw has been distributed by hand, it can be anchored by hand punching it into the soil every 1-2 feet with a dull, round-nosed shovel. A sharp shovel will merely cut the straw and not anchor it.
- A mulch anchoring tool is a tractor drawn implement designed to punch and anchor mulch into the top 2-8 inches of soil. This practice affords maximum erosion control but is limited to flatter slopes where equipment can operate safely.
- Tracking is the process of cutting straw into the soil using a bulldozer or other equipment that runs on cleated tracks. Tracking is used primarily on slopes 3:1 or shallower; where this type of equipment can safely operate. This is an effective way to crimp straw on fill slopes. Tracking equipment must operate up and down the slope so the cleat tracks are perpendicular to flow (see SS-1 Surface Roughening).

Nettings:

- Nettings of biodegradable paper, plastic or cotton netting can be used to cover straw mulch. Netting should be specified judiciously since birds, snakes and other wildlife can get trapped in the nettings.

Tackifiers:

- Polymer tackifiers are generally applied at rates of 40-60 lbs/ac, however manufacturers recommendations may vary.
- Organic tackifiers are generally applied at rates of 80-120 lbs/ac, however manufacturer's recommendations vary.
- Applications of liquid mulch binders shall be heavier at edges, in valleys, and at crests of banks and other areas where the mulch may be moved by wind or water. All other areas shall have a uniform application of the tackifier.

For enhanced performance, apply seed and mulch in a two or three-stage process.

Two Step Method:

1. Apply seed, at recommended rate, and half the recommended mulch, 750 lbs/ac, as a slurry. This first step assures maximum seed to soil contact.
2. Apply the remaining recommended mulch 750 lbs/ac, with recommended tackifier and fertilizer. Polymer tackifiers are applied at rates of 40-60 lbs/ac and organic tackifiers at a rate of 80-120 lbs/ac.

Straw blower used for mulch application on steep slope.

Three-Step Straw Mulch Method (for steep and critical erosion sites):

1. Apply seed hydraulically in a slurry with 500 lbs/ac hydraulic mulch.
2. Followed by the application of straw mulch at a rate of 1 T/ac.
3. Fertilizer, tackifier, and the remaining hydraulic mulch (500-750 lbs/ac minimum) are then applied.

Limitations

- Straw mulch applied by hand is more time intensive and potentially costly.
- When straw blowers are used to apply straw mulch, the treatment areas must be within 150 ft of a road or surface capable of supporting trucks.

Inspection and Maintenance

If properly applied and anchored, little additional maintenance is required during the first few months. After high winds, or significant rainstorms, mulched areas should be checked for adequate cover and re-mulched if necessary. Mulch needs to last until vegetation develops to provide permanent erosion resistant cover. Straw mulch can last from 6 months to 3 years.

The proper and timely application of straw mulch protects seeded areas and minimizes the amount of raw soil exposed to the elements.

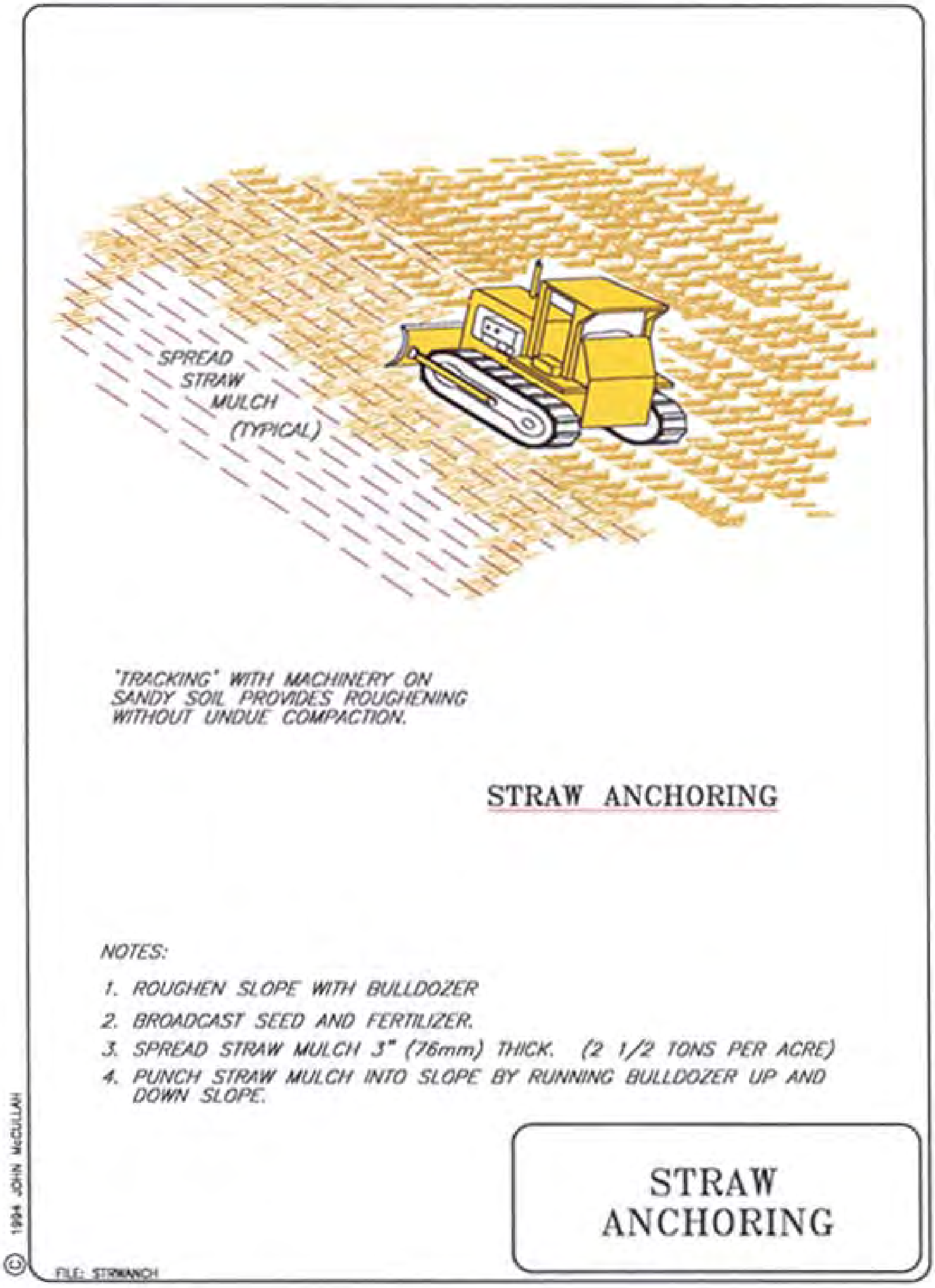
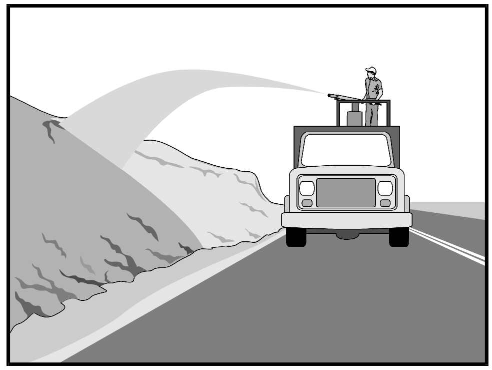


Figure 5-3. Straw Anchoring.

SS-6 Hydromulching

SWPPP Summary

Hydromulching is a soil stabilization (erosion control) technique for applying fiber mulch to the exposed and disturbed soil surface. The fiber is applied hydraulically, in a slurry, produced by mixing fiber, water and a binding agent together in a mechanical hydroseeder.



Wood fiber is widely-used but other fibers can include paper, straw, coir, corn, etc. The effectiveness of SS-6 Hydromulching is extremely dependant on the application rates (which can vary widely), the actual fibers used, and the type of bonding agent(s) added. A general rule of thumb is mulches (wood fiber, straw, compost, etc.) should have a minimum application rate of 3000# per acre for protection of the soil surface from raindrop impact erosion. Hydromulching is also useful as a tackifier to anchor straw mulch and as a means to apply seeds.

Definition / Purpose

SS-6 Hydromulching is a soil stabilization technique which is primarily intended to protect the soil surface from raindrop impact erosion. Seed can also be included, which is then referred to as Hydroseeding. By using hydraulic equipment (hydroseeders and hydromulchers) seed, soil amendments, wood fiber mulch and tackifying agents, bonded fiber matrix and liquid co-polymers can be uniformly broadcast, as hydraulic slurry, onto the soil. These erosion and dust control materials can often be applied in one operation.

High quality mulches and tackifiers that are applied as a thick blanket can be effective against erosion for over 1 year. When seed is added, SS-6 Hydromulching becomes an extremely effective permanent BMP. Hydromulching can reduce the invasion of noxious weeds which often thrive on neglected soil surfaces.

Planning Considerations

Four Types:

There are four types of hydraulic mulches which are summarized below:

1. SS-6.1 Hydromulch - wood fiber and/or paper fiber, water and tack

   Hydromulch is usually applied at a rate of 1500#-2500# per acre but it should be noted that this common application provides incomplete soil coverage.
2. SS-6.2 Bonded Fiber Matrix (BFM) – elongated wood fibers, water and stabilizing emulsion (two glues) applied as a thick slurry with a target of 100% coverage of the soil. Application rate – 3500#-4500# per acre
3. SS-6.3 Mechanical-Bonded Fiber Matrix (M-BFM) – elongated wood fiber, with mechanically (interlocking) synthetic fibers combined with special emulsions and

water. M-BFM is applied as thick slurry with 100% soil coverage. Application rate – 3500#-4500# per acre.

a. SS-6.3.1 PAM Fiber Matrix (PFM or SFM®) – wood fiber and polyacrylimides. Application rate – 3000#-4500# per acre.

4. SS-6.4 Fibermulches – wood and/or paper and/or cotton, straw, coir or other fibers applied hydraulically. Follow manufacturers recommendation for application rates.

The Hydromulching BMPs shown in these photos and on previous page are described individually as BMP SS-6.1 to SS-6.4.

Soil stabilization or erosion control is considered "source control" as raindrop impact erosion is the primary mechanism for detaching soil particles – the source of soil sediment. The State of California Construction General Permit requires that the operator "use an effective combination of soil stabilization and sediment control BMPs during the rainy season". A construction site is actually in violation of the NPDES permits if soil stabilization BMPs are not in evidence. There a four basic and effective ways to cover and protect the soil surface from raindrop impact erosion:

- Straw Mulch
- Hydromulch
- Erosion Control Blankets, Mats and other RECPs (Rolled Erosion Control Products)
- Compost or Wood Chips

Hydromulching is a very cost-effective way to apply soil stabilization (erosion control). It is appropriate for small areas, steep slopes, large DSAs greater than 1 acre, and on soils that are shallow, irregular, or rocky – conditions where anchoring other mulches is not practical. Because the material is applied hydraulically, large areas can be treated in a short period of time.

There are many types of mulches and emulsion formulations available to meet a wide range of site conditions. Likewise, there are many types and sizes of hydroseeding machines available so there are capabilities for shooting long distances by cannon or spraying from a 1.5-2" hose. Large machines can "shoot" up to 90' by cannon and hoses can be used for 200' distance from the machine.

Hydromulching is sometimes the only acceptable soil stabilization treatment for steep, critical, or rocky slopes that cannot practically be treated by other means. Slopes that are too steep for access or have shallow, irregular soil surfaces, with large clods, stumps, rock outcroppings, are candidates for the SS-6 Hydromulching BMP.

On steep critical slopes, with limited accessibility and on which mulch must be anchored and/or on shallow soils which restrict the use of erosion control blankets, hydraulic planting techniques will provide the most dependable results.

Hydromulching is a very effective method for uniformly applying seed and mulch material. The mulch also protects the seed and makes favorable conditions for seed germination and establishment.

SS-6 Hydromulching should be considered for temporary and permanent erosion control, seeding , and mulching on sites with the following conditions:

- Large (>1 acre) disturbed soil areas (DSAs), as this soil stabilization BMP requires less labor and can thereby be cost-effectively applied over large areas.
- Slopes steeper than 2:1 that cannot receive adequate seedbed preparation and mulches or erosion control blankets (ECBs) would be difficult to otherwise anchor. Cut slopes are often good candidates for Hydromulching.
- Where the slope surface is irregular with large clods, stones or a high percentage of rock.
- Where site conditions such as, irregular soil surfaces, existing vegetation, and shallow soils preclude the installation of erosion control blankets and mats.
- On windy sites where straw blowing is problematic due to air quality concerns.
- On sites where other soil stabilization, seeding, and mulching practices would require unacceptable levels of disturbance.
- On site accessible to hydroseeding equipment. Water to fill and clean the hydroseeding tank must also be available.
- Post-fire or rehabilitation sites which are accessible by hydraulic application equipment. Remote locations with steep slopes may be reached with hoses.
- On sites where it is desirable to apply water, seeds and mulch is one operation.
- On critical erosion sites where the application of seed, fiber, fertilizer followed by the application of straw mulch and tackifier (the three-step process) is desirable.
- On sites where the application of a hydraulically applied BFM or M-BFM system is desirable.
- On sites where straw mulch has been applied and the straw needs to be anchored (tacked) with tackifiers or hydraulic mulches.
- On sites where dust control is desired.

Hydromulching requires the use of a hydroseeding machine which has a tank, some form mechanical mixing (either mixing blades or hydraulic mixers), and a pump to shoot the slurry. The hydroseeding machines come equipped with hoses and or cannons to which nozzles are attached and the slurry is “shot” (applied) onto the soil. The DSA must be accessible to the hydroseeder and the hydroseeder must have access to water. Usually a nearby fire hydrant or water truck is necessary.

Hydromulch is packaged in 50# bags. The bags of mulch must be mixed with water in the tank with sufficient tackifier added. The thickness of the slurry is dependent upon the ratio of water and mulch materials. The viscosity of the slurry is also affected by the type of mulch material as well as the other ingredients added to the mix. The modern hydraulic planting machine (hydroseeder) must be capable of quickly loading and mixing a thick slurry of mulch, fertilizer, seed or sprigs, and tackifier, then effectively pumping the thick slurry through the required length of hose or the requisite distance from the tower-mounted discharge gun or hose.

All soil stabilization BMPs require proper soil surface preparation. See SS-1 Surface Roughening. There are different methods for achieving a roughened soil surface on a slope, and the selection of an appropriate method depends upon the type of slope. Roughening methods include stair-step grading, furrowing, and tracking. Factors to be considered in choosing a method are slope steepness, mowing requirements, and whether the slope is formed by cutting or filling. At a minimum the top 3 inches (76 mm) of soil should be loose, friable, moist and free of large clods and stones greater than 2.5 inches (600mm).

The soil surface roughness and soil moisture conditions can affect the amount of mulch needed. For instance, trackwalking a slope can increase the surface area by 25-35% over a smooth slope. Adjustments in quantities will sometimes be necessary and the designer/specifier should be amenable to some adjustments in quantities. The quantities of dry fiber specified is good guide but the goal of the BMP is to protect the DSA and/or establish vegetation. Often, hydromulching applications are therefore considered performance-based.

The ratio of mulch material to water is the most critical factor effecting the slurry, however, the type of fiber can also effect the application performance. Generally speaking, the longer the fiber length, the greater the mechanical bonding, however mulches comprised of predominately long fibers, 1/2 to 1 inch (12-25 mm), are more difficult to pump. A new generation of mulches have been developed which include synthetic fibers with the wood fibers. These formulations are referred to a Mechanical Bonded Fiber Mulches (M-BFMs).

Paper fiber mulch is comprised of short fibers which make less viscous slurry that can usually be mixed and pumped at a ratio of 50 lbs. mulch material per 100 gallon of water (23 kg/380 l). Wood fiber mulches have longer fibers, are more viscous and are usually recommended to be mixed at a ratio of 30 to 35 lbs. of mulch per 100 gallons of water (14 to 16 kg/380 l). The individual product brands may vary and the mixing density of a single brand can vary slightly due to variances in the manufacturing process.

All mulches can be made easier to pump by using an additive which makes the solution slick or slimy. Vegetative gums (guar) and acrylic co-polymers (tackifiers) are common additives that help lubricate the slurry thereby improving spray distance and application performance.

Proper application of the slurry requires an understanding of soil moisture conditions, antecedent rainfall, predicted rainfall, steepness of slope, surface roughness, etc. The experienced applicator will take samples (usually a handful turned slowly until slurry falls) to test viscosity and make adjustments to the soil conditions. The soil conditions, whether dry and powdery or wet and hard, often dictate the slurry thickness and viscosity. It is desirable to apply a wet soupy solution to dry, powdery soils. The use of tackifier is also recommended with soupy mixes because the fiber and glue incorporate with the dry soil to reduce erodibility and prevent the washing away of seeds.

With wet or hard soil conditions, thicker slurries are generally better. Regardless of the mulch material used, the thicker the slurry, the more likely a clog is to occur. With wood fiber mulches, thick slurry mixes, 40 lbs of mulch per 100 gallons of water, are more likely to clog the machine or hose unless mixed with an appropriate tackifier. Such a slurry can be pumped through a hose, however, the longer the hose, the more pumping power required. Thick wood fiber slurries, more than 40 lbs / 100 gallons, are usually applied by a tower-mounted discharge gun and almost always contain tackifier or some other lubricating agent.

Types of Hydraulically Applied Materials for Erosion and Dust Control:

Mulches: Hydraulically applied mulches include mulches made from wood fibers, paper fibers, combination recycled wood and paper fibers, and polyester and/or polypropylene fibers. New formulations or alternative fibers are being tested. These alternatives include straw, corn, hemp, and coir (coconut fiber).

Tackifiers: Tackifiers are typically used to anchor or glue the mulch to increase effectiveness and longevity of erosion control. Tackifiers used in conjunction with straw mulch are extremely effective in bonding the straw to itself and the soil surface, thus resisting movement by water or wind. Some tackifiers, such as those made from polymers, plant muselage (psyllium), or guar are extremely important to lubricate the slurries and increase application performance.

Liquid or granular formulations of acrylic co-polymers, and polyacrylimides (PAM), or specially formulated "cross-linking" glues are added to the mulches to produce hydraulically applied mulch called Bonded Fiber Matrix (BFM). A unique hydromulch is herein referred to as SS-6.3.1 PAM Fiber Matrix (PFM) because this formulation combines the raindrop impact erosion properties of wood mulch with the ionic bonding properties of PAM. There are some limitations to using PAM directly adjacent to waterways in California.

Soil Binders: These products are also effective, when used without mulches, to control wind erosion and dust. These soil binder formulations are intended to provide chemical (glue) or ionic bonding (PAM) of the soil particles on the surface. However, without the addition of fiber mulch, these soil binders do not provide significant protection against raindrop impact erosion. Therefore they are useful as temporary erosion control.

Cementitious Binders: These products are formulated from hydrated lime or gypsum mixed with water and applied to the soil with hydraulic equipment. Fiber mulch, seed and fertilizers can be applied with the slurry and sprayed on in one application. These cementitious binders form a permeable crust on the soil surface which control water and wind erosion.

Bonded Fiber Matrix: (BFM): Hydraulic matrix products are typically produced from longer fibers combined with tackifiers and binding agents that are hydraulically applied and conform to the ground and dry to form a bonded fiber matrix. BFMs are unique from standard hydromulches in they have two types of tackifiers. One tackifier is usually an organic tack such as guar. The second glue is a cross-linking polymer that will not re-wet after it dries. The two glues and the fiber provide the matrix that is mutually-reinforcing and long-lived (greater than 1 year).

However, to attain the full benefits of BFM, the slurry must be very viscous, the application must be thick (at least 3500#/ac), the coverage must be 100%, and the glue must have a chance to dry (24-48 hours before a rainstorm). BFM are intended to be a blanket that covers and protects the soil surface.

Seed and fertilizer can be added to the slurry and applied with the BFM in one-step application. The BFM forms a thick permeable, 3-dimensional, continuous, blanket-like covering that holds soil and seed in place. BFM is generally applied at rates from 3000-4000 lbs/ac.

Mechanically-Bonded Fiber Matrix (M-BFM): This formulation includes synthetic fibers with the wood fibers. The synthetic fibers in M-BFM provide another element of internal shear strength as the fibers interlock. The synthetic fibers tend to attract and hold water molecules, which can aide vegetation establishment, while still resisting slumping failures during application. M-BFMs do not call for the drying time required by BFMs. Additionally, M-BFMs are more flexible than BFMs when dry, which can reduce damage from animals and other light traffic on treated slopes.

<u>Construction Specifications</u>

Site Preparation:

- Grade as needed and feasible to permit the use of equipment for seedbed preparation.
- Hydromulch shall only be applied to geotechnically stable slopes that have been designed and constructed to divert runoff away from the face of the slope. Do not proceed with installation until satisfactory conditions are established.
- Slope interruption devices or water diversion techniques are recommended when slope lengths exceed 100 ft.
- The seedbed should be uniform but not compact. At a minimum the top 3 inches of soil should be loose, friable, moist and free of large clods and stones greater than 2.5 inches.
- Install needed erosion control practices, such as sediment basins, diversion dikes and channels, prior to seeding. Divert concentrated flows away from hydraulic planted areas.
- Conduct soil tests to determine pH. Add amendments as necessary to adjust pH.
- Planting: See SS-4 Seeding.
- Seed to soil contact is important for successful germination.
- Use permanent seed blends for sites to be left dormant for 1 year or more or if no further disturbances are planned.

Inspection and Maintenance

All seeded areas shall be inspected for failures and re-seeded, fertilized, and mulched within the planting season, using not less than half the original application rates.

SS-7 Compost Blankets

SWPPP Summary

A compost blanket is a layer of compost designed to prevent erosion, especially rills and gullies that may form under more traditional methods of erosion control. In many cases, a compost blanket can be more effective at vegetation establishment, weed suppression and erosion control than an Erosion Control Blanket (ECB) or hydroseeding. Compost blankets can be applied by hand, conveyor system or compost spreader; however, the most cost-effective and efficient method is the use of a pneumatic delivery system, i.e. a compost blower truck.

Definition / Purpose

A compost blanket is used on slopes to prevent raindrop erosion and in some cases, to increase infiltration rates. A trademarked form of a compost blanket, the Rexius EcoBlanket™ increased infiltration rates and decreased sediment delivery by 99% as compared to bare soil, in a study conducted by the San Diego State Erosion Control Laboratory (Rexius). The success of compost blankets is dependent upon the blanket not being undermined by water; this can be accomplished by keying in the top of the blanket, or the use of a compost berm or sock at the top of the slope. When applied correctly, compost blankets provide nearly 100% surface coverage (Faucette, 2002).

A 2 inch thick compost blanket, applied pneumatically for surface stabilization. (Photo Courtesy of Texas DOT.)

Compost, when properly made, is full of nutrients and micro-organisms that stimulate vegetative growth and increase disease resistance.

Compost binds heavy metals and can break hydrocarbons down into carbon, salts and other unharmful compounds (EPA, 1997). Many communities now have municipal recycle or "Greenwaste" programs whereby vegetation is diverted from landfills and quality compost is manufactured.

Standard Specifications for both Compost Berms and Blankets have been developed for the American Association of State Highway and Transportation Officials (AASHTO) by Ron Alexander.

Advantages:

- Compost blankets can be more effective than ECBs, because they come in better contact with the underlying soil, reducing the chance of rill formation (Faucette, 2002).
- Compost is organic, biodegradable, renewable, and can be left onsite. This is particularly important near streams.

- Compost does not generally leach nutrients (Glanville, 2003). Field tests in Connecticut have shown that run-off from compost treated sites has very low soluble salts, and all metals and nutrients are well within pollution leaching limits (Connecticut, 2001).
- Compost has been shown to suppress weeds. Over two growing seasons, the mass of weeds on compost blanket plots was 1/3 of the amount on the control plots (Glanville, 2003).

Planning Considerations

Compost blankets are usually used on slopes of 2H:1V or gentler, but can be used on slopes as steep as 1H:1V, with consideration given to the length of slope and depth of application (AASHTO). Adding components such as a tackifier, or using compost blankets in conjunction with other techniques can increase the allowable steepness of the slope to be treated. Compost blankets should be extended 3-6 feet over the top shoulder of the slope to prevent water from getting underneath. Compost blankets should not be applied in areas of concentrated flow, and can be used in conjunction with compost berms or socks.

Blankets can be applied in a variety of thicknesses from ½” to 4”, depending upon the intended purpose. As a general rule, the more precipitation an area receives, the thicker the application.

In Maine, an area of heavy precipitation, application rates vary between 4”-6” for gentle slopes, to 8 - 12” on 2:1 slopes (Diversified Landscape). For best vegetation establishment, a depth of 1 ½” is optimum (Smith, 2002). For maximum unvegetated erosion control, use thicker blankets.

Construction Specifications

There are many types of compost, all with different properties, so it is best to determine what application the compost is being used for. Compost can be derived from feedstocks, biosolids, leaf and yard trimmings, manure, wood, or mixed solid waste, and must be treated with heat to remove pathogens and destroy noxious weeds.

One of the most important criteria for quality compost is the temperature it was "cooked" at and the duration of composting. For instance, California Compost Regulations require that "windrowed compost" be kept at 131°F for 15 days and turned 5 times. Compost manufactured in bags is referred to as "in vessel" which the regulations require be kept at 131°F for only 5 days. Quality compost will then be cured for 60 days (Carvalo, 2004).

All types of vegetation have different nutrient or moisture needs; therefore, a compost sample should be inspected by a qualified individual and compost specifications modified as necessary.

Parameters 1,4	Reported as (Units of measure)	Surface mulch to be Vegetated	Surface Mulch to be left Unvegetated
pH 2	pH units	5.0-8.5	N/A
Soluble Salt Concentration 2	dS/m (mmhos/cm) (electrical conductivity)	Maximum 5	Maximum 5
Moisture Content	%, wet weight basis	30-60	30-60
Organic Matter Content	%, wet weight basis	25-65	25-100
Particle Size	% passing a selected mesh size, dry weight basis	3” (75mm), 100% passing 1” (25 mm), 90% to 100% passing ¾” (19mm), 65%-100% passing ½” (6.4mm), 0%-75% passing Maximum particle length of 6 (152mm)	3” (75mm), 100% passing 1” (25 mm), 90% to 100% passing ¾” (19mm), 65%-100% passing ½” (6.4mm), 0%-75% passing Maximum particle length of 6 (152mm)
Stability 3 Carbon Dioxide Evolution Rate	Mg CO 2 –C per g OM per day	<8	N/A
Physical Contaminants (man-made inerts)	%, dry weight basis	<1	<1

Table 5-2. (AASHTO)

[1]Recommended test methodologies are provided in Test Methods for the Examination of Composting and Compost (TMECC, the US Composting Council).

[2]Each specific plant species requires a specific pH range. Each plant also has a salinity tolerance rating, and maximum tolerable quantities are known. When specifying the establishment of any plant or turf species, it is important to understand their pH and soluble salt requirements, and how they relate to the compost in use.

[3]Stability/Maturity rating is an area of compost science that is still evolving, and as such, other various test methods could be considered. Also, never base compost quality conclusions on the result of a single stability/maturity test.

[4]Landscape architects and project (field) engineers may modify the allowable compost specification ranges based on specific field conditions and plant requirements.

For compost blankets, compost should have the following specifications (also see Table 5-2):

- Compost that is too dry is harder to apply, while that which is too wet is heavier and harder to transport. In drier areas, use compost with higher moisture content; in wet areas, use the drier compost, as it will absorb water.
- Organic matter content: The percentage of carbon based materials in finished compost should range between 40-70%. However, Texas DOT specifies no less than 70%.
- Compost must be weed and pesticide free, with manmade materials comprising less than 1% (EPA, 1997, AASHTO, 2003).

Pneumatic blower.

Installation:

Compost blankets can be applied in a variety of ways, however the most efficient and cost-effective way is through the use of a pneumatic blower truck.

- Prepare the slopes by removing loose rocks, roots, clods, stumps and debris over 2" in diameter.
- Trackwalk slopes if feasible before application.
- For very steep slopes, compost berms can be installed at intervals over the compost blanket in much a similar manner as fiber rolls.

Rainfall/ Flow Rate	*Total Precipitation and Rainfall Erosivity Index*	*Application Rate for Vegetated* Compost Blanket*	*Application Rate for Unvegetated* Compost Surface Mulch*
Low	1-25" 20-90	½ - ¾" (12.5 mm x 19 mm)	1"-1 ½" (25 mm – 37.5 mm)
Average	26-50" 91-200	3/4 – 1" (19 mm x 25 mm)	1 ½" – 2" (37 mm – 50 mm)
High	51" and above 201 and above	1-2" (25 mm x 50 mm)	2-4" (50 mm – 100 mm)

*** These lower application rates should only be used in conjunction with seeding, and for compost blankets applied during the prescribed planting season for the particular region.**

Table 5-3. Compost Blanket Application Rates (AASHTO).

Inspection and Maintenance

- Inspect blankets after each storm.
- Re-apply blanket material if needed.
- Blankets can be hydroseeded if vegetation fails to establish.

Two-inch thick compost blanket installed on Alberta DOT streambank project (at vane 1). Note compost sock installed for sediment control. (Canadian Rockies 2005)

Compost blanket at vanes 2 and 3. Note that willow cuttings were also incorporated into this streambank protection design. (2005)

Compost blankets at vane 1 after one year. Not only did the compost blankets prevent erosion, but also helped establish native grasses. (2006)

Compost blankets provide very effective erosion control initially, and also promote long-term vegetation growth. (2006)

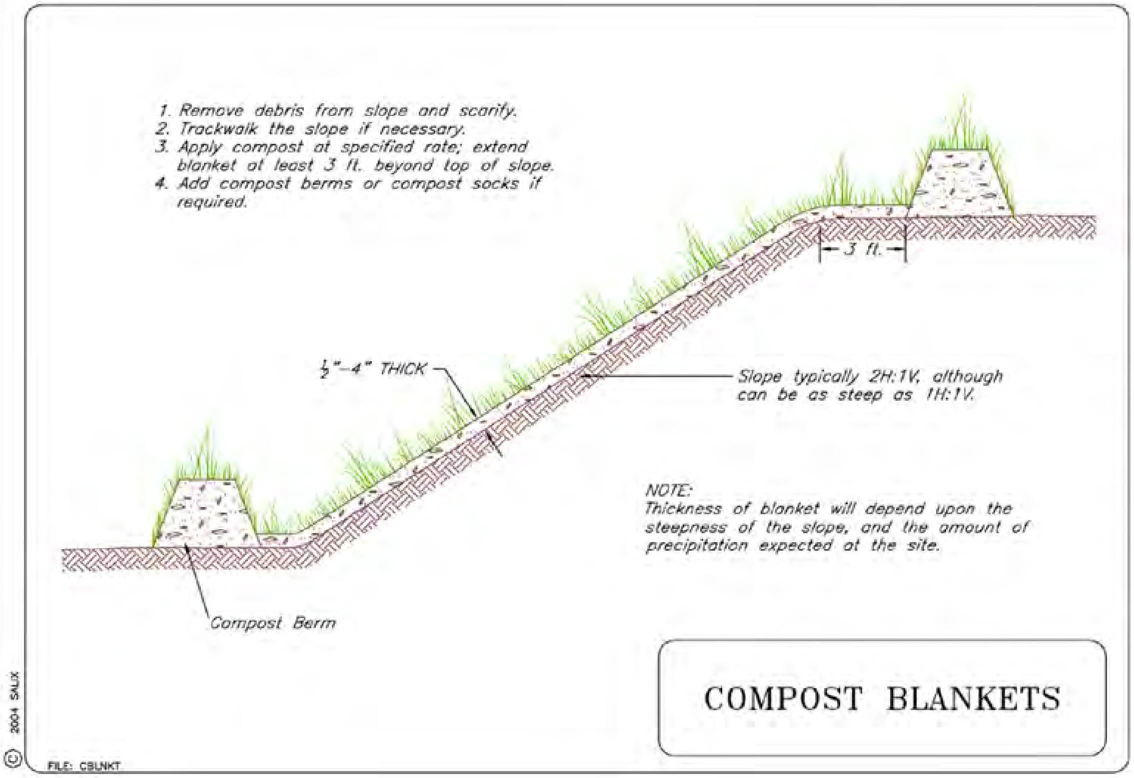
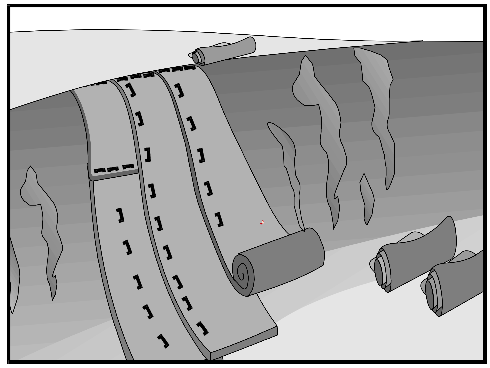


Figure 5-4. Compost Blankets.

SS-8 Erosion Control Blankets

SWPPP Summary



Erosion Control Blankets (ECBs) are a soil stabilization (erosion control) BMP, intended to protect disturbed soil surfaces from raindrop impact erosion. ECBs are carpet-like mats, installed over and anchored to the properly prepared soil surfaces. Properly selected and installed, ECBs can mimic the beneficial effects of vegetative cover thereby reducing erosion rates by over 90%. ECBs also protect seeds and provide a beneficial environment for vegetation to become established.

Definition / Purpose

ECBs are an erosion control or soil stabilization (SS) BMP. They are a type of Rolled Erosion Control Products (RECPs) - products that include Turf Reinforcement Mats (TRMs). Like Straw Mulch and Hydromulch, these rolled mats are applied to bare, disturbed soil areas (DSAs) in order to protect the exposed soil surfaces from raindrop and wind erosion.

Erosion control blankets:

- Protect bare soil from raindrop impact and wind erosion.
- Protect seeds (includes protection from predators), enhance germination and enhance plant establishment.
- Reduce desiccation and evaporation by insulating the soil and seed environment.

RECPs (Rolled Erosion Control Products).

Planning Considerations

Establishing vegetation in channels or on slopes may require additional measures beyond seeding and straw mulching. Conditions where erosion control blankets (ECBs) and Turf Reinforcement Mats are appropriate may include:

- Slopes and disturbed soils where mulch must be anchored and other methods such as crimping or tackifying are not feasible nor adequate.
- Steep slopes, generally steeper than 3:1.
- Slopes where erosion hazard is high.
- Critical slopes adjacent to sensitive areas such as streams and wetlands.

- Disturbed soil areas where planting is likely to be slow in providing adequate protective cover.
- Channels with flow exceeding 2-4 ft/sec (0.6-1 m/sec). See RC-4 Turf Reinforcement Mats/Grass-lined Channels.
- In channels intended to be vegetated and where the design flow exceeds the permissible velocity. Allowable velocity, with turf reinforcement mats after vegetative establishment, is up to 10 ft/sec (3 m/sec).

ECBs can be a temporary or permanent BMP but most commonly the products are applied in conjunction with seeding or hydroseeding as a permanent application. In most jurisdictions, slopes or DSAs with proper seed selection, soil preparation, and ECB installation are considered "permanently stabilized" and thereby eligible for a Notice of Completion (NOC) as per NPDES.

ECBs, like Straw Mulch, BFMs, M-BFMs, and Compost Blankets have been tested and proven to be over 90% effective in reducing raindrop and sheet erosion. ECBs are then one the four most effective erosion control techniques available. ECBs are basically a mulch, like straw mulch, which is secured and anchored to the slopes by the geotextile netting and soil anchor pins.

If chosen properly and installed correctly, ECBs will provide the necessary erosion protection until vegetative cover becomes established. Mulching with erosion control blankets will increase the germination rates for grasses and legumes and promote vegetation establishment.

The TOP 4

The most effective and most commonly used Soil Stabilization BMPs:

- **SS–5 Straw Mulching**
- **SS-6 Hydromulching**
- **SS-7 Compost Blankets**
- **SS-8 Erosion Control Blankets**

Testing has shown that these 4 BMPs are over 90% effective in reducing erosion caused by raindrop impact and sheet erosion.

ECBs are basically a 'mulch' (like straw mulch) that is manufactured ("sandwiched") between geotextiles. ECBs are then wrapped up into cylindrical rolls, unrolled over the bare soil, and then anchored with pins or nails to the soil surface. ECBs temporarily stabilize and protect disturbed soil from raindrop impact and surface erosion, increase infiltration, decrease compaction and soil crusting, and conserve soil moisture.

There are many types of erosion control blankets and mats, and selection of the appropriate type is based on the specific type of application and site conditions. Most ECBs are manufactured from biodegradable fibers and synthetic netting, or entirely from biodegradable materials - biodegradable fibers stitched together with biodegradable threads or netting.

Erosion control blankets are generally a machine produced mat of organic, biodegradable mulch such as straw, curled wood fiber (excelsior), coconut fiber or a combination thereof, evenly distributed on or between photodegradable polypropylene or biodegradable natural fiber netting. Synthetic erosion control blankets are a machine produced mat of ultraviolet stabilized synthetic fibers and filaments. The nettings and mulch material are stitched to ensure integrity and the blankets are provided in rolls for ease of handling and installation.

Turf Reinforcement Mats (TRMs) are high strength, flexible, machine produced, three dimensional matrix of nylon, polyethylene, polypropylene or polyvinyl chloride that have ultra violet (UV) stabilizers added to the compounds to ensure endurance and provide permanent vegetation stabilization. See RC-4 Turf Reinforcement Mats/Grass-lined Channels.

Construction Specifications

Site Preparation:

- Proper site preparation is essential to ensure complete contact of the protection matting with the soil.
- Grade and shape area of installation using seed bed preparation type techniques, e.g., spring harrow, tilling, raking, trackwalking, that are appropriate for the soil conditions.
- Prepare seedbed by loosening 2-3 inches of topsoil above final grade.
- Remove all rocks, clods, vegetative or other obstructions greater than 2 inches high so that the installed blankets, or mats will have direct contact with the soil.
- Incorporate amendments, such as lime and fertilizer, into soil according to soil test and the seeding plan.

Seeding:

- Seed area before blanket installation for erosion control and re-vegetation. It is usually preferable that the seed have contact with the soil before laying blankets, however, some mats have large openings which can then be hydroseeded/ hydromulched after the ECBs have been placed. The 3-dimensional Enka mat and hydromulch, Green Armor System ®, is another example of "seeding after" placement.

Anchoring:

- U-shaped wire staples, metal geotextile stake pins, or triangular wooden stakes can be used to anchor mats to the ground surface. Wire staples should be a minimum of 11 gauge. Metal stake pins should be 3/16 inch (4.8 mm) diameter steel with a 1 1/2 inch (38.1 mm) steel washer at the head of the pin. Wire staples and metal stakes should be driven flush to the soil surface. All anchors should be 6-8 inches (0.2-0.5 m) long and have sufficient ground penetration to resist

Metal stake pins with steel washers may be used for anchoring ECBs.

pullout. Longer anchors may be required for loose soils.

Installation on Slopes:

Anchor ECBs in a trench at top of slope.

- Begin at the top of the slope and anchor the blanket in a 6 inch deep x 6 inch wide trench. Backfill trench and tamp earth firmly.
- Unroll blanket downslope in the direction of the water flow.
- The edges of adjacent parallel rolls must be overlapped 2-3 inches and be stapled every 3 feet.
- When blankets must be spliced, place blankets end over end (shingle style) with 6 inch overlap. Staple through overlapped area, approximately 12 inches apart.
- Lay blankets loosely and maintain direct contact with the soil - do not stretch.
- Blankets shall be stapled sufficiently to anchor blanket and maintain contact with the soil. Staples shall be placed down the center and staggered with the staples placed along the edges. Steep slopes, 1:1 to 2:1, require 2 staples per square yard. Moderate slopes, 2:1 to 3:1, require 1-2 staples per square yard or square meter (1 staple 3' o.c.). Gentle slopes require 1 staple per square yard (Caltrans, 2003).

<u>Inspection and Maintenance</u>

- All blanket and mats should be inspected periodically following installation.
- Inspect installation after significant rainstorms to check for erosion and undermining. Any failure should be repaired immediately.
- If washout or breakage occurs, re-install the material after repairing the damage to the slope or drainageway.

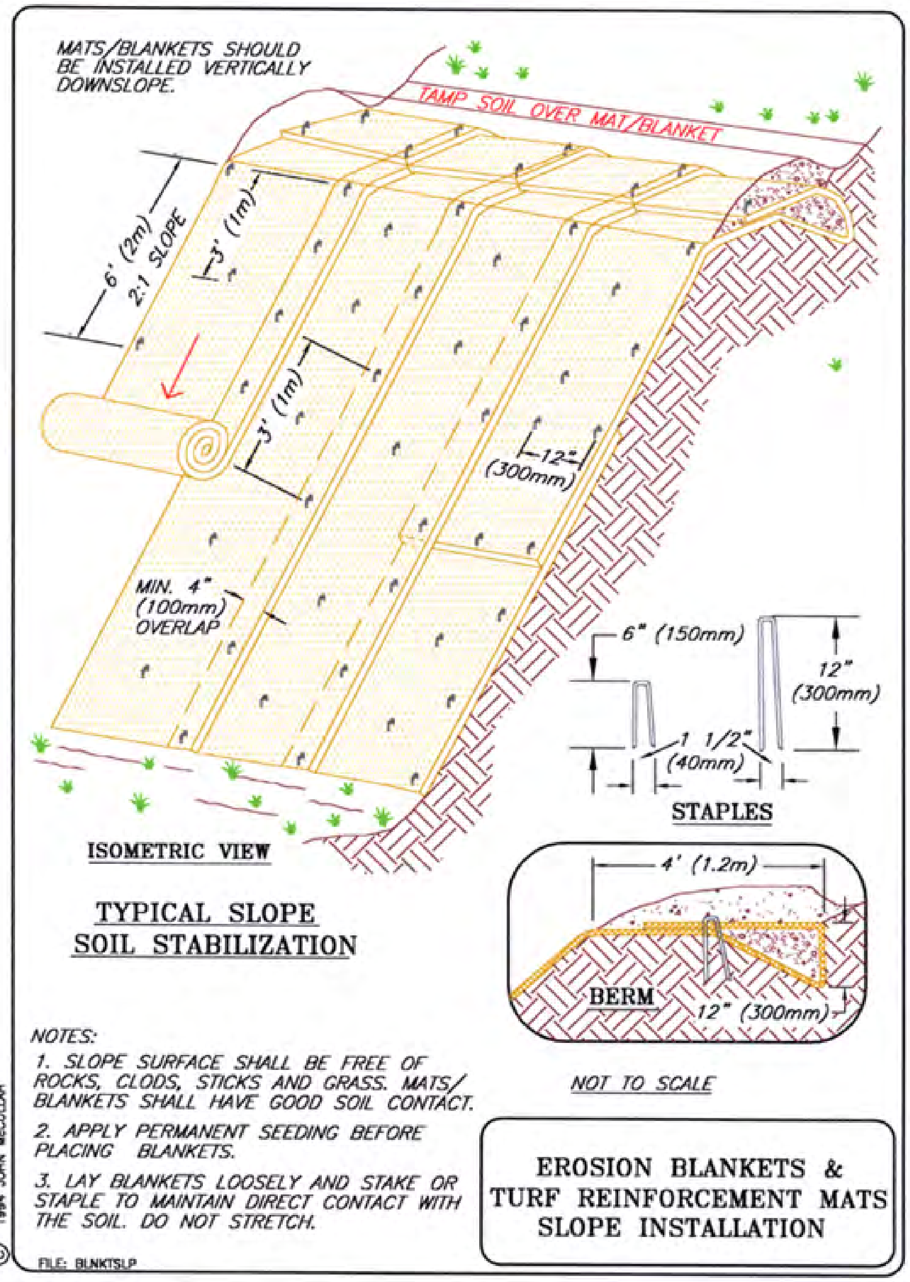


Figure 5-5. Erosion Blankets and Turf Reinforcement Mats Slope Installation.

SS-9 Cellular Confinement Systems

SWPPP Summary

Cellular Confinement Systems are three-dimensional, honeycomb earth-retaining structures used to mechanically stabilize slopes, roads, trails, and low-water crossings, and other channel lining systems. The cells can be filled with rock, gravel, or topsoil and provide an alternative to hard armor soil stabilization.

This cellular confinement system (CCS) was installed to repair a gullied trail. The stabilization was successful, but some of the cell infill became displaced over the years. Eventually, trail users avoided walking on the cells, as evidenced by the new trail on the left of the CCS. (Whiskeytown NRA)

Definition / Purpose

Cellular Confinement System (CCS) is a permanent erosion control practice intended to stabilize slopes as steep as 1V:1H (1:1). For erosion control on steep slopes, cells can be infilled with soil and vegetated or infilled with granular materials for sterile arid regions. The expandable panels create a cellular system that confines topsoil infill, protects and reinforces the plant's root zone, and permits natural subsurface drainage. The honeycombs shaped cells encapsulates and prevent erosion of the infill material. Cellular confinement systems can be installed as a framework for earth retaining structures.

CCS can also be used as flexible channel lining systems, either vegetated or rock filled. Filling the cells with rock, gravel, or topsoil can provide an alternative to hard armor revetment systems. The CCS can be specified with drainage holes filled with drainrock when used in springs, seeps and at "waters edge" applications. For road stabilization, the cells confine and reinforce select fill materials, thereby increasing load-bearing capacities, and may be used for temporary low-water stream crossings. The cells are sometimes in-filled with concrete for permanent, reinforced crossings. See RT-10 Low-Water Crossings.

Planning Considerations

Materials needed include polypropylene cellular material, aggregate or soil infill, and vegetation. Willow stakes, grass plugs or container grown trees and shrubs may be used.

Construction Specifications:

The surface of the slope should be leveled, with stones and debris removed. Gullies should be filled and well compacted. Major obstacles such as boulders can be left in place. Simply cut out panel around them.

Following excavation and fill placement operations, shape and compact the subgrade surfaces to the designed elevations and grades. Excavate the area so that when cellular confinement systems are installed, the top of the section is flush with or slightly lower than the adjacent terrain or final grade.

The cells should be anchored securely in order to prevent deformation of the panel while backfilling. On steep slopes, reinforcing "tendons" are used to prevent movement. Willow staking may be used on slopes or stream channels. Place the fill material in the expanded cells. Apply surface treatments following the placement of infill. Surface treatments such as permanent seeding or willow staking may be used.

Limitations

Cellular confinement systems are relatively expensive.

Inspection and Maintenance

Inspect slope periodically and after significant rainstorms to check for erosion. Any failure should be repaired immediately. If vegetation has not been established, fertilize and reseed or revegetate damaged and sparse areas immediately.

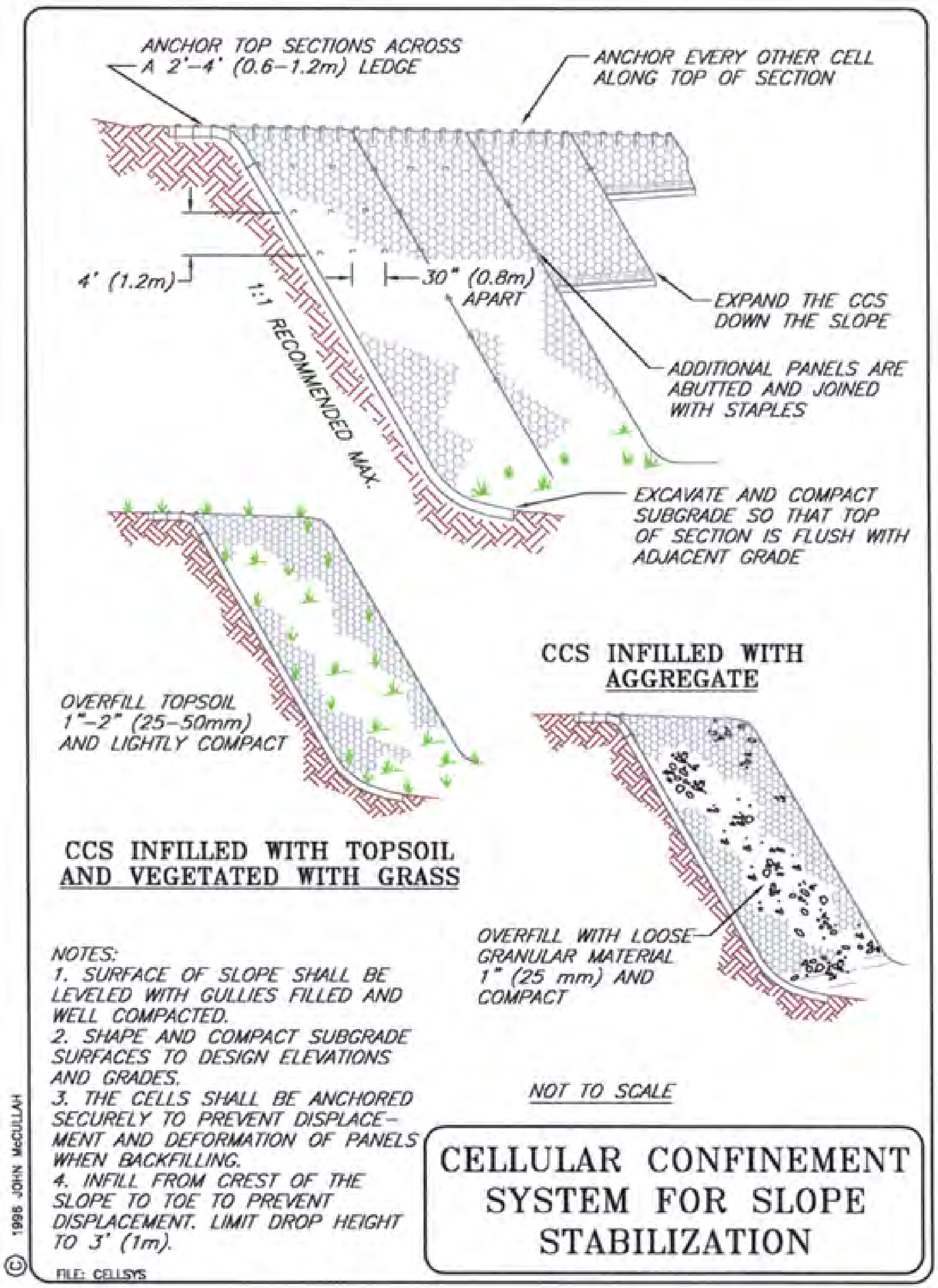


Figure 5-6. Cellular Confinement System for Slope Stabilization.

SS-10 PAM (Polyacrylamide)

SWPPP Summary

SS-10 PAM (Polyacrylamide) is useful as temporary soil stabilization and soil binding BMP which is also a flocculating agent used to reduce turbidity of runoff. PAM is also used as a tackifier, either alone or in formulation with other binding agents, for hydromulching applications.

Definition / Purpose

Surface applications of PAM bind and aggregate soil particles, which reduces the potential for raindrop, scour, or wind erosion. Stormwater treatments with PAMs promote flocculation, settling of fine soil particles, and reduced turbidity in stormwater discharged from sediment basins.

SS-10 PAM is a temporary soil stabilization BMP. It can be dry applied or wet applied to the DSA to reduce raindrop erosion and wind erosion. PAM can be effective if applied alone but effectiveness is enhanced if used to augment other soil cover BMPs, see SS-6.3.1 PAM Fiber Matrix (PFM or SFM®).

PAM is a chemical polymer which binds soil particles and is used to flocculate suspended particles. PAM aggregates soil particles, which not only binds the soil together it also increases pore space and volume. Increasing pore space will increase infiltration rates which result in less runoff and subsequently, runoff erosion.

Suspended sediments from PAM treated soils exhibit increased flocculation over untreated soils. The increased flocculation aids in their deposition, thus reducing stormwater runoff turbidity and improving water quality.

In the Pacific Northwest, single wet applications of PAM to soils reduced runoff turbidity considerably up to six weeks or more (Tobiason, Jenkins et al., 2001).

It is postulated that the wet application of PAM to the soil surface before OHV events, such as hill climbs, could reduce the turbidity of runoff and reduce the migration of sediment to critical receiving waters.

Planning Considerations

PAMs are available in solid, granular, liquid, or emulsion forms. PAM is typically used in conjunction with other BMPs to increase their performance. PAM application rates, methods, and concentrations should be adjusted to maintain optimal effectiveness, which may vary with each site.

PAMs have two general erosion and sediment control applications.

1. Temporary Soil Stabilization where the PAM is applied directly to the soil surface, either;
   a. Dry Applied - Granular PAM is applied to the soil surface by uniformly broadcasting approximately 10# per acre.

b. Wet Applied – The PAM admixture is mixed and broadcast hydraulically at a dosage rate of 40-80 mg/l which corresponds to approximately 5-10 oz/ac.

2. Sediment Control – Increased sediment capture efficiency and turbidity reduction can be achieved by applying the product to storm water as it enters sediment basins. This will cause soil particles to bind together and settle within the pond.

SS-10 PAM application, when applied alone is a temporary soil stabilization BMP, providing protection for approximately 1-3 moderate rainfall events. PAM is much more effective when used with some type of fiber mulch application. The mulch fibers will help dissipate rainfall energy, falling at 20-30 fps, while the PAM aggregates the soil particles and improves infiltration rates.

PAM is being dry-applied to a slope during trials at Shasta College (2005).

PFM (PAM Fiber Matrix) is a PAM and wood fiber mixture applied here to a slope during BMP testing at Shasta College (2005).

Anionic PAMs are environmentally benign, as long as they are applied properly. Do not over apply PAM. Excessive application of PAM can lower infiltration rate or suspend solids in water, rather than promote settling. Cationic PAMs are toxic to plant roots and animals and are not recommended for use by OHMVRD.

This practice is not intended for application to surface waters of the state. At this time, for construction activities in California permitted under the General Construction Permit, it is advisable to restrict the use of PAM (anionic) to areas draining to a secondary sediment control feature, e.g., SC-4 Silt Fence, SC-7 Compost Berms and Compost Socks, SC-5 Fiber Rolls, or within construction storm water drainages that feed into pre-constructed sediment ponds or basins.

PAM can be applied to the following areas:

- PAM can be used to augment other cover practice BMPs, though it can be effective on a temporary basis if applied alone.
- Rough graded soils that will be inactive for a short period of time.
- Final graded soils before application of final stabilization (e.g. surfacing, planting, mulching).

A water truck is used to simulate a rain event on PFM. (Shasta College, 2005)

Runoff had little turbidity from PFM treatment.

Runoff was very turbid (at least a magnitude higher) from untreated control.

- Temporary access roads prior to placement of crushed rock surfacing.
- Compacted soil road base.
- Construction staging, materials storage, and layout areas.
- Soil stockpiles.
- Areas that will be mulched.
- Helps dry wet sites.
- Studies are presently being conducted to determine the value of PAMs applied to OHV trails, to reduce erosion, increase flocculation, and reduce sediment-laden runoff.

Anionic PAM is available in emulsions, powders, and gel bars or logs. It is required that other BMPs be used in combination with anionic PAM. The use of seed and mulch for additional erosion protection beyond the life of the anionic PAM is recommended. If disturbance occurs to the target area, the application of PAM should be repeated.

The following recommendations relating to design may enhance the use of, or avoid problems with the practice:

- Use 25-foot setbacks when applying anionic PAM near natural water bodies.
- Consider that performance of PAM decreases with time and exposure to ultraviolet light.
- In concentrated flow channels, the effectiveness of PAM decreases.
- Mulch to protect seed, if seed is applied with anionic PAM.
- Never add water to PAM, add PAM slowly to water. If water is added to PAM, clumping can form which can clog dispensers. This signifies incomplete dissolving of the PAM and therefore increases the risk of under-application.

- NOTE: Not all polymers are PAM.

Construction Specifications

- Application rates should to conform to manufacturer's guidelines for application.
- Wet applied PAM (anionic) has a usual concentration of 40-80 mg/l and it is applied at only 5-10 oz. /ac
- Dry applied PAM shall be uniformly broadcast at a rate of 10# /ac. The PAM can be well mixed with sand or kitty litter to aide broadcasting the material.
- Do not over apply PAM. Excessive application of PAM can lower infiltration rates or suspend solids in water, rather than promote settling.
- Anionic PAM, in pure form, should have less than or equal to 0.05% acrylamide monomer by weight, as established by the Food and Drug Administration and the Environmental Protection Agency. To maintain less than or equal to 0.05% of acrylamide monomer, the maximum application rate of PAM, in pure form, should not exceed 200 pounds/acre/year.
- The application method should ensure uniform coverage to the target and avoid drift to non-target areas including waters of the state.
- Additives to PAM such as fertilizers, solubility promoters, or inhibitors, should be nontoxic
- The manufacturer or supplier should provide written application methods for PAM and PAM mixtures.
- The manufacturer or supplier should also provide written instructions to ensure proper safety, storage, and mixing of the product.
- Gel bars or logs of anionic PAM mixtures may be used in ditch systems. This application should meet the same testing requirement as anionic PAM emulsions and powders.
- Users of anionic PAM should obtain and follow all Material Safety Data Sheet requirements and manufacturer's recommendations.

Limitations

Toxicity:

- PAMs are classified according to their molecular weight, and ionic charge or ionicity is categorized as anionic, cationic, or nonionic. The literature indicates that anionic PAMs of higher molecular weight, such as Chemco 9107GD and 9836A, provide the best results and present little concern for toxicity (Sojka and Lentz, 1996).
- Effective doses of anionic PAM for water and soil treatment are generally an order of magnitude or more below toxic concentrations. However, the longevity of the polymers is uncertain and multiple applications can result in the accumulation of high levels downstream.

- To prevent exceeding the acrylamide monomer limit in the event of a spill, the anionic PAM in pure form should not exceed 200 pounds/batch at 0.05% acrylamide monomer (AMD) or 400 pounds/batch at 0.025% AMD.

Inspection and Maintenance

Inspections should be made before anticipated storm events (or series of storm events such as intermittent showers over one or more days) and within 24 hours after the end of a storm event of 0.5 inches or greater, and at least once every fourteen calendar days. Maintenance needs identified in inspections or by other means shall be accomplished before the next storm event if possible, but in no case more than seven days after the need is identified. Maintenance will consist of reapplying anionic PAM to disturbed areas including high use traffic areas that interfere in the performance of this practice.

SS-11 Dust Control and Tackifiers

SWPPP Summary

Wind erosion (dust) control shall be considered year-round for all disturbed soils in the park that are subject to wind erosion, when significant windy, dry conditions are anticipated, particularly during large special OHV events, around camping areas, and on areas of facility construction. Tackifiers also act as a "glue" to hold soil in place for dust control, by mixing with water and a small amount of hydraulic mulch for trace purposes, and applying from a hydroseeder.

Organic dust suppressants can be used to control dust and stabilize soil. (Carnegie SVRA)

Definition / Purpose

Wind erosion (dust control) consists of applying water or other dust palliatives as necessary to prevent or alleviate dust nuisance. Other best management practices such as hydraulic mulching, hydroseeding, soil binders, straw mulch, and erosion control blankets can also be used to control dust.

Some of the same products used as tackifiers in hydroseeding can be used to reduce dust and contain soil for longer periods of time.

Planning Considerations

This practice is implemented on exposed soils subject to wind erosion. The effectiveness depends on soil, temperature, humidity and wind velocity. Carnegie SVRA applies a non-corrosive magnesium chloride dust suppressant to the Main Park Road, campgrounds, and staging areas every spring. Water is also used for dust control on an as-needed basis.

Construction Specifications

- Water shall be applied by means of pressure-type distributors or pipelines equipped with a spray system or hoses and nozzles that will ensure even distribution.
- All distribution equipment shall be equipped with a positive means of shutoff.
- Unless water is applied by means of pipelines, at least one mobile unit shall be available at all times to apply water or dust palliative to the project or event.
- If reclaimed water is used, the sources and discharge must meet California Department of Health Services water reclamation criteria and the Regional Water Quality Control Board requirements. Non-potable water shall not be conveyed in tanks or drain pipes that will be used to convey potable water and there shall be no connection between potable and non-potable supplies. Non-potable tanks, pipes and other conveyances shall be marked "NON-POTABLE WATER – DO NOT DRINK" (Caltrans, 2003).

- Materials applied as temporary soil stabilizers and soil binders will also provide wind erosion control benefits. There are several different kinds of tackifiers and each has its own advantages, depending on the needs of the situation. Tackifiers are often classified into two categories: organic and synthetic.
- Tackifiers come in both dry and liquid forms and have various mixing requirements. It's important to read and understand product literature when it comes to mixing, curing times, temperature requirements, and other variables.

Inspection and Maintenance

Check areas that have been protected to ensure that BMPs are properly working, reapply dust controls if necessary.

Dust control reduces the surface and air transport of dust, which minimizes pollutants from infiltrating into the storm water. (Carnegie SVRA)

Water spraying is a temporary mechanical method that confines and settles the dust from the air by dust and water particle adhesion. (Carnegie SVRA)

6. TRACKING CONTROL (TC)

"Tracking Control" prevents or reduces the tracking of mud and dirt off construction sites onto public roadways, and ultimately prevents sediment from entering a watercourse.

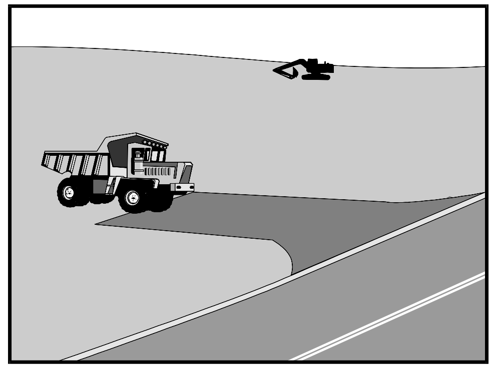
Tracking controls should be implemented year-round, as needed, to reduce the tracking of sediment from the park. During facility construction activities or special events, exits to the park should be inspected daily, and controls implemented as needed.

Maintenance and monitoring of tracking control practices is essential, especially during wet weather.

The National Pollutant Discharge Elimination System (NPDES) Construction General Permit for Stormwater Discharges Associated with *Construction* Activity requires the use of BMPs to reduce the tracking of sediment onto public or private roads at all times. (Section A.8)

TC-1 Stabilized Construction Entrance

SWPPP Summary



Temporary construction entrances are constructed at the egress point from the construction area onto a paved road. TC-1 Stabilized Construction Entrance is a *Tracking Control* BMP intended to prevent tracking of soil from the construction site by equipment and vehicles. The entrances are constructed of large angular rock and/or steel ribs (rumble strips) intended to knock the mud off the tires before traveling onto the roadway.

Definition / Purpose

The TC-1 Stabilized Construction Entrance is a 50-foot long (minimum) stabilized driving surface. The entrance/exit is covered with course angular aggregate which helps remove soil and mud off the tires of construction vehicles (or recreation vehicles) before entering a public roadway.

If the stone is not effective, the next level of BMP would include several feet of steel ribs (rumble strip) intended to help knock the mud off. If a stabilized construction entrance with rock and rumble strips is not effective, vehicle tire wash must be considered (see TC-4 Wash Racks).

Small amounts of soil tracked onto the road will also require sweeping as needed.

Planning Considerations

The California General Permit specifically calls for tracking controls and sweeping controls to prevent tracking soil onto public roadways. The soil tracked onto the roadways will effect water quality and produce dust if not sweeped and/or vacuumed on a regular basis.

It is important to designate egress areas designed to capture and contain the soil tracked by vehicles. These designated areas must be maintained as they become clogged with soil. The entrances should drain to sediment collection basin or trap. Course angular rock, well-sorted, greater than 3" diameter, is often large enough to knock the mud from the tires and the interstitial voids provide sediment storage. Some rocks, bigger than 5-6" diameter can sometimes get caught between dual truck tires and can become a hazard on the highway if not detected. The use of 'rumble strips" can make the structures more effective and can reduce the quantity of rock and length of the structure.

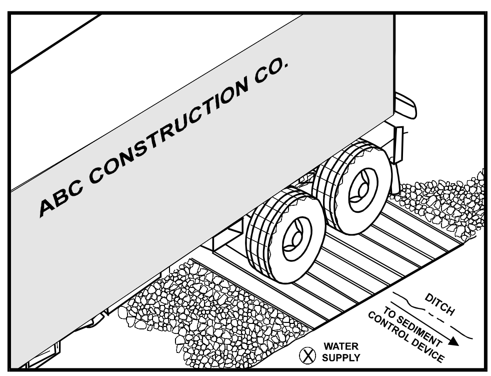
The structures must drain to sediment capture area, not onto the roadway. The use of TC-2 (Temporary Stabilized Construction Roadway) with TC-1 can reduce the amount of soil picked up on the tires and reduces the DSA.

Rumble strips are steel ribs that help knock mud off and prevent tracking of mud onto highways.

Portable rumble strips are made from plate steel and angle iron. Rumble strips are suited for construction entrances/exits where rock alone is insufficient.

Construction Specifications

- Limit the points of entrance/exit to the construction site.
- Limit speed of vehicles to control dust.
- Properly grade each construction entrance/exit to prevent runoff from leaving the construction site.
- Route runoff from stabilized entrances/exits through a sediment-trapping device before discharge.
- Design stabilized entrance/exit to support the heaviest vehicles and equipment that will use it.
- Select construction access stabilization (aggregate, asphaltic concrete, concrete) based on longevity, required performance, and site conditions. The use of asphalt concrete (AC) grindings for stabilized construction access/roadway is not allowed.
- Use of aggregate or constructed/manufactured steel plates with ribs for entrance/exit access is allowed with written approval from the RE.
- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 6-inch depth. Crushed aggregate greater than 3 inches and smaller than 6 inches shall be used.
- Designate combination or single purpose entrances and exits to the construction site.



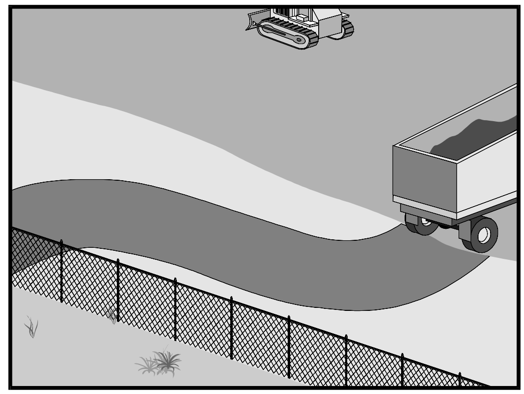
- Require all employees, subcontractors, and suppliers to utilize the stabilized construction access.

Inspection and Maintenance

- Inspect routinely for damage and assess effectiveness of the BMP. Repair if access is clogged with sediment. Remove aggregate, separate and dispose of sediment if construction entrance/exit is clogged with sediment or as directed by inspector.
- Keep all temporary roadway ditches clear.
- Inspect for damage and repair as needed.
- Remove accumulated sediment in sediment trapping devices to maintain system performance.

TC-2 Temporary Stabilized Construction Roadway

SWPPP Summary



A Temporary Stabilized Construction Roadway is a temporary access road for use during construction and expansion of facilities at the Park. It is designed and stabilized to control dust and erosion from vehicular tracking during construction activities, or if needed for special events.

Definition / Purpose

Construction roadways are stabilized access roads, stabilized staging areas, or used for short-term detour roads. TC-2 Temporary Stabilized Construction Roadways are stabilized with compacted base rock. Stabilized construction roadways are no longer considered disturbed soil areas (DSAs).

Planning Considerations

- Where mud tracking is a problem during wet weather.
- Where soil tracked onto roads may becomes dust problems during dry weather.
- Adjacent to water bodies.
- Where poor soils are encountered.
- Where there are steep grades and additional traction is needed.

Construction Specifications

- Properly grade roadway to prevent runoff from leaving the construction area.
- Design stabilized access to support the heaviest vehicles and equipment that will use it.
- Stabilize roadway using appropriate aggregate for performance and site conditions.
- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 12 in depth.

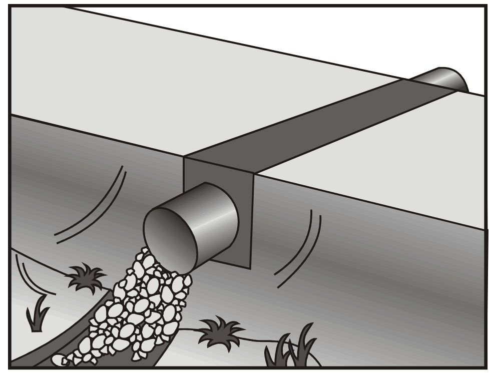
Limitations

- Materials may need to be removed prior to final project grading and stabilization.
- Site conditions will dictate design and need.
- May not be applicable to very short duration projects or events.
- Limit speed of vehicles to control dust.

Inspection and Maintenance

Inspect routinely for damage and repair as needed. Keep all temporary roadway ditches clear. When no longer required, remove stabilized construction roadway and regrade and repair slopes.

TC-3 Temporary Equipment Crossings



SWPPP Summary

A temporary equipment crossing is a structure placed across a waterway that allows heavy equipment and other vehicles to cross the waterway during construction or maintenance activities. Proper design, installation, and maintenance of TC-3 Temporary Equipment Crossings shall be implemented in order to minimize sedimentation and ecological damage to waterways.

Definition / Purpose

This BMP minimizes sedimentation and ecological damage caused by vehicles which must temporarily cross the waterway.

Planning Considerations

Temporary equipment crossings are installed at sites:

- Where appropriate permits have been secured (1601 Agreements, 404 Permits, and 401 Certification).
- Where construction equipment or maintenance vehicles need to frequently cross a waterway.
- When alternate access routes impose significant constraints.
- When crossing perennial streams or waterways causes significant erosion.
- Where construction activities will not last longer than one year.

Location of temporary equipment crossings shall address:

- Site selection where erosion potential is low.
- Areas where the side slopes from road runoff will not spill into the side slopes of the crossing.

The following types of temporary stream crossings shall be considered:

- Culverts - Used on perennial and intermittent streams. Also see RT-8 Culvert Crossing.
- Fords – Appropriate during the dry season in arid areas. Used on dry washes and ephemeral streams, and low flow perennial streams. Cellular confinement systems work well as ford crossings and are appropriate for use in streams. Also see RT-10 Low Water Crossings, and SS-9 Cellular Confinement Systems.
- Bridges – Appropriate for streams with high flow velocities, steep gradients and/or where temporary restrictions in the channel are not allowed.
- Avoid oil or other potentially hazardous waste materials for surface treatment.

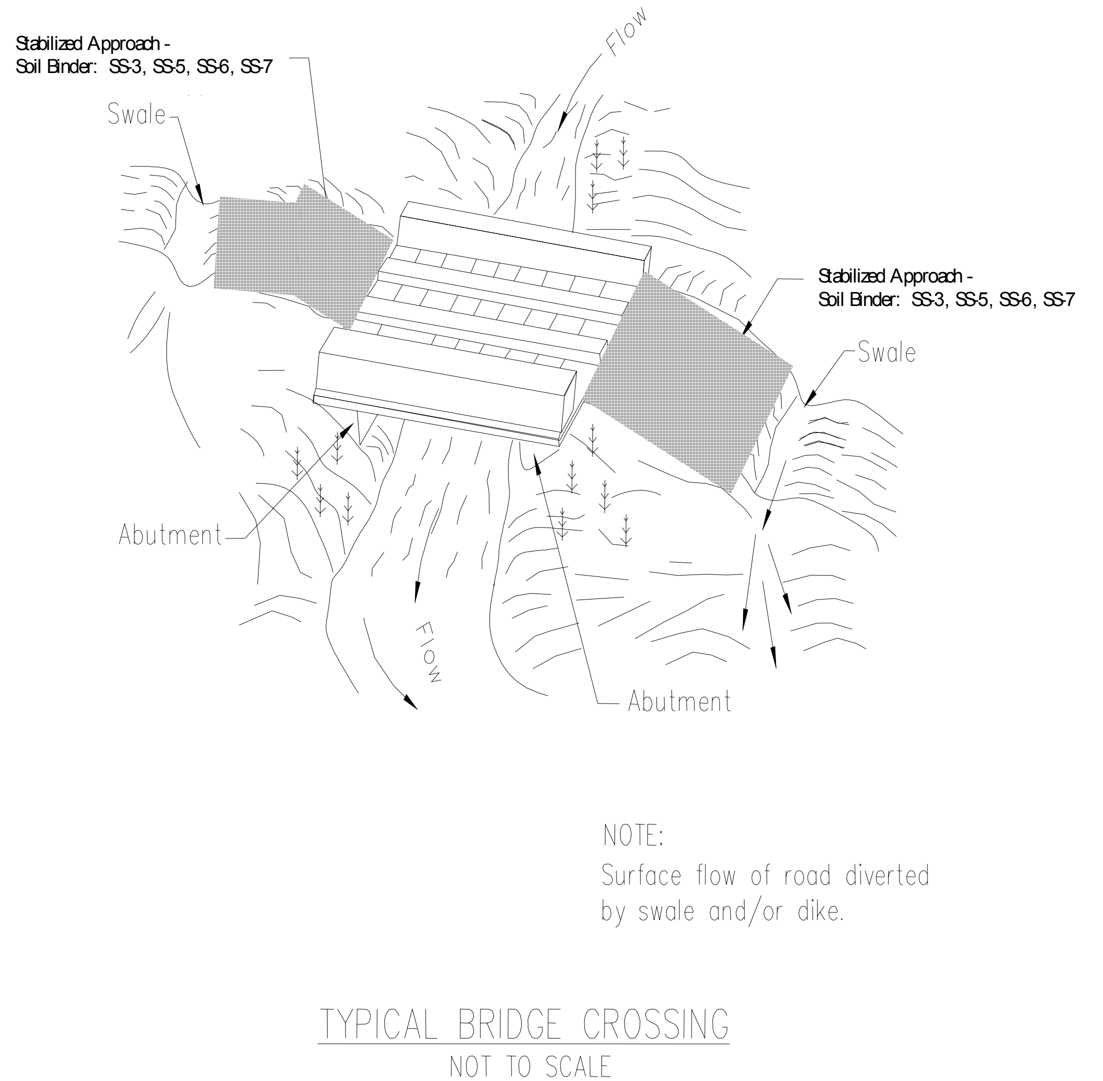


Figure 6-1. Temporary Bridge Crossing (from Caltrans Construction Site BMP Manual, 2003).

Construction Specifications

- Stabilize construction roadways, adjacent work area, and stream bottom against erosion.
- Construct during dry periods to minimize stream disturbance and reduce costs.

Design and installation requires knowledge of stream flows and soil strength. Designs shall be prepared under direction of, and approved by, a registered civil and/or structural engineer. Both hydraulic and construction loading requirements shall be considered with the following:

- Comply with the requirements for culvert and bridge crossings, particularly if the temporary stream crossing will remain through the rainy season.

- Provide stability in the crossing and adjacent areas to withstand the design flow. The design flow and safety factor shall be selected based on careful evaluation of the risks due to over topping, flow backups, or washout.

Limitations

- Will usually disturb the waterway during installation and removal.
- May require Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit and approval by California Department of Fish and Game. If numerical-based water quality standards are mentioned in any of these and other related permits, testing and sampling may be required.
- Installation may require dewatering or temporary diversion of the stream.
- May become a constriction in the waterway, which can obstruct flood flow and cause flow backups or washouts. If improperly designed, flow backups can increase the pollutant load through washouts and scouring.
- Use of natural or other gravel in the stream for construction of cellular confinement systems (ford crossings) will be contingent upon approval by fisheries agencies.
- Ford crossings may degrade water quality due to contact with vehicles and equipment.
- Temporary equipment crossings should not be used in excessively high or fast flows.
- Upon completion of construction activities, artificial crossings such as cellular confinement systems must be removed from the stream.

Inspection and Maintenance

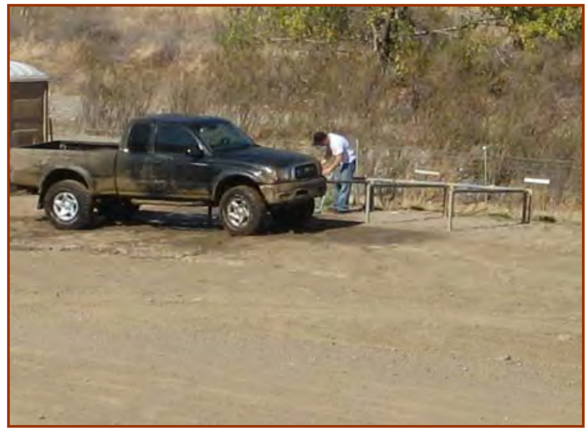
- Inspections for TC-3 Temporary Equipment Crossings shall, at a minimum, occur weekly and after each significant rainfall.
- Periodically inspect crossings to ensure stability is intact, and repair as necessary.
- Periodically remove debris behind fords, in culverts, and under bridges.
- Check for erosion of abutments, channel scour, riprap displacement, or piping in the soil.
- Check for structural weakening of the temporary crossing, such as cracks, and undermining of foundations and abutments.

TC-4 Wash Racks

SWPPP Summary

OHV park visitors often like to leave with mud-covered trucks. However, wash racks shall be used where mud and dirt is tracked onto public roads. Wash racks shall be located near paved or stabilized gravel roadways to remove soil and sediment from motorcycles and ATV's. The wash rack would be located at a point where vehicles exit the park.

During construction of roads, trails and new park facilities, wash racks shall be located in the staging areas to remove soil and sediment from construction equipment. Runoff from all wash racks will be channeled away from natural drainages and into sediment traps.



One gallon of oil has the potential to contaminate up to one million gallons of water. Wash areas should drain into a sediment trapping device, as the runoff and accumulated sediment *may* have to be treated as hazardous materials, due to hydrocarbons, solvents, etc., from vehicles.

Definition / Purpose

Mud and dirt is removed from tires and undercarriages in order to prevent sediment from being tracked onto public roadways.

Planning Considerations

This BMP should be used during special events, during wet weather, during large-scale construction of park facilities or new roads/trails, or any other time when mud may be tracked off-site.

Construction Specifications

- Construct on level ground when possible, on a pad of coarse aggregate, greater than 3 in and smaller than 6 in. A geotextile fabric shall be placed below the aggregate.
- Wash rack shall be designed and constructed/manufactured for anticipated traffic loads.
- Provide a drainage ditch that will convey the runoff from the wash area to a sediment trapping device (SC-2 Sediment Traps). The drainage ditch shall be of sufficient grade, width, and depth to carry the wash runoff.
- Require all park visitors and employees that leave the site with mud-caked tires and/or undercarriages to use the wash facility.

Limitations

This best management practice will require a supply of wash water, as well as a turnout, doublewide exit or other area to avoid blocking the exit/entrance to park.

Also refer to PO-6 Solid and Liquid Waste Management, on best management guidelines for wash water that may be contaminated with oil residue or other harmful pollutants.

Inspection and Maintenance

Remove accumulated sediment in wash rack and/or sediment trap to maintain system performance, and dispose of properly (also see PO-5 Stockpile Management). Inspect routinely for damage and repair as needed.

Mud pit at Carnegie SVRA.

7. RUNOFF CONTROL (RC)

"Runoff Control" relates to hydrological impacts of the area of activity. Road and trail construction usually results in diversions of the natural hydrological flow (drainage patterns). Roads, trails, and other park activities also contribute to impermeable surfaces, which can increase the volume and velocity of runoff. Increases of runoff volume and velocity lead to increased erosion (gullying), and in the runoff sediment is transported and delivered into streams unless it is captured using Sediment Control (SC) BMPs. The *best* way to control runoff is to use Erosion Prevention (EP) and Road and Trail Drainage (RT) measures and *prevent* runoff concentration in the first place, such as scheduling, outsloping roads, and properly installing rolling dips on trails.

Road and trail design should always ensure that runoff water and drainage from the trail is collected in a stabilized area or sediment basin.

As described here, Runoff Control BMPs are practices which control already-concentrated flow in the best way to prevent gullying, deliver the outlet of runoff as gently as possible, or prevent scour of the area where the runoff is delivered. Some examples of runoff control include; outlet protection (energy dissipators), diversion dikes, slope drains, rock-lined channels, and grass-lined channels. *Runoff control involves the use of structures to reduce velocities and/or safely carry concentrated flow in a manner which reduces erosion and sediment transport.*

To reduce runoff impacts implement practices which use the 4 D's.

Decrease - decrease the amount of runoff

Detain - decrease the velocity

Divert - divert runoff to less erodible areas

Dissipate - spread the runoff out

Roads and trails usually result in diversions of the natural drainage patterns of a hillside. Certain design practices, such as the use of rolling dips and outsloping, are ideal for maintaining natural drainage patterns, but are not always possible. When it is necessary to channelize runoff (such as crowned roads, insloped trails, and culverts), use Runoff Control BMPs to transport the runoff as gently as possible to a stabilized area or a Sediment Control BMP.

BMPs which reduce runoff velocity, such as check dams, can also reduce the potential for sediment transport. However, check dams should only be used as a temporary measure while a channel is permanently establishing vegetation. Check dams used for gully repair are permanent "grade control structures" and should be designed by qualified professionals.

RC-1 Energy Dissipator.

Although hydrology is not an exact science, it is possible to obtain solutions that are functionally acceptable to form the basis for design of roads and trails. The relatively simple "Rational Formula", an empirical method, is generally adequate for estimating the rate and volume of runoff for the design calculations of Runoff Control BMPs.

Rational Formula: $Q = CiA$

Q = *Design discharge in cubic feet per second*

C = *Coefficient of runoff*

i = *Average rainfall intensity in inches per hour for the selected frequency and for a duration equal to the time of concentration*

A = *Drainage area in acres*

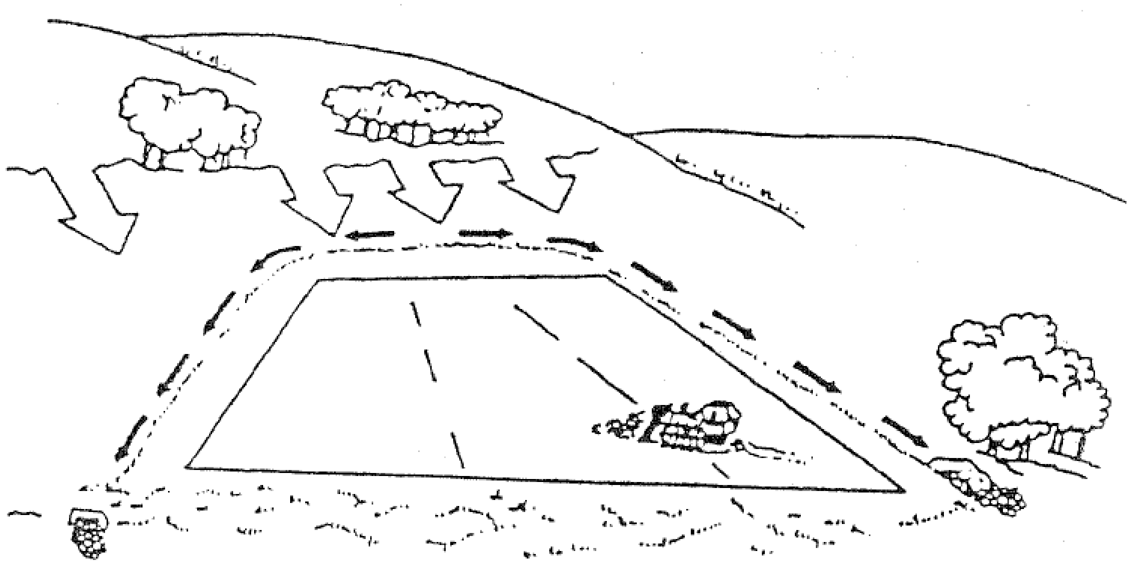
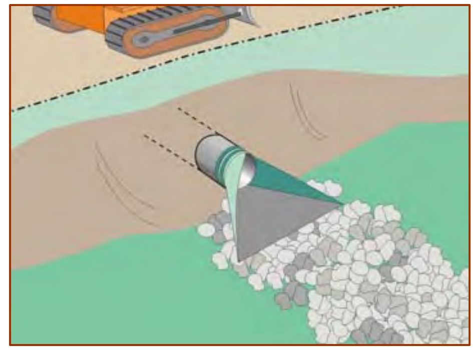


Figure 7-1. Use Of Perimeter Dikes As Diversions (North Carolina Erosion And Sediment Control Manual, 1988). Also see RC-5 Diversion Dikes and Diversion Swales.

RC-1 Energy Dissipator

<u>SWPPP Summary</u>



An energy dissipator is a structure designed to control erosion at the outlet of a channel or conduit.

<u>Definition / Purpose</u>

Energy dissipators prevent erosion at the outlet or transition zone of a stormwater conduit. Energy dissipators generally reduce the velocity of flow by dissipating or spreading out the flow energy.

<u>Planning Considerations</u>

These structures are most commonly used at:

- Outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits or channels.
- Outlets located at the bottom of mild to steep slopes.
- Discharge outlets that carry continuous flows of water.
- Points where lined conveyances discharge to unlined conveyances.
- Outlets subject to short, intense flows of water, such as flash floods.

The outlets of channels, conduits, culverts, diversion structures, downdrains and other structures are points of high erosion potential, because they frequently carry flows at velocities that exceed the allowable limit for the area downstream. To prevent scour and undermining, an outlet stabilization or transition structure is needed to absorb the impact of the flow and reduce the velocity to non-erosive levels.

Riprap apron-type Energy Dissipator.

A riprap-lined apron is the most commonly used practice for this purpose because of its relatively low cost and ease of installation. The riprap apron may need to be extended downstream until stable conditions are reached, even though this transition zone may exceed the length calculated for design velocity control.

There are several alternatives to carry runoff through the transition zone from the outlet of the pipe to a stable outlet. The designer might consider Articulated Concrete Block (ACB) system or Scour Stop®, a new permanent structural protection made from recycled plastic that can be vegetated. Recent University testing has demonstrated that Scour Stop® can prevent erosion at high velocities and shear – comparable to ACBs.

Riprap-stilling basins or plunge pools reduce flow velocity rapidly. They should be considered in lieu of aprons where overfalls exit at the ends of pipes or where high flows would require excessive apron length. Consider other energy dissipators such as concrete impact basins or paved outlet structures where site conditions warrant. Some local codes require permanent concrete energy dissipators.

Both a conventional rock energy dissipator and the Scour Stop® were demonstrated at the Shasta College ECTF. (J. McCullah, 2007)

Structures like Scour Stop® or level-spreaders dissipate energy by spreading the flows. Trials at Shasta College Erosion Control Training Facility (ECTF) demonstrated that both techniques, spreading the energy or absorbing the energy against rock, were equally effective, however spreading the flows out allows vegetation to become established.

Design Criteria:

There are three basic types of energy dissipators commonly used:

- Pools; Rock-armored stilling pool, concrete, or grouted riprap spreader.
- Riprap Aprons; Large loose rock dissipators, these can also be engineered from concrete pylons or blocks.
- Transitional Devices; Transition runoff from concentrated to spread out - thence into channels.

The energy dissipator and the energy spreader appeared comparable – both withstood velocities exceeding 12 fps. (J. McCullah, 2007)

Riprap aprons are the most common devices used during construction.

The criteria for design of *riprap aprons* are:

Capacity: 10-year peak runoff or the design discharge of the water conveyance structure, whichever is greater.

Tailwater Depth: Determine the depth of the tailwater immediately below the pipe outlet based on the design discharge plus other contributing flows. If the tailwater depth is less than half the diameter of the outlet pipe and the receiving stream is sufficiently wide to accept the divergence of flow, it is classed as a minimum tailwater condition.

If the tailwater depth is greater than half the pipe diameter, it is classed as a maximum tailwater condition. Pipes that outlet onto broad flat areas with no defined channel may be assumed to have a minimum tailwater condition unless site conditions indicate otherwise.

Apron Size: The apron length and width can be determined according to the tailwater condition. If the water conveyance structure discharges directly into a well-defined channel, extend the apron across the channel bottom and up the channel banks to an elevation of 0.5 feet (150 mm) above the maximum tailwater depth or to the top of the bank, whichever is less.

Determine the maximum allowable velocity for the receiving stream, and design the riprap apron to reduce the flow to this velocity before the flow leaves the apron. Calculate the apron length for velocity control or use the length required to meet stable conditions downstream, whichever is greater.

Grade: Ensure that the apron has zero grade. There should be no overfall at the end of the apron; that is, the elevation of the top of the apron, at the downstream end, should be the same as the elevation of the bottom of the receiving channel or the adjacent ground if there is no channel.

Alignment: The apron should be straight throughout its entire length, but if a curve is necessary to align the apron with the receiving stream, locate the curve in the upstream section of riprap.

Materials: Ensure that riprap consists of a well-graded mixture of stone. Larger stone should predominate, with sufficient smaller sizes to fill the voids between the stones. The diameter of the largest stone size should be no greater than 1.5 times the d50 size.

Thickness: The minimum thickness of riprap shall be 1.5 times the maximum stone diameter.

Stone Quality: The rock should be hard, angular, and highly weather-resistant. The specific gravity of the individual stones should be at least 2.5.

Filter: Install a filter to prevent soil movement through the openings in the riprap. The filter should consist of a graded gravel layer or a synthetic filter cloth.

Table 7-1 provides general guidelines for rock size (D50) and apron length based on the culvert diameter and discharge (Q). The detailed typical drawing, Figure 7-2, also provides guidance for designing and building a riprap apron-type dissipator.

<u>Construction Specifications</u>

- Ensure that the subgrade excavation is deep enough for the filter and riprap. Compact any fill required in the subgrade to the density of the surrounding undisturbed material. Low areas in the subgrade on undisturbed soil may also be filled by increasing the riprap thickness.
- Construct the apron on zero grade with no overfall at the end. Make the top of the riprap at the downstream end level with the receiving area or slightly below it.
- Ensure that the apron is properly aligned with the receiving stream and preferably straight throughout its length. If a curve is needed to fit site conditions, place it in the upper section of the apron.
- Riprap may be field stone or rough quarry stone. It should be hard, angular, highly weather-resistant and well graded.

- The minimum thickness of the riprap should be 1.5 times the maximum stone diameter.
- Geotextile or filter cloth, when used, must meet design requirements and be properly protected from punching or tearing during installation. Repair any damaged fabric by removing the riprap and placing another piece of filter cloth over the damaged area.
- All connecting joints should overlap a minimum of 1 foot. If the damage is extensive, replace the entire filter cloth.
- Riprap may be placed by equipment, but take care to avoid damaging the filter.
- Immediately after construction, stabilize all disturbed areas with vegetation.

Inspection and Maintenance

Inspect riprap outlet structures after heavy rains to see if any erosion around or below the riprap has taken place or if stones have been dislodged. Immediately make all needed repairs to prevent further damage.

Pipe Diameter (inches)	*Discharge* (ft^3/s)*	*Apron Length (feet)*	*Rip Rap D_{50} Diameter (Min inches)*
12	5 10	10 13	4 6
18	10 20 30 40	10 16 23 26	6 8 12 16
24	30 40 50 60	16 26 26 30	8 8 12 16

*For higher flows consult a Registered Civil Engineer.

Table 7-1. Riprap size and apron length criteria based on culvert diameter and discharge (CASQA, 2003).

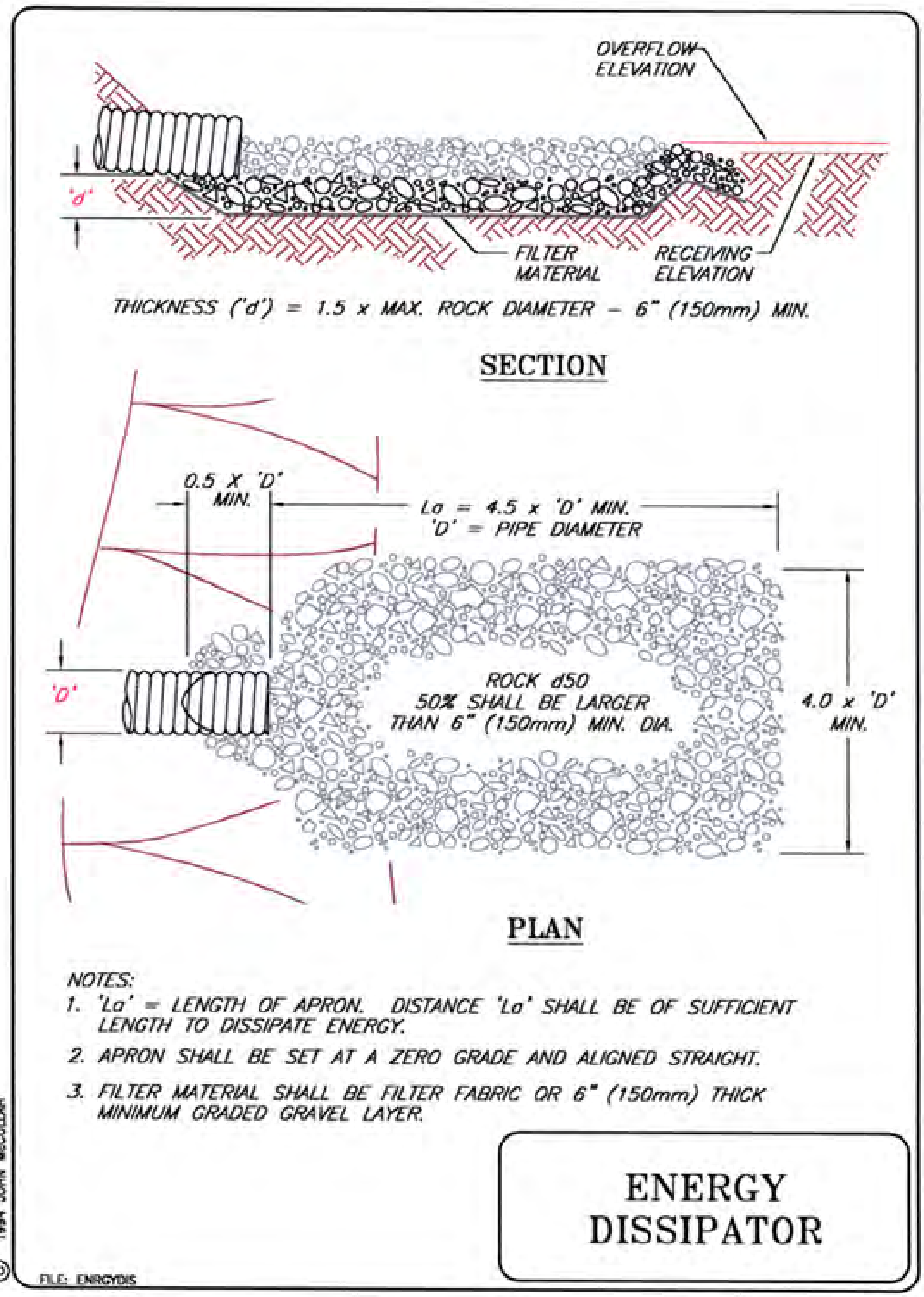


Figure 7-2. Typical Energy Dissipator- shows a typical riprap apron-type dissipator. The drawing also provides guidance for designing rock size (d50) and length of apron based on 'D' – culvert diameter.

Riprap apron installed step by step. First the apron area, determined by culvert size, e.g., 4.5 x Dia= apron length.

Apron is "overcut" to accommodate riprap thickness, and then lined with anchored geotextile.

Outlet structure is non-eroding at 1/2 pipe-full discharge, approximately 10-12 fps.

The structure is intact after trials.

RC-2 Rock-lined Channel

SWPPP Summary

Rock-lined channels are channels or roadside ditches lined with rock or riprap and incorporated into road and trail design in order to reduce sedimentation and improve the quality of surface water. Rock-lined channels shall be used to convey runoff and provide bed stability where an unlined or grassed waterway would be inadequate.

RC-2 Rock-lined Channels.

Definition / Purpose

RC-2 Rock-lined Channels convey concentrated surface runoff without erosion.

Planning Considerations

This practice applies where design flow exceeds 2 ft/sec (.61 m/sec) such that channel lining is required, but conditions are not suitable for vegetative protection. Specific conditions include:

- All roadside ditches or drainage channels greater than 2% and located in highly erodible soils that have a low maximum permissible velocity.
- The channel design velocity exceeds that allowable for a grass-lined channel.
- The channel will continue to down-cut without protection because it is adjusting to increased flow or a new base line (outlet elevation).

Design Criteria:

- Capacity: peak runoff from 10 year storm.
- Side slopes: 2:1 or flatter.
- Stone size: d = 2 inch minimum. Use engineering design procedures for sizing riprap for large or critical drainage channels. See ABAG (1995) and NCSCC (1988) for the design of stable channels.
- Riprap thickness: T = 1.5 times the stone diameter or as shown on the plans; 6 inch thick minimum.
- Foundation: Extra-strength filter fabric or an aggregate filter layer, if required.
- Use a foundation for decomposed granite sands or other highly erodible soils.
- Channel cross section should conform as shown on plans for design high flow.
- Outlet must be stable.

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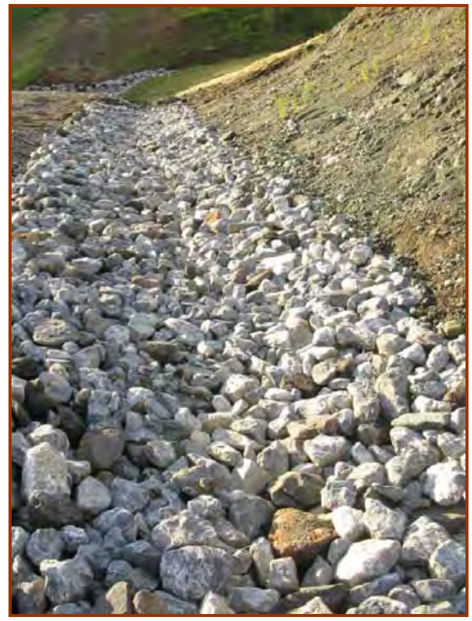
Construction Specifications

- Excavate cross section to the grades shown on plans. Overcut for thickness of rock and filter.
- Place filter fabric or gravel filter layer, and rock as soon as the foundation is prepared.
- Place rock so it forms a dense, uniform, well-graded mass with few voids. Hand placement may be necessary to obtain good size distribution.
- No overfall of channel construction should exist. Grass-lined channels with riprap bottoms must have a smooth contact between riprap and vegetation.
- Channel outlet shall be stabilized.



Rock should be placed in a dense, uniform, well-graded mass with few voids.

Inspection and Maintenance

Inspect channels at regular intervals and after major storms. Remove debris and make needed repairs where stones have been displaced. Take care not to restrict the flow area when stones are replaced.

Give special attention to outlets and points where any concentrated flow enters the channel. Repair eroded areas promptly. Check for sediment accumulation, piping, bank instability, and scour holes and repair promptly.

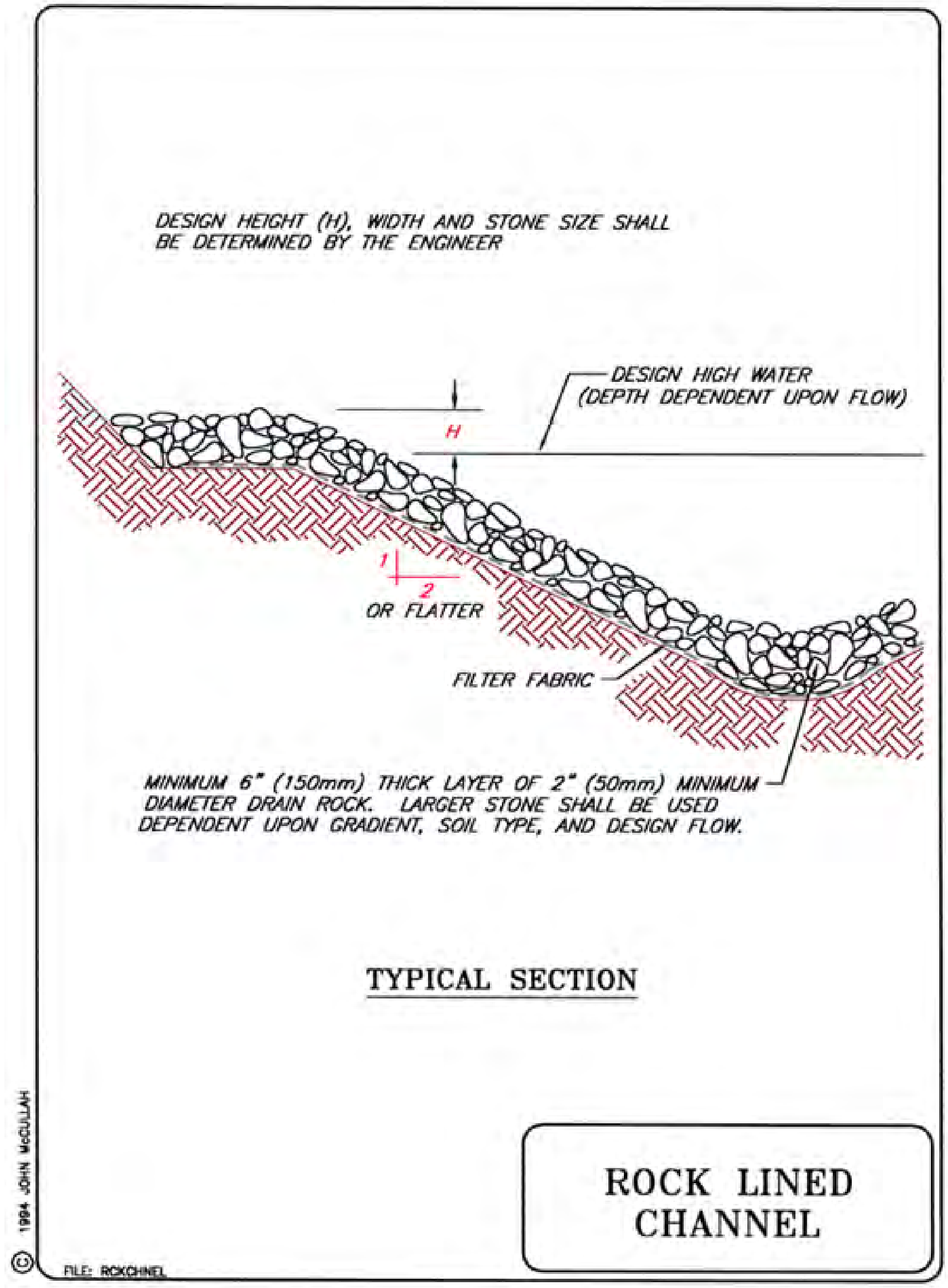


Figure 7-3. Rock Lined Channel.

RC-3 Riprap

SWPPP Summary

Riprap is a layer of stone designed to protect and stabilize areas subject to erosion. Riprap is a versatile, highly erosion-resistant material that can be used effectively in many locations and in a variety of ways to control erosion on construction sites, slopes, roadsides, and streambanks.

Riprap improves the stability of slopes that are subject to seepage.

Definition / Purpose

RC-3 Riprap protects the soil surface from erosive forces and/or improve stability of soil slopes that are subject to seepage or have poor soil structure. See RR-5 Vegetated Riprap BMP for guidelines for incorporating vegetation into riprap installation.

Riprap is used for the following applications:

- Cut-and-fill slopes subject to seepage or weathering, particularly where conditions prohibit establishment of vegetation.
- Channel side slopes and bottoms.
- Inlets and outlets for culverts, bridges, slope drains, grade stabilization structures, and storm drains.
- Streambank and stream grades.

Planning Considerations

Graded Versus Uniform Riprap:

Riprap is classed as either graded or uniform. Graded riprap includes a wide mixture of stone sizes. Uniform riprap consists of stones nearly all the same size.

Graded riprap is preferred to uniform riprap in most applications because it forms a dense, flexible cover. Uniform riprap is more open and cannot adjust as effectively to movement of the stones. Graded riprap is also cheaper to install requiring less hand work for installation than uniform riprap, which must be placed in a uniform pattern. Uniform riprap may give a more pleasing appearance.

Riprap sizes are designated by either the mean diameter or the weight of the stones. The diameter specification is often misleading since the stones are usually angular. However, common practice is to specify stone size by the diameter of an equivalent size of spherical stone. Table 7-2 lists some typical stones by weight, spherical diameter, and the corresponding rectangular dimensions. These stone sizes are based upon an assumed specific weight of 165 lbs/ft3 (2600 kg/m3).

Weight lbs. (kg)	**Spherical Dia. ft (m)**	**Length ft (m)**	**width/height ft (m)**
50 (22.7)	0.6 (.2)	1.4 (.4)	0.5 (.3)
100 (45.4)	1.1 (.3)	1.8 (.6)	0.5 (.2)
150 (68.0)	1.3 (.4)	2.0 (.6)	0.7 (.2)
300 (136.1)	1.6 (.5)	2.6 (.8)	0.9 (.3)
500 (226.8)	1.9 (.6)	3.0 (.9)	1.0 (.3)
1000 (453.6)	2.2 (.7)	3.7 (1.2)	1.3 (.4)
2000 (907.2)	2.8 (.9)	5.4 (1.7)	1.8 (.6)
4000 (1814.4)	3.6 (1.1)	6.0 (1.8)	2.0 (.6)

Table 7-2. Stone Sizes.

A method commonly used for specifying the range of stone sizes in graded riprap is to designate a diameter for which some percentage, by weight, will be smaller. For example "d85" specifies a mixture of stones in which 85% of the stone by weight would be smaller than the diameter specified. Most designs are based on "d50", size stones.

When considering riprap for surface stabilization, it is important to anticipate visual impacts, including weed control, hazards from snakes and other animals, danger of slides and hazards to areas below steep riprap slopes, damage and possible slides from people moving stones, and general safety.

Proper slope selection and surface preparation are essential for successful long term functioning of riprap. Adequate compaction of fill areas and proper use of filter blankets or aggregate foundation is necessary.

A pre-constructed type of riprap includes grid pavers, articulated concrete mats, concrete armor units, and interlocking concrete blocks. These are modular concrete units with interspersed void areas which can be used to armor slopes and streambanks while maintaining porosity and allowing the establishment of vegetation. These structures may be obtained in pre-cast blocks or mats, or they may be formed and poured into place. Grid pavers, articulated concrete mats, concrete armor units, and interlocking concrete blocks are installed like riprap. The specific design and installation should follow manufacturer's instructions.

Sequence of Construction:

Schedule disturbance of areas that require riprap protection so the placement of riprap can follow immediately after grading. When riprap is used for outlet protection, place the riprap before, or in conjunction with the installation of the structure so that it is in place before the first runoff event.

Design Criteria:

Gradation: Riprap should be a well-graded mixture with 50% by weight larger than the specified design size. The diameter of the largest stone size in such a mixture should be 1.5 times the d50 size with smaller sizes grading down to 1 inch.

Size: The designer should determine the riprap size that will be stable for site conditions. Having determined the design stone size, the designer should then select the size or sizes that equal or exceed riprap gradation commercially available in the area. For more design criteria see ABAG (1995), North Carolina SCC (1988), and Virginia DOCR (1992).

Thickness: Construction techniques, dimensions of the area to be protected, size and gradation of the riprap, the frequency and duration of flow, difficulty and cost of maintenance, and consequence of failure should be considered when determining the thickness of riprap linings. The minimum thickness should be 1.5 times the maximum stone diameter, but in no case less than 6 inches.

Quality of Stone: Stone for riprap may consist of field stone or quarry stone. The stone should be hard, angular, of such quality that it will not break down on exposure to water or weathering, and suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

Size of Stone: The sizes of stone used for riprap protection are determined by purpose and specific site conditions.

Slope Stabilization: Riprap stone for slope stabilization not subject to flowing water or wave action should be sized for stability for the proposed grade. The gradient of the slope to be stabilized should be less than the natural angle of repose of the stone selected.

Riprap used for surface stabilization of slopes does not add significant resistance to sliding or slope failure and should not be considered a retaining wall. The inherent stability of the soil must be satisfactory before riprap is used for surface stabilization. Slopes approaching 1.5:1 may require special stability analysis.

Outlet Protection: Design criteria for sizing stone and determining the dimensions of riprap pads at channel or conduit outlets can be found in ABAG (1995) and other engineering design manuals.

Filter Blanket: A filter blanket is a layer of material placed between the riprap and the underlying soil to prevent soil movement into or through the riprap.

A suitable filter may consist of a well-graded gravel or sand-gravel layer or a synthetic filter fabric manufactured for this purpose. The design of a gravel filter blanket is based on the ratio of particle size in the overlying filter material to that of the base material in accordance with the criteria below. The designed gravel filter blanket may consist of several layers of increasingly large particles from sand to erosion control stone.

A *gravel filter blanket* should have the following relationship for a stable design:

$$\frac{d_{15} filter}{d_{85} base} \leq 5$$

$$5 \leq \frac{d_{15} filter}{d_{15} base} \leq 40$$

$$\frac{d_{50} filter}{d_{50} base} \leq 40$$

In these relationships, filter refers to the overlying material and base refers to the underlying material. These relationships must hold between the filter material and the base material (soil foundation) and between the riprap and the filter. More than one layer of filter material may be needed. Each layer of filter material should be at least 6 inches (150 mm) thick.

A synthetic filter fabric may be used with or in place of gravel filters. The following particle size relationships should exist:

- Filter fabric covering a base with granular particles containing 50% or less (by weight) of fine particles (less than U.S. Standard Sieve no. 200 (0.0074mm):

  $$\frac{d_{85} base\ (mm) > 1}{EOS^{*}\ filter\ fabric}$$

  *EOS - Equivalent Opening Size compared to a U.S. standard sieve size.

  Note: Total open area of filter should not exceed 36%.

- Filter fabric covering other soils: EOS is no larger than U.S. standard sieve no. 70 (0.21 mm).

  Note: Total open area of filter should not exceed 10%.

No filter fabric should have less than 4% open area or an EOS less than U.S. Standard Sieve No. 100 (0.15 mm). The permeability of the fabric must be greater than that of the soil. The fabric may be made of woven or nonwoven monofilament yarns and should meet the following minimum requirements:

a. thickness 20-60 mils (32.18-96.54 km),

b. grab strength 90-120 lbs (40.84-54.43 kg),

c. conform to ASTM D-1682 or ASTM D-177.

Filter blankets should always be provided where seepage is significant or where flow velocity and duration of flow or turbulence may cause the underlying soil particles to move through the riprap.

Construction Specifications

- Before laying riprap and filler, prepare the subgrade to the required lines and grades shown on the plans. Compact any fill required in the subgrade to a density approximating that of the surrounding undisturbed material.
- Overfill depressions with riprap.
- Remove brush, trees, stumps, and other objectionable material.
- Cut the subgrade sufficiently deep so that the finished grade of the riprap will be at the elevation of the surrounding area. Channels should be excavated sufficiently to allow placement of the riprap in a manner such that the finished inside dimensions and grade of the riprap meet design specifications.
- Place the sand and gravel filter blanket immediately after the ground foundation is prepared. For gravel, spread filter stone in a uniform layer to the specified depth. Where more than one layer of filter material is used, spread the layers with minimal mixing.
- Place the filter fabric directly on the prepared foundation. Overlap the edges by at least 12 inches (300 mm), and space anchor pins every 3 feet (1 m) along the overlap. Bury the upper and lower ends of the cloth a minimum of 12 inches (300 mm) below ground. Take care not to damage the cloth when placing riprap. If damage occurs remove the riprap and repair the sheet by adding another layer of filter material with a minimum overlap of 12 inches (300 mm) around the damaged area. If extensive damage is suspected, remove and replace the entire sheet.
- Where large stones are used or machine placement is difficult, a 4 inch (100 mm) layer of fine gravel or sand may be needed to protect the filter fabric.
- Placement of riprap should follow immediately after placement of the filter. Place riprap so that it forms a dense, well-graded mass of stone with a minimum of voids. The desired distribution of stones throughout the mass may be obtained by selective loading at the quarry and controlled dumping during final placement.
- Place riprap to its full thickness in one operation.
- Do not place riprap by dumping through chutes or other methods that cause segregation of stone sizes.
- Take care not to dislodge the underlying base or filter when placing the stones.
- The toe of the riprap slope should be keyed to a stable foundation at its base.
- The toe should be excavated to the depth about 1.5 times the design thickness of the riprap and should extend horizontally from the slope.

- The finished slope should be free of pockets of small stone or clusters of large stones. Hand placing may be necessary to achieve the proper distribution of stone sizes to produce a relatively smooth, uniform surface. The finished grade of riprap should be apparent.

Inspection and Maintenance

Properly designed and installed riprap requires very little maintenance. Riprap should be inspected periodically for scour or dislodged stones. Control of weed and brush growth may be needed in some locations.

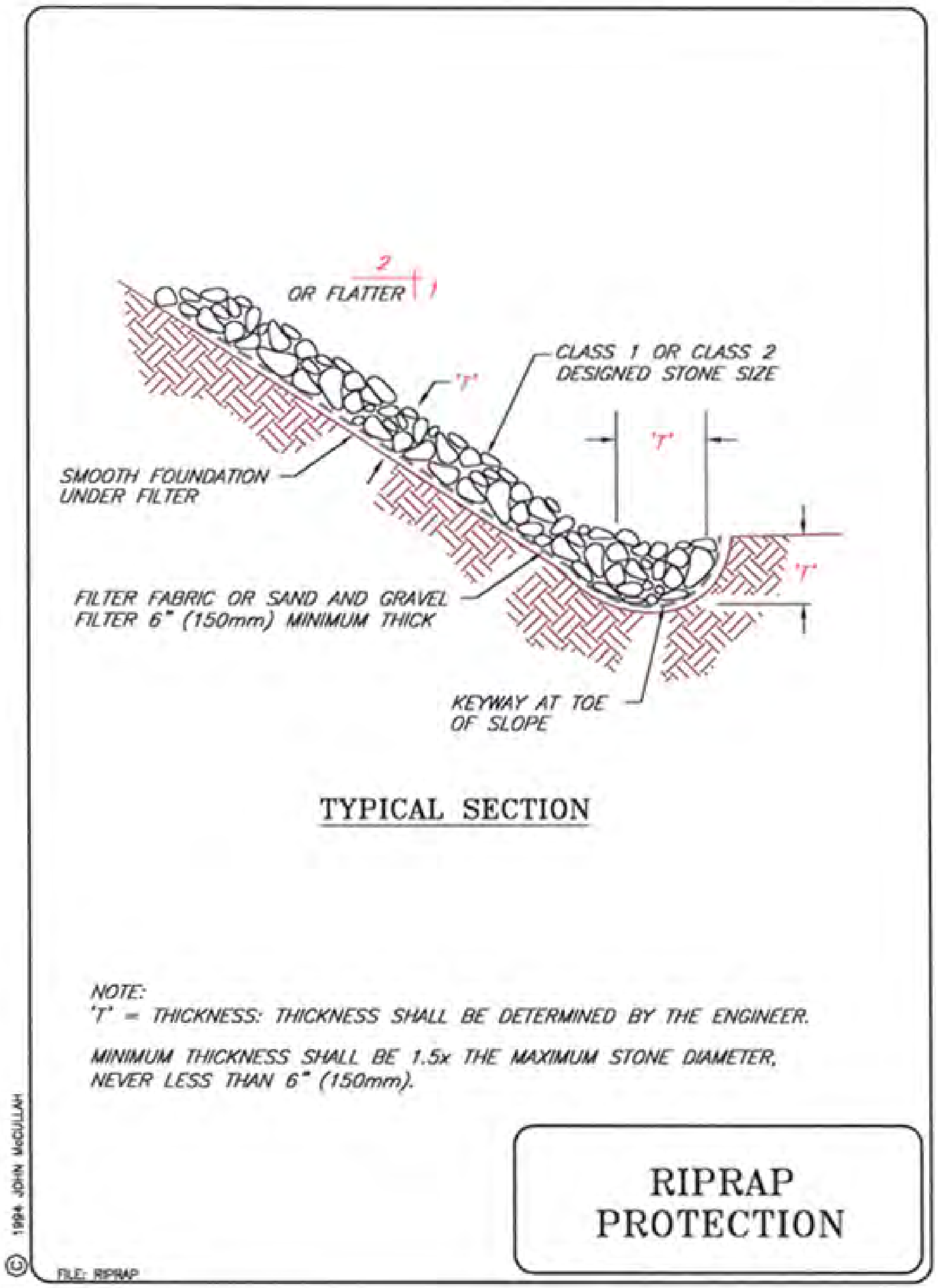
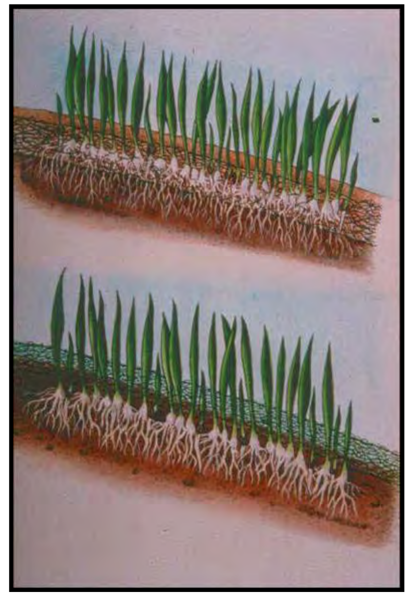


Figure 7-4. Riprap Protection.

RC-4 Turf Reinforcement Mats / Grass-lined Channels

SWPPP Summary

Turf Reinforcement Mats (TRMs) are a runoff control BMP, intended to protect soil from the tractive (erosive) forces of flowing water. They are used to line drainage conveyance channels on a temporary basis or, most commonly, until grasses or other natural vegetation becomes established (Grass-lined Channels).



TRMs are a *biotechnical* erosion control BMP. The vegetation and structural material work in a "mutually-reinforcing manner".

Vegetated TRMs are a biotechnical erosion control BMP because the structural materials (geotextile) and biological components (roots and shoots reinforcement) mutually reinforcing manner. However, some TRMs are very effective and long-lasting for use when vegetation is difficult to establish.

Definition Purpose

TRMs are a runoff control BMP because they are designed to resist the tractive force of flowing water. TRMs are specifically designed to stabilize channelized flow areas or on slopes needing additional surface structural support. Because they are so strong and durable, TRM-type products are sometimes specified and used on extremely difficult or steep slopes.

Most commonly TRMs are intended to protect the channel bottom from erosion when flows are expected to exceed the soil's maximum permissible velocity; 3 ft/sec as a general rule. Most TRMs are chosen from materials and installed in a manner that will encourage vegetation (grass) establishment.

Planning Considerations

Turf reinforcement mats are high strength, flexible, machine produced, three dimensional matrix of nylon, polyethylene, polypropylene or polyvinyl chloride. These geotextiles have ultra violet (UV) stabilizers added to the compounds to ensure endurance and provide permanent vegetation stabilization. The mats are often manufactured with an inner core of biodegradable material, usually coir, which is intended to increase moisture holding, roughness and seed protection. Heavy duty coir netting, 9 g/m^2, is

This gully repair is three years old. The biotechnical restoration included a TRM in the bottom to stabilize an ephemeral stream.

sometimes used as a channel liner which is entirely biodegradable. This material should be limited to areas relatively easy to vegetate or combined with other biotechnical measures.

The designer or planner must often choose between rock (riprap) and TRMs as erosion-resistant, channel-lining materials. TRMs or rock channel linings are preferable, even as a temporarily BMP, to check dams because these types of "channel obstructing" measures often cause erosion as they cause hydraulic jumps or flow anomalies. Turf reinforcement mats are expensive compared to standard erosion control blankets (ECBs). The channel gradients for TRMs and vegetated channels are generally less than 5%. The designer must also consider:

- If a vegetative lining can provide sufficient stability for the channel grade by increasing maximum permissible velocity;
- The site conditions required to establish vegetation i.e., climate, soils and topography are present.
- Resistance to shear stress and high velocity;
    1. Lining channels with rock is probably preferable for non-uniform drainage conveyances with uneven flow lines, turns, or impinging flow. This is where shear increases and rock or Scour Stop (see RC-1 Energy Dissipator) may be necessary.
    2. Recent studies have shown that TRMs with established grasses can withstand velocities comparable to 12-18" diameter rock - greater than 10-12 ft/sec, however. Scour Stop has been tested to resist velocities of greater than 20 ft/sec.
- Grass-lined channel systems sometimes requires a prolonged vegetation establishment period while rock-lined channels are effective immediately;
    1. Sometimes high flows can be diverted from a channel until the vegetation can be established.
    2. Temporary supplemental irrigation can be provided during the establishment period if necessary.
- Cost of materials and installation;
    1. Rock costs, availability, and transport should be considered and compared to TRM cost.
    2. Rock or riprap lining installation must have good equipment access, both for delivery and placement.
    3. TRMs are more labor intensive to install.
- Aesthetics and maintenance;
    1. Generally, grass-lined channels are more aesthetically pleasing and can be mowed and maintained easier than rock.

TRM-type blankets and mats are designed to aid the establishment of vegetation in waterways while increase the maximum permissible velocity of the given channel. The

TRMs reinforce the soil and resist the forces of erosion during runoff events. As vegetation becomes established, the stems, roots and rhizomes of the vegetation become intertwined with the mat, further reinforcing the soil and anchoring the mat. Vegetated TRM systems can often withstand twice the shear stress as non-vegetated systems. Biotechnical systems actually get stronger with time.

TRMs require a uniformly graded channel bottom and the substrate cannot to too hard or rocky so anchors can be installed. TRMs must be anchored securely to ensure complete and "intimate" contact with the soil. Terminal slots, check slots and longitudinal slots are also necessary. Sometimes a double row of closely spaced staples or anchors can substitute for an excavated check slot.

Installation of TRMs can be labor intensive because of the channel preparation work and complete anchoring that is necessary – check slots, longitudinal slots, anchor slots etc. Sometimes the TRM will be specified with the additional application of topsoil infill.

Additional Design Criteria:

- Capacity: Design flows are recommended to be sufficient to convey 10 year - 24 hour storm.
- Velocity: The allowable design velocity for grass-lined channels is based on soil conditions, type of vegetation, and method of establishment. If design velocity of a channel to be vegetated exceeds 2-4 ft/sec (0.6-1.2 m/sec), a TRM or rock liner is required.
- To reduce erosion potential, design the channel to avoid sharp bends and steep grades. The channel cross section should be wide and shallow with relatively flat side slopes so surface water can enter over the vegetated banks without erosion. Riprap may be needed to protect the channel banks at intersections where flow velocities approach allowable limits and turbulence may occur.
- *Side Slopes:* Grassed channel side slopes generally are constructed 3:1 or flatter to aid in the establishment of vegetation and for maintenance.
- *Grade:* Generally restricted to gradients of 5% or less. Either a uniform or gradually increasing grade is preferred to avoid sedimentation.
- Grass-lined channels must not be subject to severe sedimentation from disturbed areas. Sediment traps may be needed at channel inlets and outlets to prevent sedimentation.
- An established grass-lined channel resembles natural drainage systems and is usually preferred if design velocities are below 5 ft/sec (1.5 m/sec).
- Outlets should function with a minimum of erosion. The terminal slot is critical to prevent channel head-cutting.
- Channels with design velocities greater than 2 ft/sec (0.6 m/sec) will require that turf reinforcement mats, erosion control blankets, or the new Enka / Hydromulch system be used at the time of seeding to provide stability until the vegetation is fully

established. It may also be necessary to divert high erosive flows from the channel or provide supplemental irrigation until vegetation is established.

- Whenever design velocities exceed 4-5 ft/sec (1.2 m/sec) a permanent type of turf reinforcement mat with vegetation should be necessary.

TRMs, with ECBs on the channel banks, being tested at the Shasta College Erosion Control Training Facility. The top of the channel has a polypropylene (green) TRM, followed downstream by a polypropylene/coir composite. These types of TRMs are seeded under the mats.

The black TRM is Enka Mat produced from nylon. This 3-dimensional matrix can be seeded on top and then in-filled with soil.

Cross-section designs include:

V-shaped Channels:

Generally used where the quantity of water is relatively small, such as roadside ditches. The V-shaped cross section is less desirable where velocities may be high because of difficulty stabilizing the bottom. A TRM and grass lining will suffice where velocities are low. Rock or riprap lining may be necessary for high velocities.

Parabolic Grass-lined Channels:

Often used where larger flows are expected and sufficient space is available. The shape is pleasing and may best fit site conditions. Riprap should be used where higher velocities are expected and where some dissipation of energy (velocity) is desired. Combinations of grass with riprap centers or turf reinforcement mat centers are useful where there is a continuous low flow in the channel.

Trapezoidal Grass Channels:

Used where runoff volumes are large and slope is low so that velocities are non-erosive to vegetated linings. Trapezoidal channels generally have concrete or riprap lined center for low flow.

Construction Specifications

Check slots are extremely important to prevent erosive flows from getting under the mats. Check slots can be constructed per manufacturer's specifications. Generally the slots are 6 inches deep and 6 inches wide. The most important element of effective TRM installation is the intermittent check slot placed every 25 feet apart. The ECTC (Erosion Control Technology Council) has recently allowed the use of double rows of staples / anchors, staggered at 4 inches apart, instead of actually digging a 6" X 6" slot.

- Grade the channel uniformly and smooth. Remove any rocks, clods, or detritus that might interfere with intimate mat-to-soil contact.
- Dig and construct terminal and longitudinal check slots as needed.
- Loosen, till or otherwise prepare the soil surface for seed.
- Seed or hydroseed the channel. This is also the time to add fertilizer and other soil amendments such as mycorrhizae innoculum. This seeding step will be delayed if the TRM is to be in-filled.
- Roll out the TRMs as specified remembering to "shingle" the mats (like roofing a house) so the top mat overlaps the lower mat in the direction of flow. Generally the mats on the channel bottom go down first. The mats on the channel sides go down last so those mats lap over the bottom mats. This will prevent run on entering the channel via the side slopes from getting under the mats.
- Anchor the TRMs as specified (3 foot OC minimum) and anchor the mats in the slots before backfilling and compacting the slots. Use the staking or stapling layout per manufacturer's specifications.
- For TRM requiring soil in-fill, spread the seed as specified after the mats are securely anchored. For the Green Armor System, uniformly spray the hydromulch directly into the 3-dimentional mat. Use moderately high pressure to really force the slurry into the matrix and into the soil.
- For soil in-filled mats spread and lightly rake ½ - ¾ inches of fine topsoil into the mat apertures to completely fill mat thickness. Use backside of rake or other flat implement. Spread topsoil using lightweight loader, backhoe, or other power equipment. Avoid sharp turns with equipment. Do not drive tracked or heavy equipment over mat. Avoid any traffic over matting if loose or wet soil conditions exist. Use shovels, rakes or brooms for fine grading and touch up. Smooth out soil filling, just exposing top netting of matrix.
- For biotechnical methods, substitute live willow stakes for metal or wooden stakes. Willow wattles and fascines may be used to help anchor the mats into the slots.

Inspection and Maintenance

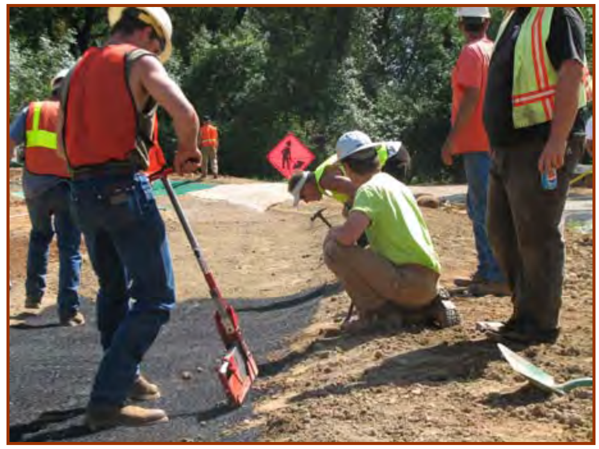
- During the initial establishment, RC-4 Turf Reinforcement Mats/Grass-lined Channels should be repaired and grass re-established if necessary. Inspect the channel prior to a predicted, runoff-producing, storm event.

A 3-dimensional nylon TRM is being keyed into a terminal check slot.

A coir composite TRM being installed and anchored into a check slot.

- After grass has become established, the channel should be checked periodically to determine if the channel is withstanding flow velocities without damage. Inspect the channel during a prolonged (more than 24 hours) runoff-producing storm
- Inspect the establishing channel after a runoff-producing storm event. Check the channel for debris, scour, or erosion and immediately make repairs. It is particularly important to check the channel outlet and all road crossings for bank stability and evidence of piping or scour holes and make repairs immediately.
- Remove all significant sediment accumulations to maintain the designed carrying capacity.
- Keep the grass in a healthy, vigorous condition at all times, since it is the primary erosion protection for the channel.
- Permanent grassed waterways should be seasonally maintained by mowing or irrigating, depending on the type of vegetation selected.

Longitudinal anchor trench should be 6 in wide x 6 in deep. On this test channel, the bottom was covered with 6 in of highly erosive decomposed granite soil (2 ft/s max permissible velocity).



Follow the manufacturer's recommended anchoring pattern. The test site TRMs were anchored using hand driven anchor pins and a high speed stapler.

Observing the installed TRMs at the Shasta College ECTF by Caltrans Hydrologists, May 2007.

Hydrologists measured 4 ft/sec over the un-vegetated polypropylene mat with no erosion.

All the TRMs tested; polypropylene, coir composite, in-filled Enka mat, and hydromulched Enka mat (Green Armor System) effectively protected the channel from erosion.

The channel below, un-protected by the TRM, showed significant erosion (more than 6 inches) after brief test flows or 4 ft/s.

Gully repair with Enka mat w/ soil-cement check slots at 25' intervals being installed in Northern California circa 1991.

The same gully repair site in 2004 with native grasses and vegetation permanently established. (J. McCullah photos)

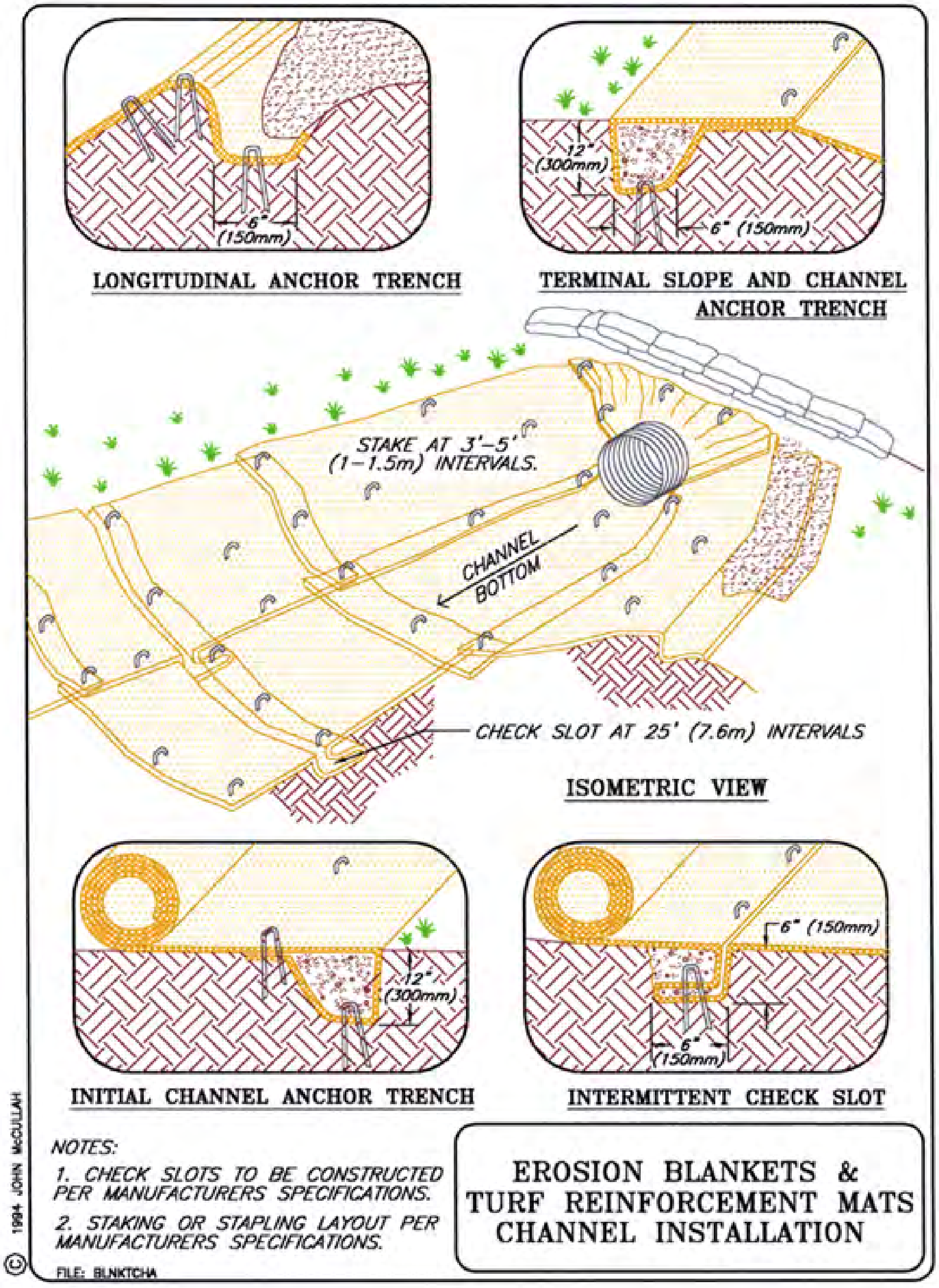


Figure 7-5. Erosion Blankets and Turf Reinforcement Mats Channel Installation.

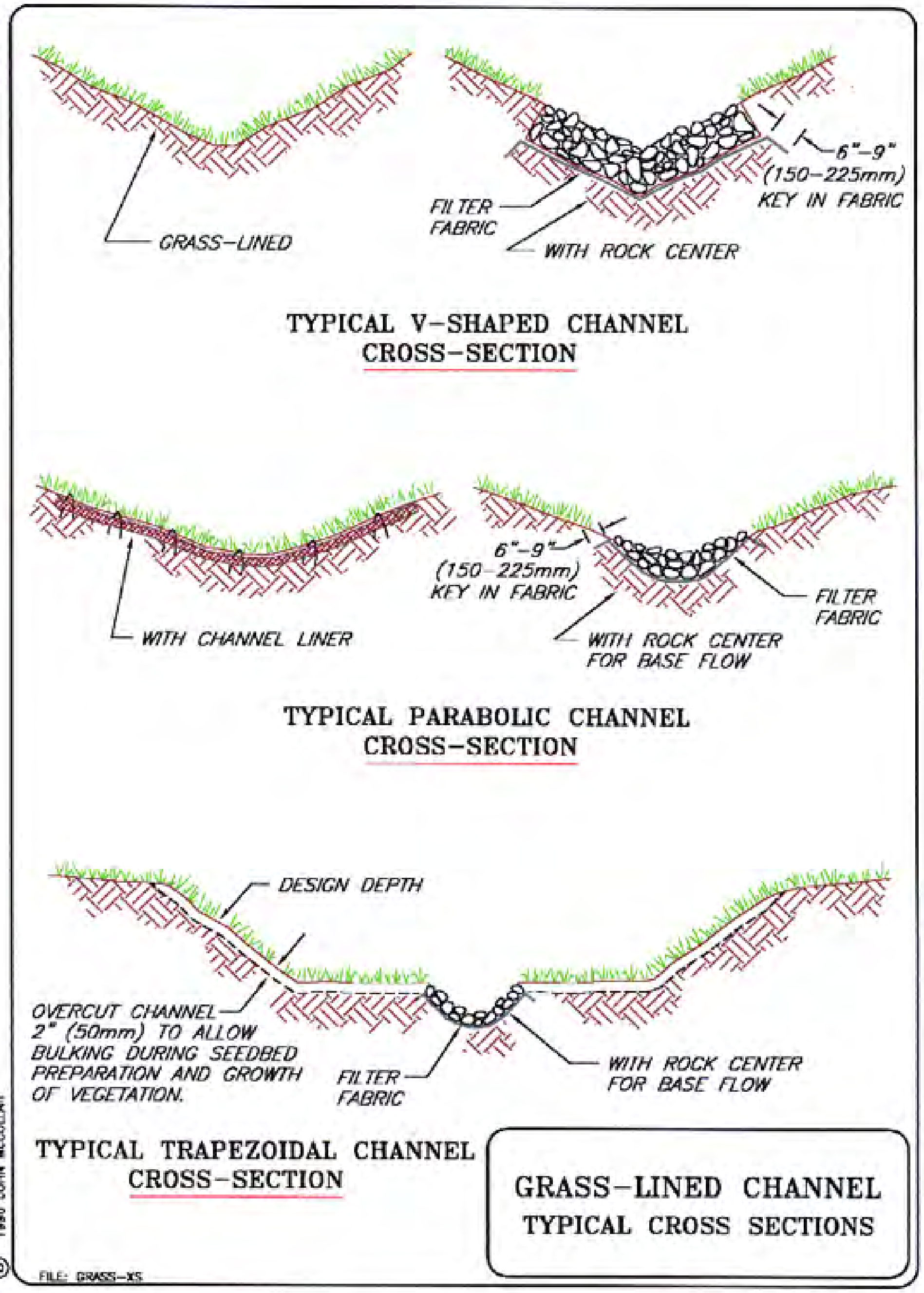
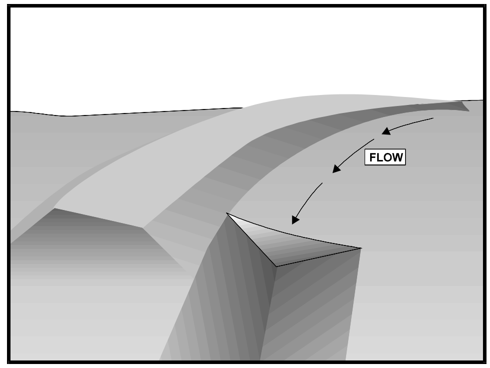


Figure 7-6. Grass-lined Channel Typical Cross Sections.

RC-5 Diversion Dikes and Diversion Swales

SWPPP Summary

A *Diversion Dike* is a temporary ridge of compacted soil constructed immediately above a new cut or soil fill slope or around the perimeter of a disturbed area. *Diversion Swales* are ditches cut into the soil in a roughly parabolic or trapezoidal shape, and they accompany diversion dikes for intercepting runoff.



Definition / Purpose

Diversion dikes may be used to:

- Divert storm *run-on** from upslope drainage areas away from unprotected disturbed areas and slopes to a stabilized outlet.
- Divert sediment-laden runoff from a disturbed area to a sediment-trapping facility such as a sediment trap or sediment basin.
- An upslope dike can improve working conditions at a construction area and prevent erosion. A downslope dike assures that sediment-laden runoff will not leave the area without treatment.

The primary function of top and toe of slope diversion swales, ditches, and berms is to minimize sheet flow over slope surfaces and reduce sedimentation by conveying collected runoff to a protected drainage system.

***_Run-on_ is concentrated flow, coming on to your project site, slope, or disturbed soil area from off-site sources. Recognizing run-on sources and then directing run-on safely through your work area is critical.**

Planning Considerations

Temporary drains and swales are appropriate for diverting any upslope runoff around unstabilized or disturbed areas. In this regard, they divert or bypass sensitive areas and convey to stable or protected areas. Sensitive areas may include hill climbs and other rider features, rehabilitation or restoration sites, material storage areas, equipment fueling and maintenance areas, wash rack areas, or any other area where the runoff may become contaminated or sediment-laden.

- It is very important that a diversion dike be stabilized immediately following installation with temporary or permanent vegetation to prevent erosion of the dike itself. The gradient must have a positive grade to assure drainage, but if the gradient is too great, precautions must be taken to prevent erosion due to high velocity channel flow behind the dike.
- This practice can use material available on the site and can usually be constructed with equipment needed for other project work. The useful life of the practice can be extended by stabilizing the dike with vegetation. Diversion dikes are preferable to

linear sediment barriers, e.g., silt fence, fiber rolls, and straw bales, because they are more durable, less expensive, and require much less maintenance when constructed properly. When used with sediment traps or sediment basins, they become a logical choice for a control measure once the control limits of the silt fence, fiber roll barrier, or straw bale dike have been exceeded.

- Temporary diversion dikes are often used as a perimeter control in association with a sediment trap or a sediment basin, or a series of sediment-trapping facilities, on moderate to large DSAs (Disturbed Soil Areas). If installed properly and in the first phase of grading, road-building, or other construction, maintenance costs are very low.
- Diversion dikes and diversion swales are appropriate below steep grades where runoff begins to concentrate, but prior to where there is potential for rill and gully erosion.

Design Considerations:

Recommended diversion dike and swale design:

- *Drainage Area:* 5 acres or less
- *Velocity:* 2.5-4.5 fps, depending on channel lining
- *Side slope:* 2:1 or flatter
- *Width:* 2 foot (.6 m) (top width)
- *Height:* 1.5 feet (.5 m)
- *Freeboard:* 0.5 feet (.2 m)

Diversion dikes, diversion swales, or brow ditches should be installed as a first step in the land-disturbing activity and must be applied to cut and fill slopes before applying Soil Stabilization BMPs.

Recommended diversion swale channel design:

- *Shape:* parabolic or trapezoidal recommended
- *Side slope:* 2:1 or flatter
- *Stabilization:* vegetation, TRMs, or riprap
- *Grade:* The swale behind the dike shall have a positive grade to a stabilized outlet. If the swale slope is less than or equal to 2%, no stabilization is required. If the slope is greater than 2%, the swale shall be stabilized.
- *Outlet:* Divert sediment-laden water into a temporary sediment trap or sediment basin. Runoff from undisturbed areas should empty into outlet protection, unless well-stabilized natural outlets exist.

Construction Specifications

- Diversion dikes and diversion swales must be installed as a first step in the land-disturbing activity and must be functional prior to upslope land disturbance.
- A combination of a swale and diversion dike at the top of a slope can safely divert runoff to a location where it can safely be brought to the bottom of the slope.
- A combination dike and swale is easily constructed by a single pass of a bulldozer or grader and compacted by a second pass of the tracks or wheels over the ridge.

- Remove all trees, stumps, obstructions, and other objectionable material from the swale when it is built.
- The dike and swale should be adequately compacted to prevent failure.
- The swale must not be overtopped by a 10-year, 24-hour storm.
- Temporary or permanent seeding and mulch shall be applied to the dike or swale immediately following its construction.
- The dike and swale should be located to minimize damage by construction operations and OHV traffic.
- Swales should be stabilized using vegetation, rock riprap, TRMs, or other physical means of stabilization, if significant erosion will occur within the channel from high velocities.
- Any swale which conveys sediment or pollutant-laden runoff must be diverted into a sediment basin or trap before it is discharged from the site.

Inspection and Maintenance

- The measure shall be inspected after every storm and repairs made to the dike, swale, outlet or sediment trapping facility, as necessary.
- Once every two weeks, whether a storm event has occurred or not, the measure shall be inspected and repairs made if needed.
- Diversion swales and sediment traps shall be inspected and cleaned out after every significant storm. Note: Altering existing waterways or clearing existing vegetation may require permits from the U.S. Army Corps of Engineers or other agencies.
- Damage caused by construction traffic or other activity must be repaired before the end of each working day.
- If vegetation has not been established, reseed damaged and sparse areas immediately.

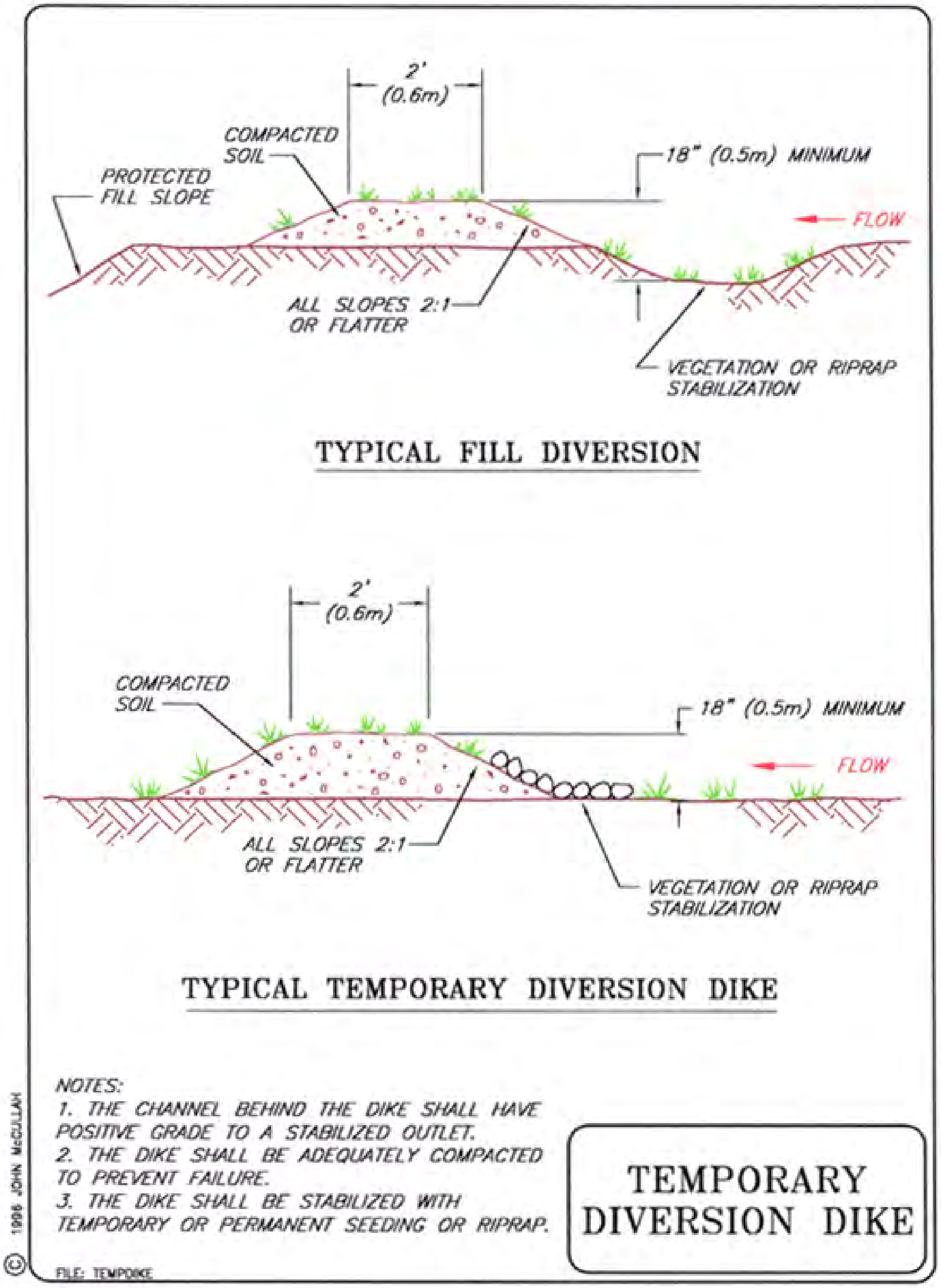


Figure 7-7. Temporary Diversion Dike.

8. SEDIMENT CONTROL (SC)

"Sediment Control" describes measures that are passive systems which settle out the particles in runoff. Sedimentation is the deposition of soil particles that have been transported by water or wind. Stokes Law is used to predict how sediment is settled out of suspension based on particle size (sand, silt, clay) and time of detention. The quantity and size of the particles transported increases with the velocity of the runoff.

Sediment Control is used to keep sediment, the product of erosion, isolated and contained. Sediment Control involves the construction of structures that allow sediment to settle out of suspension. Sediment Control structures, therefore, require frequent inspection and maintenance. Sediment that has been effectively contained must be removed from where it has accumulated, and disposed of at a stable location.

Generally, sediment is retained by two methods: a) slowing runoff velocities, as they flow through an area, sufficiently so that sediment cannot be transported, and b) impounding sediment-laden runoff for a period of time so that the soil particles settle out.

A natural "biofilter" at the Tesla Mine area (DPR).

One of the most cost-effective "water quality" controls for OHV parks is the use of vegetative "biofilter" systems. These "biofilters" can range from engineered bioretention systems and natural bioswale features (see SC-3 Bioretention and Bioswales) – to natural vegetated stream buffers and grass buffer strips (see EP-3 Minimize Disturbance and Buffer Strip). These BMPs are natural sediment and pollutant-filtering devices, and are extremely effective for removing and retaining sediment and pollutants from *sheet flow* runoff. A Caltrans study showed that 6-9 ft wide vegetated (grassed) areas adjacent to highways removed 44-88% TSS from runoff (Scharff, 2003). Be aware that vegetated buffers, bioretention areas and bioswales are only effective for runoff with low sediment loads and can become overwhelmed.

Most practices referred to as "sediment filtering" actually work by slowing velocities and allowing sediment impoundment to de-water in a very slow and controlled manner. For effective sediment control planning and design, materials such as geotextiles, silt fences, and straw bales should be considered for their ability to impound water and slow runoff velocities, not for their ability to "filter" sediment. These types of "sediment barriers" are relatively ineffective (<20%), only trapping a small portion of the suspended material. However, well-designed sediment ponds, with outlet control (skimmer outlet for example) and high length to width ratio and proper detention time can be relatively effective (50-90%).

Structural sediment control can be divided into three general types;

1) Sediment basins (sediment ponds)
2) Sediment traps
3) Sediment barriers

Sediment ponds are recommended for the outlet of disturbed drainage areas ranging from 5 ac to 100 ac. Sediment ponds should be designed by a qualified professional.

Sediment traps are recommended for disturbed drainage areas less than 5 ac. A typical sediment trap designed to handle .5 inches of runoff over a 24 hour period would require a settling zone capacity of 67 yd3/ac of contributing drainage area and a sediment storage capacity of 33 yd3/ac of drainage area.

Sediment barriers are BMPs that are intended to separate sediment from sheet flow runoff. They function by reducing runoff velocity and ponding small quantities of storm water. Sediment barriers are only intended for areas experiencing sheet flow and they must be installed in areas that can pond water and accumulate sediment and, most importantly, they must be accessible for cleanout. Some examples of sediment barriers are:

- Silt fence
- Fiber rolls (straw rolls)
- Compost berms and compost socks

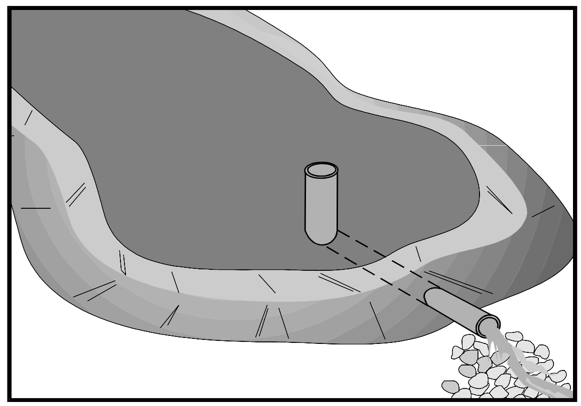
Again, it cannot be emphasized enough that source control is the most important measure to control sediment. Emphasis should never be solely placed on *Sediment Control* - it is a "last ditch" effort, or "last line of defense" before runoff enters a stream system.

SC-1 Sediment Ponds

SWPPP Summary

A sediment pond is usually created by excavation and/or construction of an embankment; it is designed to retain or detain runoff for a time sufficient to allow sediment to settle out of suspension. The skimmer outlet device improves sediment-trapping efficiency by regulating filling and draining of the sediment basin better than conventional methods using perforated risers or stone. Sediment basins shall be designed such that the flow length from the inlet to the outlet is relatively long. Flow length (L:W ratio) and detention time are the critical factors for increasing sediment pond efficiency.

Sediment pond at Carnegie SVRA. The sediment from the prior winter was removed.



The outlet structure is one of the most important elements of sediment pond design.

Definition / Purpose

Stoke's Law predicts how sediment is separated from sediment-laden storm water.

Stokes Law: Sediment control requires the 'ponding' of sediment-laden water (under nascent conditions) long enough for the desired size of sediment to 'fall out' of suspension. Sand-size particles have a settling velocity of 0.017 ft/sec; this is an order of magnitude faster than the settling velocity of silt (SV =.00096 ft/sec), for example. The ability to pond water, especially at the onset of the storm event, is critical. Therefore, the outlet structure is one of the most important elements of the pond design.

This BMP recommends the use of the 'Skimmer' outlet devise to ensure the pond fills up with water and that the sediment-laden water is detained, under nascent conditions, for a sufficient time to allow the design particles to settle out of suspension. This BMP also recommends designing the pond shape or installing 'baffles', in a way that increases the flow length, from inlet to outlet, across the pond. A length to width ratio (L:W ratio) greater than 5:1 is desirable.

Planning Considerations

Detention Time:

The most effective sediment pond will be one that fills quickly at the onset of a sediment-producing storm. An effective sediment pond will have a detention time of 48-72 hours after the storm recedes. The basin can then be maintained and cleaned out if necessary before the next storm event.

The skimmer orifice has a constant head that causes the basin to fill, creating conditions for sedimentation to occur, and then drains the basin slowly, at a constant rate, from near the surface.

Conventional sediment basins with perforated risers or stone outlets frequently do not fill properly because the outlet structures do not adequately regulate the outflow. When the 'riser' ponds do fill with sediment-laden water, they often drain from the lowest perforations, actually sucking the sediments from the bottom of the pond

Size and Shape:

Another important design consideration is the size of the pond. The pond must be sized in relation to the drainage area or watershed area if possible. The pond size must take into account the drainage area and the design storm event. If the pond is too small for the drainage area, most of the sediment-laden runoff from the storm event will necessarily pass right through the pond. Remember, depth does not improve efficiency, increased depth only allows more sediment storage, but often at the cost of reduced efficiency.

Some design guidelines will be more effective than others. *Option 1* below is the most basic but doesn't take into account factors such as soil type, erodibility, or the duration, intensity or frequency of the storm events.

Option 1:

Sediment basin(s), as measured from the bottom of the basin to the principal outlet, shall have at least a capacity equivalent to 3,600 cubic feet of storage per 1 acre draining into the sediment basin. The length of the basin shall be more than twice the width of the basin (L:W ratio > 2:1). The length is determined by measuring the distance between the inlet and the outlet; and the depth must not be less than 3 ft nor greater than 5 ft for safety reasons and for maximum efficiency (EPA).

Increasing sediment pond depth or size does not necessarily improve pond efficiency at trapping sediment or improving water quality. The flow length thru the pond and the detention time are factors that improve efficiency. A very deep pond with a L:W ratio of < 3:1 could be extremely ineffective in improving water quality - it could store a lot of sediment but silt particles could flow through the pond unabated.

Option 2:

Sediment basin(s) shall be designed using the standard equation:

$$As = 1.2Q/Vs$$

Where:

As = Minimum surface area for trapping soil particles of a certain size

Vs = Settling velocity of the design particle size chosen

Q = C I A

Where:

Q = Discharge rate measured in cubic feet per second

C = Runoff coefficient

I = Precipitation intensity for the 10-year, 6-hour rain event *

A = Area draining into the sediment basin in acres

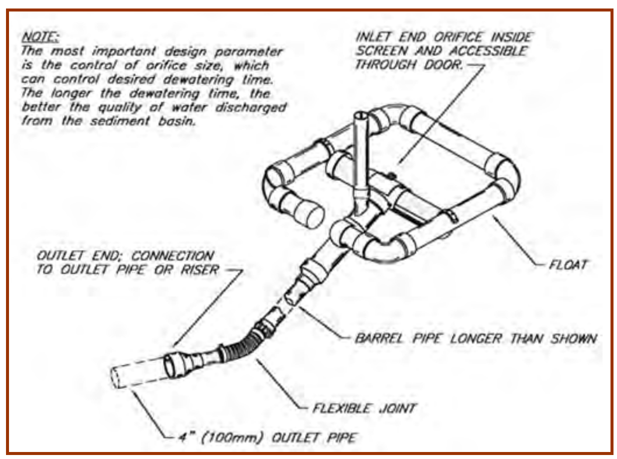
* The design storm for your region may vary. Contact your RWQCB for more information or new guidelines as necessary.

Generally the design particle size used is fine to medium silt. The design particle size shall be the smallest soil grain size determined by wet sieve analysis, or the fine silt sized (0.01mm) particle, and the *Vs* used shall be 100 percent of the calculated settling velocity.

The length is determined by measuring the distance between the inlet and the outlet; the length shall be more than twice the dimension as the width; the depth shall not be less than 3 ft nor greater than 5 ft for safety reasons and for maximum efficiency (2 ft of sediment storage and 2 ft of capacity). The basin(s) shall be located on the site where it can be maintained on a year-round basis and shall be maintained on a schedule to retain the 2ft capacity.

Option 2 is a more robust design criteria because it determines area by particle size and settling velocity, thereby giving you a reasonable detention time.

Neither Option 1 nor Option 2 will work properly if the outlets structure doesn't detain storm water sufficiently or suck sediment from the bottom while draining. If the pond doesn't drain between storms it cannot be cleaned out and if the pond cannot be cleaned regularly it might become a designated wetland area.



The floating skimmer outlet for sediment ponds.

Skimmer Basin:

The use of a skimmer outlet device is recommended. The skimmer is a floating outlet, constructed of PVC pipe. The PVC pipe provides the floatation and also acts as a trash rack, combined with a screen, to prevent the outlet orifice from plugging up with leaves or trash.

The skimmer attaches to a discharge pipe, usually 4” PVC, which has a flexible coupling to allow the skimmer to float up and down.

The skimmer maximizes the use of the volume and surface area of the basin by:

1. Ensuring the pond fills up. The skimmer device is fitted with an orifice, usually ½” to 2” diameter. Since all storm water must flow through the orifice, unless the pond overflows, even a small runoff-producing storm will be captured.
2. The skimmer, by virtue of the orifice size again, can control the rate the pond drains. Thereby the detention time can be regulated.
3. Therefore, the skimmer outlet structure will maintain a pool of water for a controlled amount of time which will promote sedimentation as per Stokes Law.

Diverting both on-site and off-site runoff that does not require treatment is an important first step. If possible locate pond outside of a watercourse or stream. This will avoid disturbing the natural channel and reduce the size of the basin.

Because of the increased trapping efficiency, more sediment will be caught, and thus, more sediment storage is sometimes needed. The skimmer does not overcome poor performance caused by inadequate surface area and volume, improper shape, short circuiting, etc., that affect many improperly designed sediment basins. Skimmer outlet structures are available in many different sizes. Most importantly, the skimmer outlet allows the pond to drain down between storms. This will allow the ponds to be cleaned out and maintained as needed. Also, the ponds will not become seasonal wetlands.

- The skimmer drains the pond slowly over several days, and at a constant rate to maximize sedimentation.
- The skimmer outlet device can be fitted with different sized orifices which in turn, can predictably control detention time.
- Instead of draining the pond from the bottom, and releasing the runoff containing the most sediment, the skimmer releases the least polluted water from near the surface.

The skimmer should be used in combination with baffles to achieve optimal sediment pond performance. Use common sense in baffle placement and pond design to allow sediment removal without damaging the baffles.

Baffles:

The use of skimmer outlet structure in combination with baffles, which increase L:W ratio, will allow greatly improved water quality efficiency within a relatively smaller basin size. Silt fence is commonly used for constructing a baffle system.

Baffles are necessary for proper sediment trapping efficiency. Silt fence baffles can improve sediment retention by diverting the flow through opposing weirs to increase the flow path and residence times (Millen et al., 1997).

The most important design criteria is detention time, the designer must determine the settling velocity of the 'designed particle" and the pond and skimmer must allow that detention time. Generally 72 hours detention will allow silt particles to settle. Next, the pond shape shall take into account L:W ratios and settling chambers. Silt particles having to travel a long path from inlet to outlet will have a better chance of settling out versus a particle with a short route.

- The pond size must take into account the drainage area and the design storm event. If the pond is too small for the drainage area, most of the sediment-laden runoff from the storm event will necessarily pass right through the pond. Remember, depth does not improve efficiency, increased depth only allows more sediment storage, but often at the cost of reduced efficiency.
- Each sediment basin design must consider the particular site conditions, soil type, drainage area, potential sediment generated, rainfall and runoff and damage potential downstream. There also may be local regulations for sediment basin design and maintenance.
- Sediment ponds with skimmers are usually less expensive because the pipes, risers, etc. are much smaller.

Construction Specifications

First, make the basin shape and drainage fit the topography as much as possible. A permanent skimmer pond should be designed with chambers and baffles. When the pond is full of water and a subsequent "plume of sediment-laden water" comes in, it is possible for most of the heavy sediment to fall out in the first chamber. Design the chambers so they can be accessed and cleaned out independently. The peninsulas that define the baffles or chambers can be designed for heavy vehicles, such as backhoes or excavators, which can perform year-round cleanout if necessary.

- A skimmer will control filling and draining of the basin and help to utilize the surface area and volume to create conditions that will maximize sedimentation.
- Basin size should be determined for the entire catchment to the basin, not just the disturbed area.
- Maximize surface area; shallow depth maximizes trapping efficiency and keeps sediment away from the skimmer.
- Make the basin twice as long as wide (except for small basins). Then use baffles, peninsulas, or chambers to increase the L:W ratio to > 5:1.
- Inflow must be directed into the upper end of the basin to prevent "short circuiting".


The skimmer drains the basin from the top, where the stormwater is cleaner (BMP testing at the Shasta College Erosion Control Training Facility, 2005).

- Place the skimmer on a slightly elevated pedestal (bricks, blocks or a gravel mound) to prevent the skimmer from getting stuck in the mud when the pond recedes and then refills.
- A minimum orifice diameter of ½" is recommended to avoid clogging.
- Outflow from the skimmer will still be turbid, so dispersing outflow into a wooded or vegetated buffer is recommended for additional treatment.
- The outlet barrel should consist of a 4" Sch 40 PVC pipe of sufficient length to be installed through the dam with positive drainage. The barrel should be at least 8 feet (2.4 m) long, or longer if additional length is needed so that the skimmer could be pulled to the side of the basin for maintenance.
- Instead of a riser and barrel, a spillway lined with fabric can be used in appropriate locations. The fabric-lined spillway shall extend to undisturbed ground and/or an energy dissipator.
- The skimmer cannot withstand being yanked around with a backhoe; use the rope to pull the skimmer out of the way.

Inspection and Maintenance

All sediment ponds should be constructed, inspected and certified operational before the rainy season. Sediment ponds serving active areas should be inspected before a predicted rainstorm, during a prolonged (24 hours) storm event, and after a runoff-producing storm event. The effectiveness of basins decline as they fill up with sediment, so ponds should be maintained at less than 1/3 full when ever possible. Sediment basins serving the active SVRA areas need clean-out once a year or when 1/3 full, which ever comes first. Sediment basins should have effectiveness monitoring and sampling performed (such as turbidity testing) during storm events to ensure effectiveness or indicate corrective actions that may need to be taken. Careful consideration should be given to pond design and baffle placement so equipment can safely and easily access the pond for clean out. Location of stockpiled sediment after clean-out also needs consideration during the planning and design phase.

- Inspect after each rain.
- All damages caused by soil erosion or equipment shall be repaired before the end of the day.
- Remove sediment when the pond is 1/3 full (of sediment). This sediment shall be placed in such a manner that it will not erode from the site (see PO-5 Stockpile Management). The sediment shall not be deposited downstream from the embankment or in or adjacent to a stream or floodplain.
- When temporary sediment ponds have served their intended purpose and the contributing drainage area has been properly stabilized, the embankment and resulting sediment deposit shall be leveled or otherwise disposed of in accordance with the approved erosion and sediment control plan.

This huge stockpile was stabilized through the winter with straw mulch and silt fence installed by "slicing" with a silt fence machine (see PO-5 Stockpile Management).

If there are still concerns about the turbidity leaving the sediment pond, then secondary treatment might be warranted.

Sediment ponds need to be cleaned out prior to the rainy season, and the sediment needs to be stockpiled and properly protected.

This sediment pond at Carnegie SVRA will be redesigned (2007 photo).

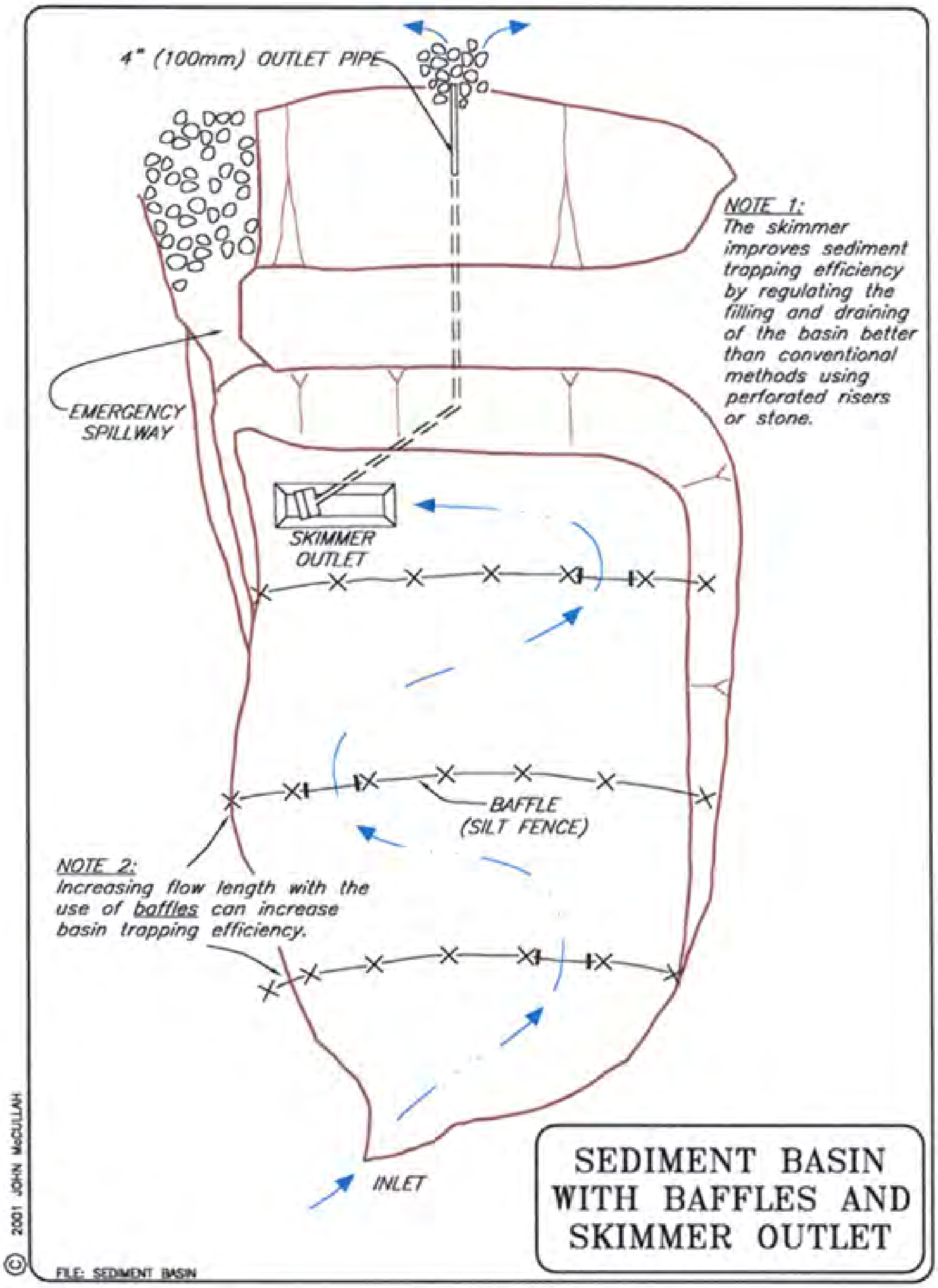


Figure 8-1. Sediment Basin with Baffles and Skimmer Outlet.

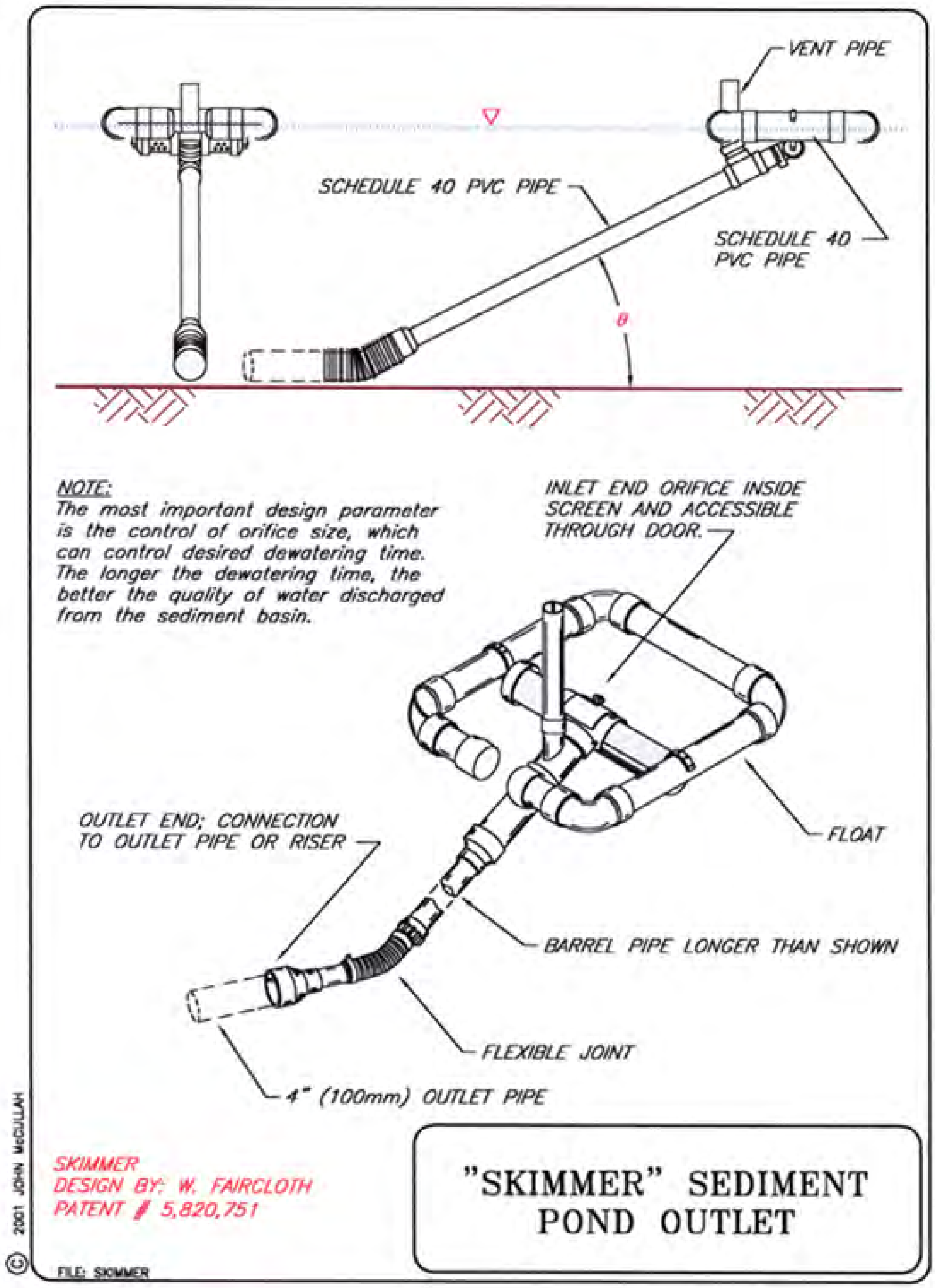
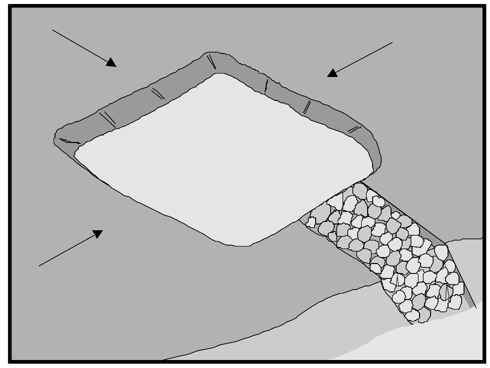


Figure 8-2. "Skimmer" Sediment Pond Outlet.

SC-2 Sediment Traps

SWPPP Summary



A sediment trap is a temporary containment area that allows sediment in collected stormwater to settle out during infiltration of before the runoff is discharged through a stabilized spillway. Sediment traps are formed by excavating or constructing an earthen embankment across a waterway or low drainage area. Sediment traps shall be used in conjunction with BMPs such as TC-4 Wash Racks, PO-5 Stockpile Management, and PO-6 Solid and Liquid Waste Management.

Definition / Purpose

As a supplemental control, sediment traps provide additional protection for a water body or for reducing sediment before it enters a drainage system.

Planning Considerations

Sediment traps may be used on construction projects or special events where the drainage area is less than 5 acres. Traps should be placed where sediment-laden stormwater runoff enters a watercourse, and near vehicle wash areas.

Construction Specifications

- Construct sediment traps prior to rainy season and construction activities.
- Trap shall be situated according to the following criteria: 1) by excavating a suitable area or where a low embankment can be constructed across a swale, 2) where failure would not cause loss of life or property damage, and 3) to provide access for maintenance, including sediment removal and sediment stockpiling in a protected area.
- Trap shall be sized to accommodate a settling zone and sediment storage zone with recommended minimum volumes of 67 yd3/ac and 33 yd3/ac of contributing drainage area, respectively, based on 0.5 in of runoff volume over a 24-hr period. Multiple traps and/or additional volume may be required to accommodate site specific rainfall and soil conditions.
- Traps with an impounding levee greater than 5 ft tall, measured from the lowest point to the impounding area to the highest point of the levee, and traps capable of impounding more than 35,300 cubic feet, shall be designed by a professional civil engineer registered with the State of California. The design should include maintenance requirements, including sediment and vegetation removal, to ensure continuous function of the trap outlet and bypass structures.
- Areas under embankments, structural works, and sediment traps shall be cleared and stripped of vegetation.
- Use rock, geotextiles, or vegetation to protect trap outlets against erosion.

- Fencing shall be provided to prevent unauthorized access.

Limitations

- Requires large surface areas to permit infiltration and settling of sediment.
- Not appropriate for drainage areas greater than 5 ac.
- Only removes large and medium sized particles and requires upstream erosion control.
- Attractive and dangerous to children and other visitors, requiring protective fencing.
- Not to be located in live streams.

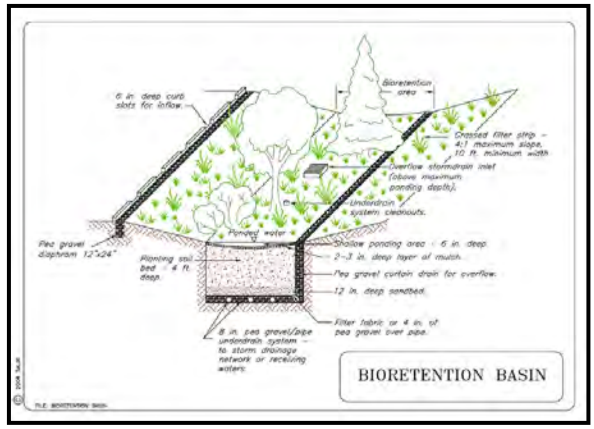
Inspection and Maintenance

- Inspect sediment traps before and after rainfall events and weekly during the rest of the rainy season. During extended rainfall events, inspect sediment traps at least every 24 hours.
- If captured runoff has completely infiltrated within 72 hours then the sediment trap must be dewatered.
- Inspect trap banks for embankment seepage and structural soundness.
- Inspect outlet structure and rock spillway for any damage or obstructions. Repair damage and remove obstructions as needed.
- Inspect outlet area for erosion and stabilize if required.
- Remove accumulated sediment when the volume has reached one-third the original trap volume.
- Properly dispose of sediment, debris, or liquid waste pollutants removed from the trap.
- Inspect fencing for damage and repair as needed.

SC-3 Bioretention and Bioswales

SWPPP Summary

Bioretention basins and bioswales direct sheet flow across a grass buffer strip to a ponding area for infiltration. They utilize soils and both woody and herbaceous plants to remove pollutants from storm water runoff. The ponding area generally consists of a surface layer containing organics such as mulch, trees, native grasses and shrubs, a subsurface layer of planting soil, and a sand bed.



Definition / Purpose

Bioretention areas are typically used to treat storm water runoff from impervious surfaces in commercial, residential and industrial developments, but can be just as effective in treating runoff from intensively managed open spaces, such as parks, golf courses, or gardens. Bioretention ponds can be used to filter storm water prior to discharge to a storm drain or sewer system or as an infiltration device with no outflow.

Bioretention areas:

- Significant decrease pollutants such as: Phosphorus, Copper, Zinc, Lead, Kjeldahl nitrogen, suspended solids and sediment, organics and bacteria (EPA, 1999).
- May reduce surface water temperatures (SMRC, 2003).
- Require relatively little engineering compared to other storm water management techniques, help recharge groundwater, require relatively little maintenance, reduce noise, create habitat, may act as a windbreak, provide shade, and improve aesthetics (LA Co, 2002).

Planning Considerations

Each element of the bioretention area has a specific function. The grass buffer strip slows the velocity of sheet flows, prevents erosion, and removes sediment. The sand/pea gravel curtain further reduces runoff velocity. After passing through the gravel curtain, the storm water is ponded in the retention area, where physical and biological processes including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation, and volatilization lower pollutant levels (EPA, 1999). Once collected, the storm water either evaporates or infiltrates the sub-surface soils and recharges groundwater.

Bioretention areas should be custom designed to suit the site parameters, soil types, and weather conditions. Custom features of a bioretention area can include pond size, grassed buffer strip width, sand curtain, vegetation type, buffer strip diaphragm, depth of soil in potting bed, slotted curbs, overflow storm drain inlet, and pipe underdrain system.

Bioretention size:

The drainage area for a bioretention area should be between 0.25 and 1 acre; larger areas require multiple bioretention areas. Bioretention areas should be a minimum of 15 feet wide by 40 feet long, and be approximately twice as long as it is wide. A site-specific bioretention area can be calculated by multiplying the drainage area by the rational method runoff coefficient "*c*". If several areas with different runoff coefficients are being drained then their relative sizes can be added. The bioretention area should be 5 to 7% of the calculated drainage area. The 5% specification should be used for bioretention areas with a sand curtain, and the 7% specification without the curtain (EPA, 1999).

Example:

A site contains 10,000 sq. feet of grassed area and 20,000 sq. feet of compacted, impervious surface. A bioretention area without a sand curtain is going to be constructed. The runoff coefficient (*c*) is 0.9 for the paved area and 0.25 for the grassed area. The bioretention area should be = 0.07 (10,000*0.25+20,000*0.9) or 1435 ft^2. Using the 2:1 length to width ratio, the resulting bioretention area should be 27' wide by 54' long. The total area drained is approximately 0.7 acres, less than the 1 acre suggested maximum.

Sizing should be adjusted if 10-year storm events produce relatively large sheet flow volumes.

Sometimes areas that already serve as bioretention and bioswales can be found on site - such as this shallow swale which serves as a "biofilter" at the Tesla Mine area (DPR). The grasses and other plants can help filter pollutants and promote microorganisms that degrade contaminates.

The photo above shows an engineered bioretention basin with a curb cut, which allows stormwater to flow onto the swale. Engineered bioretention systems often include a gravel underdrain and an overflow outlet. Native plants work well in bioretention basins and should be used whenever possible.

Ponding Depth:

Bioretention ponds should not be deeper than 6 inches (ID DEQ, 2003). This depth provides adequate storage and prevents water depths that would be detrimental to some plants or limit initial plant selection. The 6-inch depth also prevents water from standing for excessive periods of time. Surface water should not be present in the bioretention pond for more than 4 days, as this can promote populations of mosquitoes and other insects (EPA, 1999).

Planting Soil Selection:

An appropriate planting soil should be selected and backfilled into the excavated bioretention area to a minimum depth of 4 feet. Good soils include sandy loam, loamy sand, or soils with a loam texture and 10 to 25% clay content. The clay content of the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and some pesticides (EPA, 1999).

The infiltration rate of the soil is very important and should be between 0.5 and 3.0 inches per hour. Low soil infiltration rates can cause bioretention ponds to fail. Soil should be a uniform mix free of stumps, roots, rocks or other objects, with a soil pH range between 5.5 and 6.5. Soils should contain a minimum of: 35 lbs. per acre of magnesium, 75 to 100 lbs. per acre of phosphorus, 85 lbs. per acre of potassium, contain less than 500 ppm soluble salts, and have 1.5 to 5.0% organic matter (EPA, 1999, LA Co, 2002, ID DEQ, 2003).

It is important to prevent soil compaction at the base of the soil bed and in the soil bed, as compaction will significantly decrease infiltration and could lead to design failure.

Trees, Shrubs, and Ground Cover:

The bioretention pond should be vegetated with trees and shrubs and should resemble the local ecosystem. Native plant species should be selected whenever possible. Select plant materials that can tolerate extreme hydrologic changes and pollutant loading. The shrub to tree ratio should be 2:1 or 3:1, with a total of approximately 1000 trees and shrubs per acre. Aesthetics, site layout, and maintenance requirements should be considered when selecting plants and shrubs. Invasive species near the site should be identified and removed or contained prior to planting (EPA 1999).

Once trees and shrubs are planted, ground cover should be established. The ground cover acts like the leaf litter in a forest, preventing erosion and drying of underlying soil. The ground cover filters pollutants and can promote the growth of microorganisms that degrade petroleum-based and organic contaminants. Native plants or mulch should be used whenever possible. Grasses or legumes tend to make good ground cover. Mulch (either shredded hardwood or shredded hardwood chips) should be aged from 6 months to 1 year (EPA, 1999). Mulch should be 2 to 3 inches deep and uniformly applied across the site immediately after tree and shrub planting in order to prevent soils from drying out.

Grass Buffer:

Grass buffer strips should be located on either side of the bioretention pond to reduce runoff velocities and filter out coarse sediments (SMRC, 2003). The width and slope of the strip should be adjusted according to site needs. Wide strips should be used if storm water contains a high level of course sediment. Storm water velocities should be less than 0.3 ft/s as it flows across the buffer strip and the slope of the buffer strip shouldn't exceed 4% (ID DEQ, 2003). Shallow slopes should be used if water volume or velocity is unusually high. Grasses planted on buffer strips should be hardy, and native grasses should be used whenever possible.

Underdrain System, Overflow Inlet:

Bioretention areas can include underdrain systems and an overflow inlet, both of which direct storm water to a storm drain or sewer system. An under drain consists of a perforated pipe or pipes in a gravel bed, located below the planting bed. They should have a minimum slope of 0.5% and a drainage rate greater than the soil infiltration rate. Underdrain systems should include observation wells or clean-out pipes. Overflow inlets should be at least 6 inches above the surface of the bioretention pond (LA Co, 2002).

Construction Specifications

- Excavate pond location to appropriate depth. When possible, use a backhoe to remove original soil. If using a loader, use wide track or marsh rack equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction, resulting in reduced infiltration rates and storage volumes.
- Install underdrain system if specified.
- Till 2 to 3 inches of sand into the base of the bioretention facility before backfilling the required sand layer. Pump any standing water before preparing (rototilling) base.
- Avoid compacting soil at the base of the soil bed and in the soil bed. Compaction can be alleviated at the base of the bioretention pond by tilling operation with a chisel plow, ripper, or subsoiler that will refracture the soil profile through the 12-inch compaction zone. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.
- When back filling topsoil over the sand layer, first place 3 to 4 inches of topsoil over the sand, then rototill the sand/topsoil to create a gradation zone.
- Select and backfill an appropriate planting soil into the excavated bioretention area to final grade, with a minimum depth of 4 feet.

Trees, Shrubs, and Ground Cover:

- Plant selected trees and shrubs at a ratio of 1:2 or 1:3, with a total of approximately 1000 trees and shrubs per acre.
- Once trees and shrubs are planted, ground cover (either native plants or mulch) should be established. If using mulch, apply 2 to 3 inches uniformly across the site immediately after tree and shrub planting.

Grass Buffer:

- Grade grass buffer strip as designed, and install turf or seed with native grasses and mulch immediately.

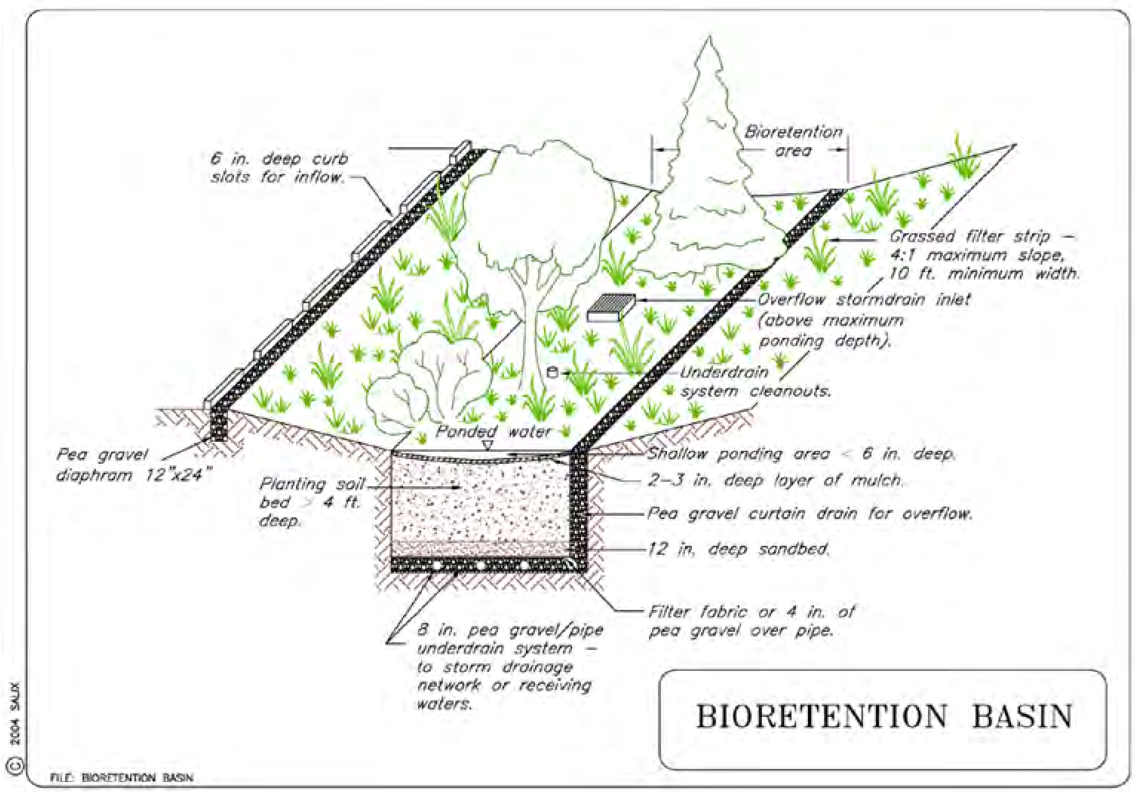


Figure 8-3. Bioretention Basin.

Limitations

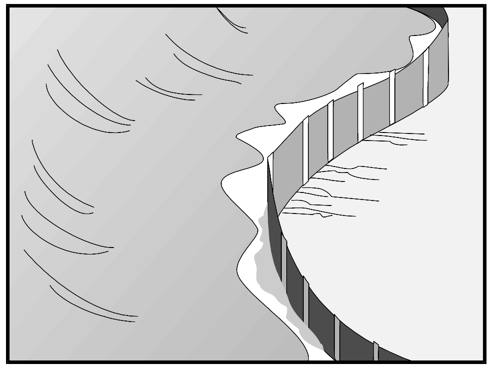
- Not applicable to steep (>20%) slopes or adjacent to flat areas (<2% slope) (EPA, 1999).
- Not suitable for unstable soils such as Marlboro Clay or soils with a clay content greater than 25% (EPA, 1999).
- Requires relatively large areas.
- Cannot be implemented in areas where groundwater is less than 6' below ground surface (LA Co, 2002).
- Cannot be implemented within 100' of a water supply well (Prince George, 2002).
- Cannot be implemented within 50' of a septic system (Prince George, 2002).
- Clogging can be a problem and may require engineering solutions if receiving water contains large sediment loads.

Inspection and Maintenance

Bioretention areas require regular maintenance to function properly. Litter, excess sediment, and debris should be removed frequently, as high sediment input from accelerated erosion can plug the system and result in failure of the basin. Trees and shrubs should be inspected regularly for damage and disease, and any dead or diseased plants should be treated or removed. Additional mulch should be added as needed. Soil should be inspected regularly and any erosion should be repaired. Plants should be watered daily immediately after installation of bioretention area and watered as needed during dry months. Tree stakes and wire should be maintained and replaced regularly. Grass buffer strips should be monitored regularly and any bare spots should be immediately revegetated. With proper maintenance, a bioretention area can last 10 to 20 years.

SC-4 Silt Fence

SWPPP Summary



A silt fence is a temporary sediment barrier consisting of filter fabric entrenched into the soil and attached to supporting posts. Silt fence is intended to be installed where sediment-laden water can pond, thus allowing the sediment to fall out of suspension and separate from the runoff. Silt fence installed with a trencher or by slicing is the most effective installation method to ensure against common silt fence failures.

Definition / Purpose

Silt fence is a sediment control practice. It is not intended to be an erosion control practice. Silt fence must only be installed where water can pond. When placed off contour, silt fence will effectively divert runoff if that is desired. Improperly applied or installed silt fence will increase erosion. Reasons for the high failure rate of improperly designed and installed silt fence include:

- Improper placement on the site.
- Allowing excessive drainage area to the silt fence structure.
- Shallow trenches with little or no soil compaction.
- Inadequate attachment to posts.
- Failure to maintain the silt fence after installation.
- Installing silt fence along property boundaries producing "concentrated" runoff.

Silt fence can be used where:

- Non-concentrated sheet flow will occur.
- Protection of adjacent property or “waters of the United States” is required.
- The size of the drainage area is no more than 1/4 acre per 100 linear feet of silt fence.
- The maximum flow path length above the barrier is 100 feet (30.5 m).
- The maximum slope gradient above the barrier is 2:1.

This silt fence is properly located and installed correctly. It is ponding water and allowing sediment to settle.

- Small swales are carrying silt, the slope is less than 2%, and the drainage area is less than 2 acres (again, sheet flow only).
- No practice other than a silt fence is feasible.

Silt Fence should *not* be used:

- Across slopes, even on contour.
- Around the perimeter of the construction site, unless J-hooks and/or "smiles" are used. Long continuous runs of silt fence will divert and concentrate sediment laden runoff and almost certainly result in failure.
- J-hooks or "smiles" are preferable to linear installations. A good "rule of thumb" is to drain no more than 1/3 acre of disturbed area into each discrete J-hook or "smile" segment.

<u>Planning Considerations</u>

Typical silt fence specifications were written 25 years ago and have changed little since. Some states have recognized some of the inherent problems, such as inadequate trench depth, and implemented minor changes to improve efficacy. Time and experience has shown that the outdated construction specifications, combined with the improper application and incorrect installation of silt fences, has resulted in it being one of the most ineffective storm water pollution controls in use.

Do not install silt fences across streams, channels, or drainage ways. Silt fences cannot "filter" the volumes generated by channel flows. When installed across a concentrated flow path, undercutting or "end cutting" of the fence often occurs. Silt fences should not be designed to impound sediment or water more than 18 inches high.

Designers are advised to reconsider the performance of silt fence. Silt fence material, filter fabric, or other similar geotextiles do not really "filter" silt-laden runoff. During the most erosive storm events the silt particles, carried by the sediment-laden runoff, actually plug up the fabrics pore openings. That is how the fabric prevents the discharge of silt. However, the fabric, if properly installed and anchored, will then pond water and sediment can begin to fall out of suspension. The silt fence will have tremendous pressure exerted upon it. Failure will occur if too much water runoff is directed to the fence, if the stakes are not of sufficient strength to support the tremendous forces or, most importantly, the fence is not keyed deeply into a trench (or sliced) and compacted such that runoff cannot go under or around the fence.

Designers, construction personnel and Park staff are advised to think of silt fence material as sheets of poly plastic. It will help to visualize the forces that can come into play during runoff events, and aid in the realization that a few wooden posts - spaced meters apart - cannot possibly hold back the water that can be impounded.

Some general design considerations include:

- Determine what kind of runoff, and how much, is coming onto the site; too much volume of water per silt fence area means failure will happen.
- Determine where and how the total volume is going to exit; total drainage area is the prime consideration of silt fence quantity, not necessarily slope.

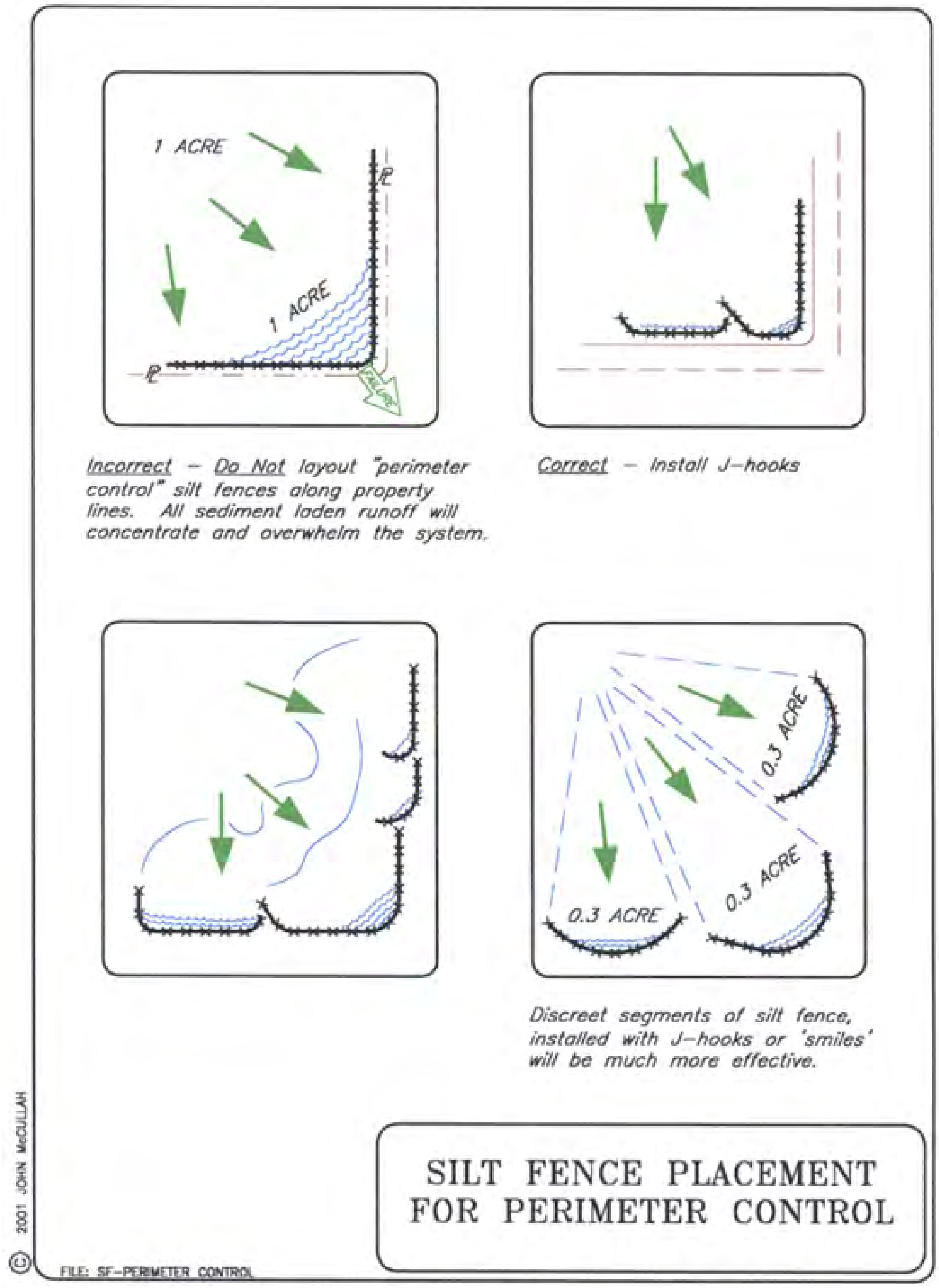
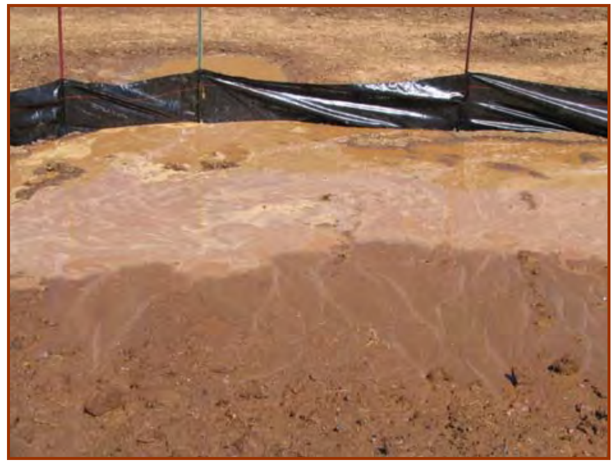


Figure 8-4. Silt Fence Placement for Perimeter Control.

- Soil type can play a role in the placement and quantity requirements; sandy soils might require more silt fence per area to contain the volume of potential sediment; clay soils might need fewer fences because the volume of potential sediment loss is less, although the volume of water might be greater because clay soils allow less rainfall infiltration.

- Type, size and spacing of fence posts; wood posts are inadequate and should not be used; steel t-posts weighing at least 1.25 lbs/ft are required, as they can be driven 24 inches into compacted soil, which is necessary to hold a horizontal load 18 inches high, and they can also be recycled and used repetitively; improper spacing of posts causes failures.

- Type of filter cloth; if all the elements of the silt fence installation are properly adhered to, the fabric does not make much difference; even lightweight non-woven fabric will hold 18 inches of sediment; wire supported fence is costly and ineffective.



Soil type can play a role in silt fence installation. Clay soils might need fewer fences because the volume of potential sediment loss is less, although the volume of water might be greater because clay soils allow less rainfall infiltration.

Construction Specifications

- Install silt fence material into a trench, 4" wide and at least 6" deep, with vertical sides. A preferred installation technique involves static slicing with an implement such as the "Tommy Silt Fence Machine" or equivalent. The soil should be sliced and the fabric mechanically installed into the soil.

- The trench must be backfilled and compacted.

- Install silt fences with 'smiles' or J-hooks to reduce the drainage area that any segment will impound.

- Silt fences placed at the toe of a slope shall be set at least 6 feet from the toe in order to increase ponding volume.

- The height of a silt fence shall not exceed 36 inches. Storage height and ponding height shall never exceed 18 inches.

- The ends of the fence should be turned uphill.

- Steel support posts should be utilized, properly spaced and driven into compacted soil. Place the posts on the downstream side of the fabric. Post spacing shall not exceed 6 feet. The filter fabric is wire-tied directly to the posts with three diagonal ties. Filter fabric shall not be stapled to existing trees.

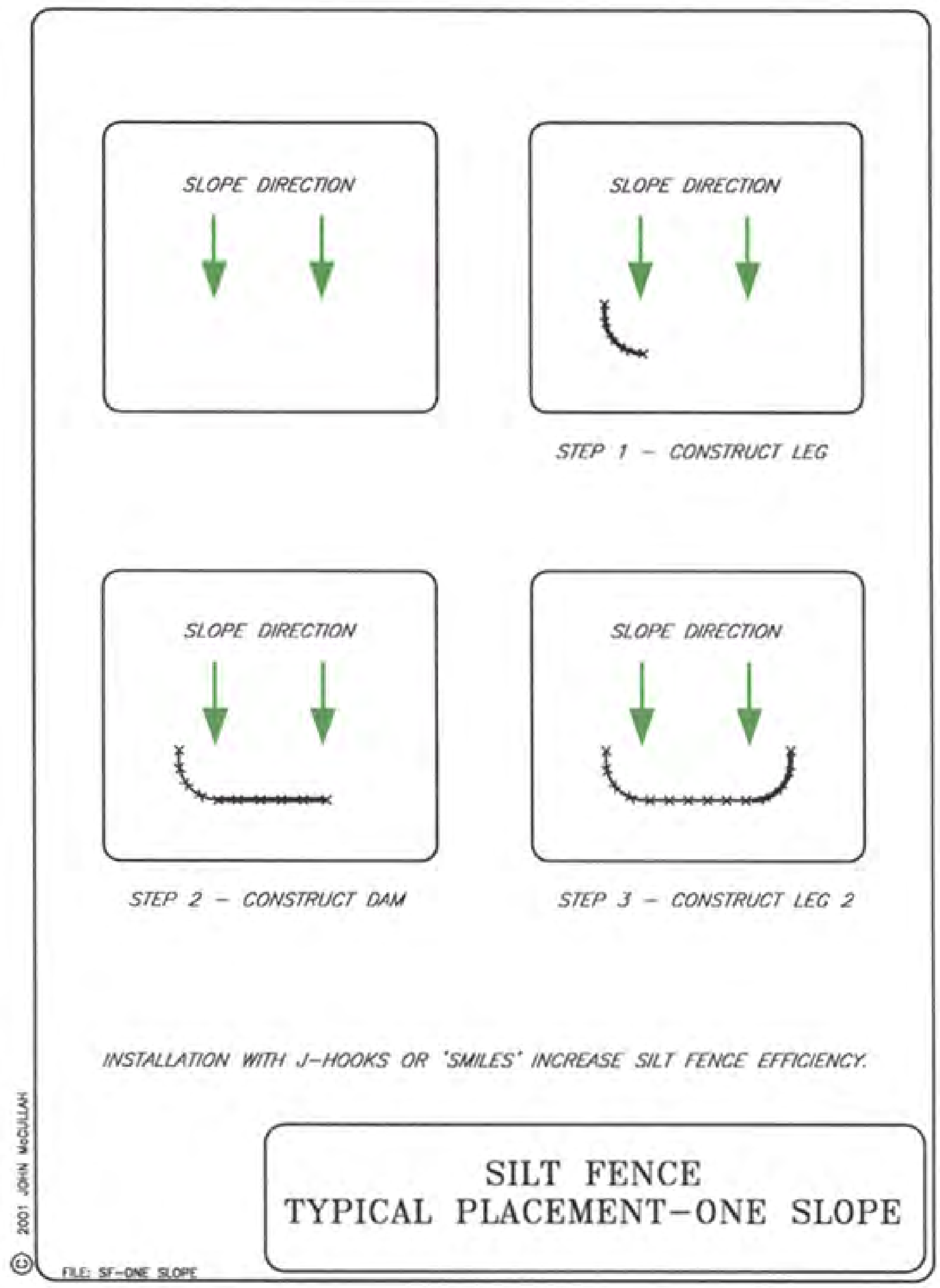


Figure 8-5. Silt Fence Typical Placement-One Slope.

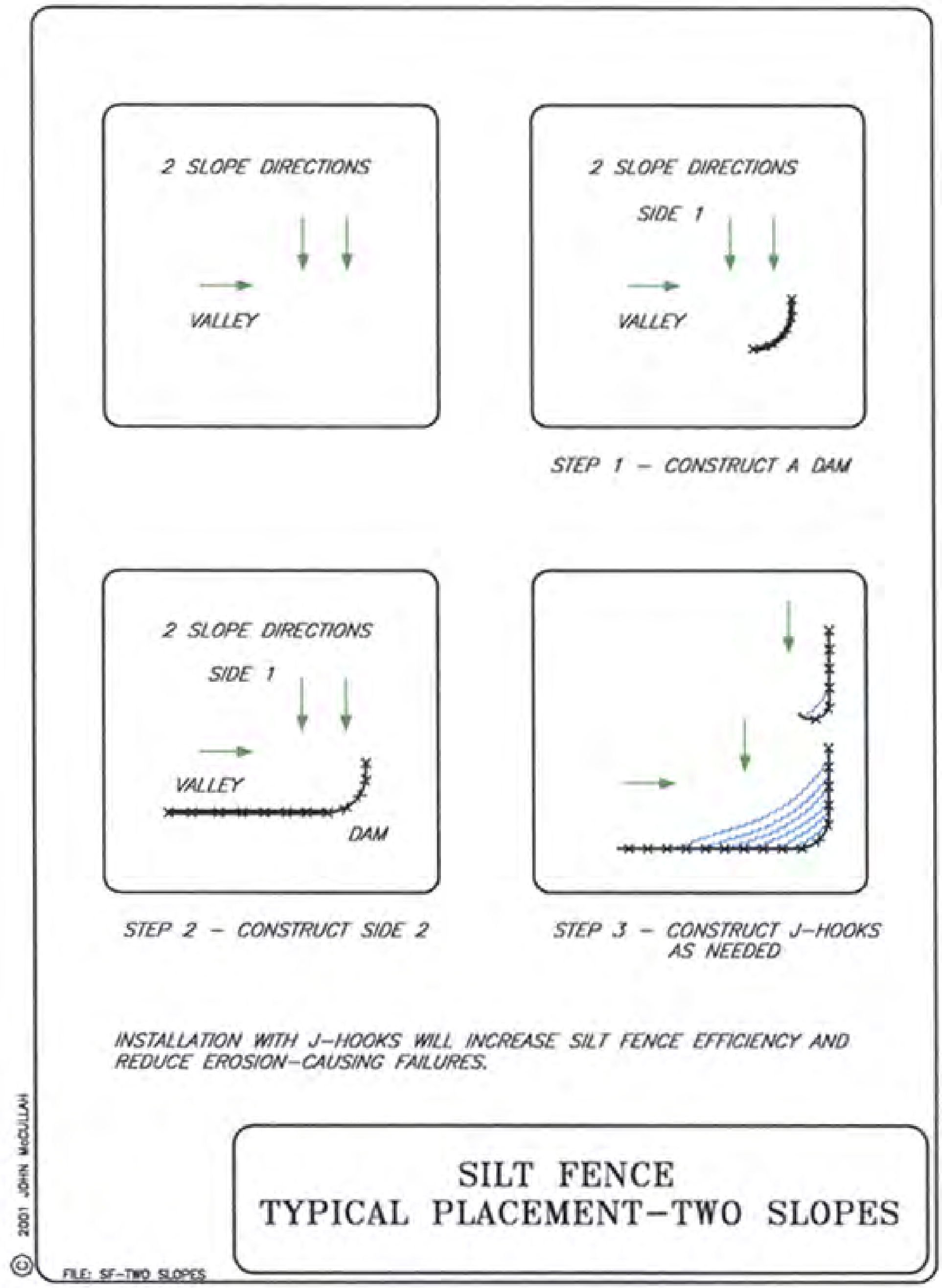


Figure 8-6. Silt Fence Typical Placement-Two Slopes.

Silt Fence Installation by Slicing Method:

The slicing method for silt fence installation utilizes an implement towed behind a tractor to "plow" or slice the silt fence material into the soil. The slicing method requires the "Tommy" silt fence machine or equivalent. Silt fence machines install the silt fence by slicing through the soil, rather than excavating it. Slicing minimally disrupts the soil upward and slightly displaces the soil, maintaining the soil's profile and creating an optimal condition for future mechanical compaction. Compacted soil resists water infiltration and moisture saturation, thus nearly eliminating washouts.

Silt fence installed by slicing method.

The slicing method has the capability to turn in a short distance, thus properly installing silt fence where needed. Turning enables upturns on the ends of silt fence runs, maneuvering around obstacles on construction sites, protection along property lines, and following contours.

<u>Limitations</u>

Silt fences have a useful life of one season. Their principal mode of action is to slow and pond the water and allow soil particles to settle. Silt fences are not designed to withstand high heads of water, and therefore should be located where only shallow pools can form Their use is limited to situations in which sheet or overland flows are expected. Sometimes site conditions aren't always suitable for slicing machines.

<u>Inspection and Maintenance</u>

- Inspect fence for proper installation and compaction by pulling up on the fence while kicking the toe of the fabric. If the fence comes out of the ground, do not "accept" the installation.
- If there are long, linear runs of silt fence without J-hooks or "smiles", do not "accept" the installation.
- Sediment shall be cleaned from behind the fence when it reaches 50% of the designed impoundment height (9 in).
- Silt fences and filter barriers shall be inspected weekly after each significant storm (1 inch in 24 hour). Any required repairs shall be made immediately.
- Sediment should be removed when it reaches 1/3 height of the fence or 9 inches maximum.
- The removed sediment shall conform to the existing grade and be vegetated or otherwise stabilized.

- Silt fences shall be removed when they have served their useful purpose, but not before the upslope area has been permanently stabilized and any sediment stored behind the silt fence has been removed.

The soil should be sliced and the fabric mechanically installed into the soil. Slicing minimally disrupts the soil upward and slightly displaces the soil, maintaining the soil's profile and creating an optimal condition for future mechanical compaction.

Inspect silt fence for proper installation and compaction by pulling up on the fence while kicking at the toe of the fabric. If the fence comes out of the ground, do not "accept" the installation.

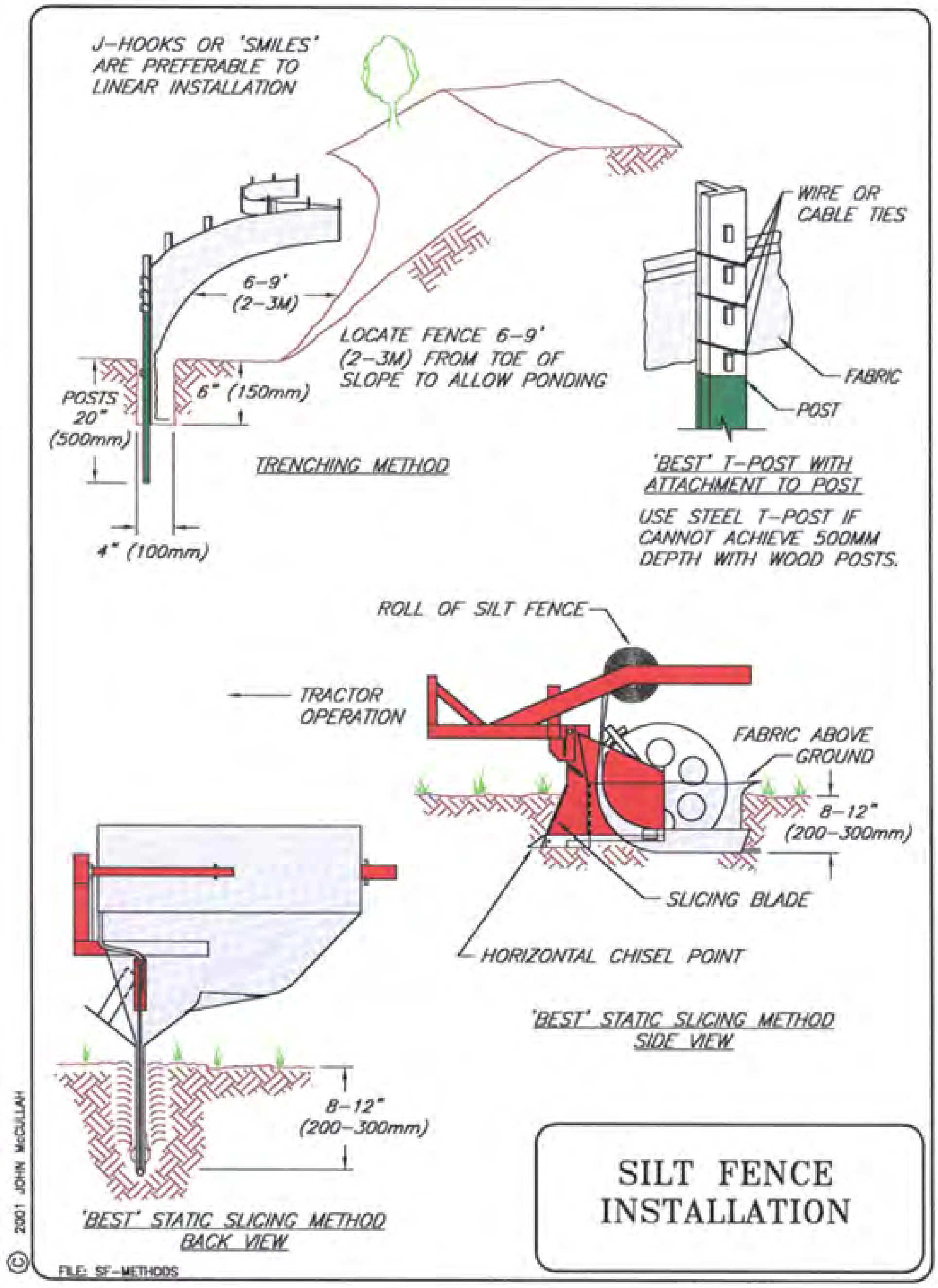


Figure 8-7. Silt Fence Installation.

SC-5 Fiber Rolls

SWPPP Summary

Fiber rolls are manufactured from straw, wood excelsior, coconut fibers, and/or other materials which are bound with polypropylene or biodegradable netting into tight tubular rolls. Fiber rolls control three types of erosional processes; erosion control, run off control, and sediment control. SC-5 Fiber Rolls are extremely effective as; 1) "slope interrupters" to reduce erosion on newly constructed slopes; 2) temporary "ditch checks" to reduce runoff velocities in drainage channels, and 3) sediment control barriers for small DSAs such as stockpiles, discrete slopes or individual lots.

Definition / Purpose

Slope Interrupters:

Long, uninterrupted, and unvegetated slopes are subject to sheet and rill erosion unless protected by slope interrupters, e.g. contour furrows, steps, benches or fiber rolls. Fiber roll are placed across slopes, on the slope contours, to break up the slope length. SC-5 Fiber Rolls reduce sheet flow velocities and quantity by providing hydraulic roughness and increasing infiltration.

Ditch Checks:

Fiber rolls can be installed across drainage channels (perpendicular to flow) as temporary velocity checks. Temporary velocity checks, such as fiber rolls, can reduce erosive velocities and the tractive forces of flowing water and reduce erosion of the channel bottom until the drainage way is permanently stabilized. The fiber rolls are relatively low so they are less likely to result secondary erosion (scour, end-runs, gullies) which may occur from check dams.

This portable trailer manufactures fiber rolls on-site and can produce any length of roll.

Sediment Barriers:

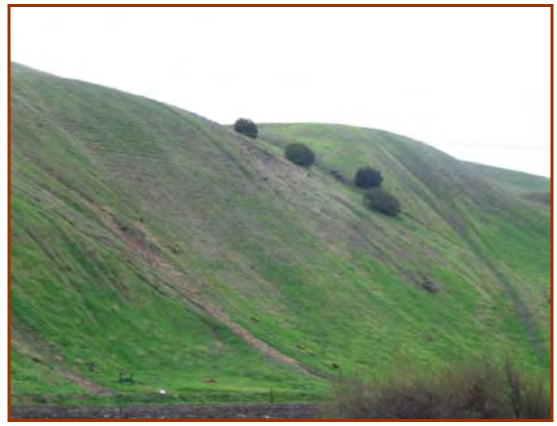
Fiber rolls are effectively used for sediment barriers. Sediment barriers can hold limited amounts of sediment-laden runoff which allows larger grained sediments to become trapped. Sediment barriers are useful for small DSAs with relatively small drainage areas.

Planning Considerations

Sites conditions appropriate for straw rolls are:

- Along the face and grade breaks of slopes susceptible to sheet and rill erosion.
- Below the toe of exposed and erodible slopes susceptible to sheet and rill erosion.
- On slopes producing dry ravel.
- On slopes susceptible to freeze/thaw activity or otherwise difficult to vegetate because of soil movement.
- Sites requiring an "effective combination" of erosion and sediment control BMPs during the rainy season (California General Construction Permit).
- Around temporary stockpiles.
- Across small drainage ditches as temporary ditch checks to reduce runoff velocity.
- At storm drain inlets when anchoring is feasible and flows are very low.

Straw rolls are appropriate for a variety of applications.



Unrestricted open riding areas, hill climb events, landslides, and fires can significantly reduce vegetation coverage on hill slopes. These exposed areas are more susceptible to erosion and are typically targeted by Park staff for protection and rehabilitation. Fiber rolls can be installed across the slopes to reduce the overall slope length. The rolls are spaced 20 to 50 feet apart, depending on hill slope and contour, and are anchored with wooden stakes every four feet. Field investigations have revealed that fiber rolls, used in conjunction with other BMPs such as seeding, mulching, and erosion control blankets, are effective at minimizing erosion and reestablishing vegetation on SVRAs.

Fiber rolls are temporary – the biodegradable fibers of straw, excelsior, or coir can last 1-3 years, while the polypropylene netting takes approximately 10 years to photodegrade. Fiber rolls can be specified with biodegradable mesh if necessary. Fiber rolls are generally useful until vegetation becomes established. The vegetation establishment - combined with the fact that the fiber rolls and stakes do biodegrade and photodegrade - generally eliminates the need to retrieve the materials after the slopes are stabilized.

- Fiber rolls should be installed with the ends turned slightly upslope. Any flows should be over the fiber roll, not around the ends (end runs).
- SC-5 Fiber Rolls' effectiveness is dependent on secure contact with the soil or erosion under the roll will become exacerbated. The fiber rolls must be securely anchored by one of the two approved methods:
    1. Stake and trench method;
    2. Stake and rope method (trenching unnecessary).
- Fiber rolls have a limited sediment capture zone.
- Do not use fiber rolls on slopes subject to slumping, creep, or landsliding as the increased infiltration can exacerbate geotechnical slope problems.

Slope Interrupter:

- Fiber rolls are useful placed along the face of newly constructed slopes to shorten slope length and reduce sheet flow velocities
- Erodible slopes longer than 20 feet can benefit from fiber roll slope interrupters placed along the face.

The "stake and rope method" of anchoring fiber rolls was used for sediment control along this outsloped recreational trail.

- SC-5 Fiber Rolls can be used with SS-8 Erosion Control Blankets. The fiber rolls can enhance the ECBs by further reducing erosion and helping to anchor the ECBs securely to the slope. The fiber rolls should be placed on top of the ECBs and anchored (un-trenched) with the "stake and rope method".
- On wildland rehabilitation sites fiber rolls tend to capture native seeds, organic matter and soil material immediately behind them and can often can produce a local environment conducive to native plant establishment. They catch soil material that moves down the slope by the freeze/thaw processes and retain moisture from rainfall, which aids in growth of tree seedlings planted along the upslope side of the rolls.
- Fiber roll interval is based on slope inclination;
    1. Slope inclination of 4:1 or flatter: Fiber rolls shall be placed at *20-foot* slope intervals.
    2. Slope inclination of 4:1 to 2:1: Fiber rolls shall be placed at *15-foot* slope intervals.
    3. Slope inclinations of 2:1 or greater: Fiber rolls shall be placed at *10-foot* slope intervals.

Runoff Control:

- Fiber rolls may be used to reduce flow velocities as temporary ditch checks on unlined ditches during the vegetation establishment period or until permanent measures are in place.
- Fiber rolls used in ditches should be anchored with the stake and rope method.
- Fiber rolls may cause erosion or be washed away during high flows, therefore they are recommended for small drainage areas on a temporary basis only.
- Fiber rolls are relatively ineffective for sediment capture in drainage ditch as the detention time is extremely short.
- Fiber rolls can be used at the top of slopes to divert concentrated runoff if there is a positive gradient. Do not place rolls at the top of slope in a manner that may concentrate flows onto the slope.

Sediment Control:

- SC-5 Fiber rolls can be used for sediment control, replacing silt fence, for small drainage areas, at the toe of short shallow slopes, or other areas where sheet flow and sediment production is expected to be low, e.g., stock piles, lower perimeters of small graded areas, and slopes having received soil stabilization (hydromulching, ECBs, compost blankets, straw mulch).
- Weighted fiber rolls, manufactured from non-degradable mesh and excelsior encapsulating a roll of rocks, are effective as temporary sediment barriers on pavement or other surfaces where staking is not feasible.

Weighted fiber rolls can be used on pavement or other surfaces where staking is not feasible.

Construction Specifications

Fiber Rolls: Fiber rolls are generally manufactured from biodegradable fibers (straw, coir, excelsior) encased in UV resistant polypropylene netting or biodegradable burlap mesh. The prefabricated tubes typically 8-inches diameter but rolls of 12- to 20-inches are also available. The fiber rolls are generally 20-30 ft long.

The densities of the rolls are dependant on the fiber and the fabrication process. Rolls manufactured by blowing straw into the mesh tubes are generally less dense than straw roll manufactured with a screw-type press. While the denser straw rolls are more durable, they are sometimes more difficult to drive stakes through.

“Field rolled” fiber rolls are fabricated from rolled up erosion control blankets bound at regular intervals (2 ft) with rope or twine.

Stakes: Wooden stakes should be 1-inch x 1-inch (¾" x ¾" nominal) and 24" long minimum. Construction stakes (1"x 2") can also be used. Live willow stakes can also be used if the secondary benefits of vegetative growth (bioengineering) are desired.

Installation:

- Prepare the slopes or soil areas prior to installation. Gullies and rills need to be repaired, regarded, and receive properly drainage control, e.g., control run on, install diversion ditches, brow ditches, swales, gravel bag berms, etc.
- Fiber roll interval is based on slope inclination;
  1. Slope inclination of 4:1 or flatter: Fiber rolls shall be placed at *20-foot* slope intervals.
  2. Slope inclination of 4:1 to 2:1: Fiber rolls shall be placed at *15-foot* slope intervals.
  3. Slope inclinations of 2:1 or greater: Fiber rolls shall be placed at *10-foot* slope intervals.
- SC-5 Fiber Rolls must be anchored securely using one of the following methods;
  1. *Trench and stake method* – Dig a 3-inch deep trench on the slope contours. Install fiber roll in the trench and anchor with stakes at 4-foot intervals maximum.
  2. *Stake and rope method* – In this method the trench is optional. However, the soil surface must be smooth and regular to ensure uniform soil-to-fiber roll contact. The anchoring stakes are installed at 2-foot intervals along each side of the fiber roll in a staggered pattern.

When using the *stake and rope method*, anchor stakes are installed at 2-foot intervals along each side of the roll, in a staggered pattern.

Drive the stakes partially into the soil until secure. Use heavy twine, rope or polypropylene rope (1/4-inch polypropylene braided rope is recommended) and secure it to the first stake as low on the stake as possible. Overlap the fiber roll with the rope to the next stake and secure with a half-hitch, again as low as possible while keeping tension on the rope and the fiber roll. Proceed until the fiber roll is securely held by the overlapping ropes. Drive the stakes into the ground until the rope is properly tensioning the fiber roll to the soil surface. This is the technique that makes trenching unnecessary.

Removal:

- Fiber rolls are typically left in place on slopes after vegetation is established.
- Fiber rolls as sediment barriers and velocity checks will require removal along with removal of sediment accumulation. Compact and fill any hole, depressions, or trenches and stabilize the soil surface.

Inspection and Maintenance

Inspect fiber rolls following a rainfall event and daily during prolonged rainfall. Look for the following:

1. Make sure the rolls are in intimate contact with the soil and securely anchored.
2. Look for evidence of rills, gullies, end runs or scouring under the roll.
3. Make a note of sediment accumulation.

- Inspect the fiber rolls before anticipated rain events.
- For sediment barriers, maintain proper sediment accumulation zones after storms (and before the next storm event).
- Repair any rills or gullies promptly.
- Reseed or replant DSA if necessary until the slope is stabilized.

Fiber rolls can be used to protect stream crossings when developing new trails. (Gold Run Creek Trail, Redding, CA)

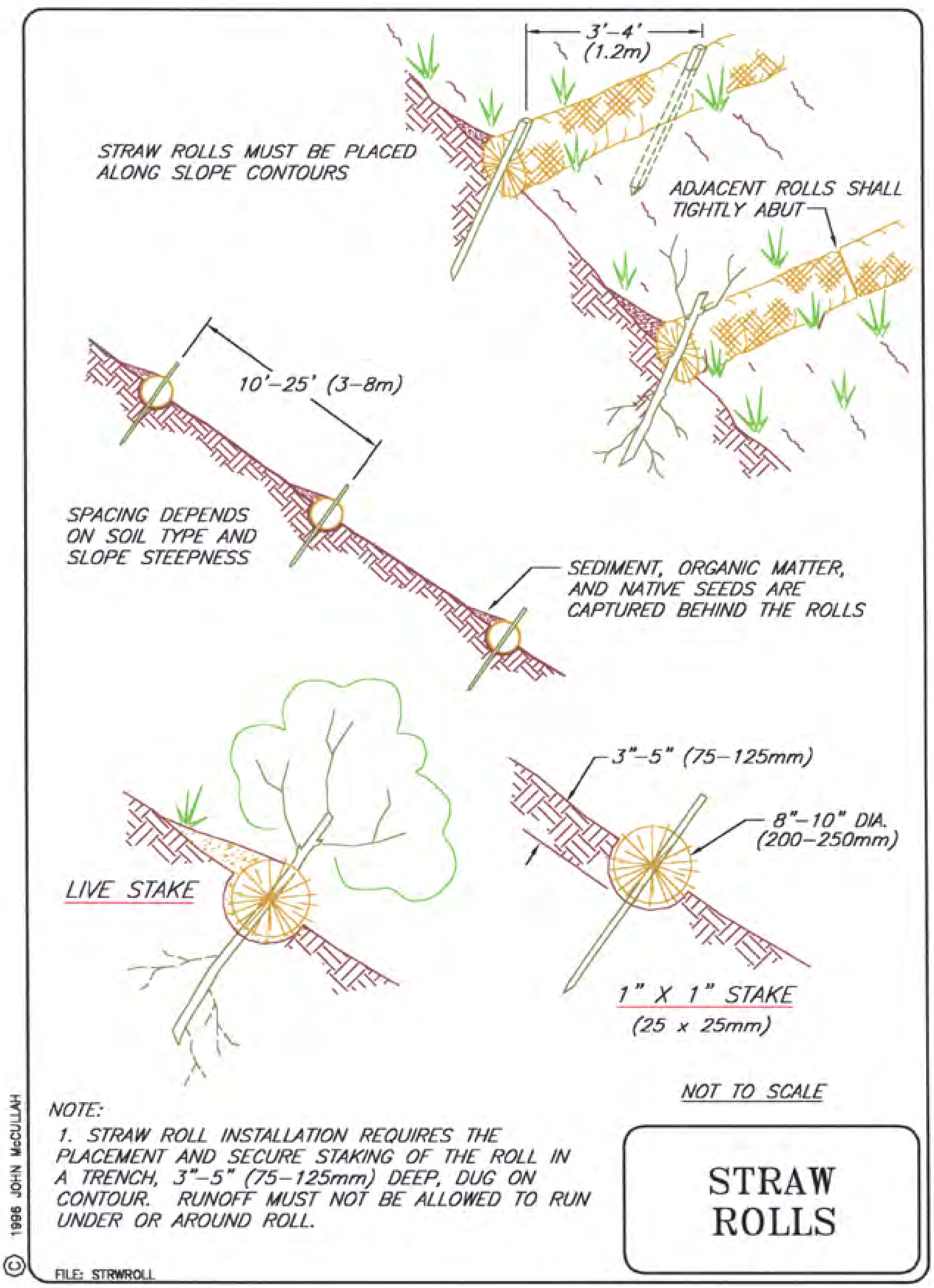
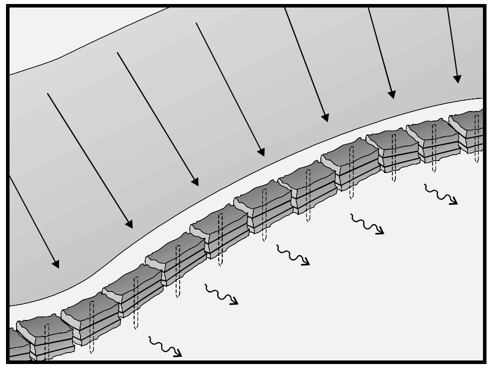


Figure 8-8. Straw Rolls (Fiber Rolls).

SC-6 Straw Bale Dike

SWPPP Summary

A straw bale dike is a temporary barrier consisting of straw bales installed across a slope, at the toe of a slope, and/or around the perimeter of the construction site. Straw bale dikes intercept and detain small amounts of sediment transported by sheet type runoff.



Definition / Purpose

SC-6 Straw Bale Dikes detain sediment by ponding water and allowing sediment to settle out. The dikes also slow runoff velocities, thus reducing sheet and rill erosion. They are also useful for erosion and sediment control around the perimeter of a DSA (Disturbed Soil Area). Straw bale dikes may be used where the following conditions apply:

- The placement area is not a slope nor likely to receive concentrated runoff;
- The maximum slope gradient above the barrier is 2:1;
- The maximum slope length above the barrier is 100 feet;
- The placement area is suitable for ponding of sheet runoff and sedimentation can occur.

Planning Considerations

- The bales are to be placed along the slope contour or at the toe of the slope.
- The principal modes of action are to pond water and allow particles to settle. Straw bale dikes are not designed to withstand high heads of water; therefore they should be located where shallow pools can form.
- Straw bale dikes are suitable for sheet flow only.
- Straw bales have a useful life of less than 6 months; however, the life is extended when used with filter fabric

Construction Specifications

- The bales shall be placed on the slope contour at the toe of the slope or around the perimeter of the construction site. If the dike is constructed at the toe of a slope, place it 5-6 feet away from the slope if possible.
- Do not construct the dike more than one bale high.
- Bales shall be placed in a row with the ends tightly abutting.
- Each bale shall be embedded in the soil a minimum of 4 inches. Use straw, rocks, or filter fabric to fill any gaps between the bales and tamp the backfill material to prevent erosion under or around the bales.

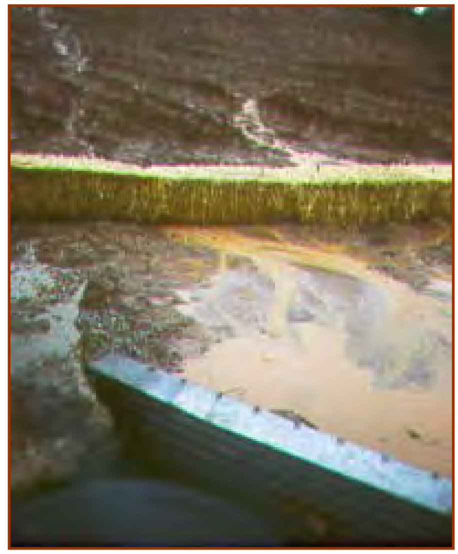
- The bales shall be securely anchored in place by two wooden stakes or driven through the bales. The first stake in each bale shall be driven toward the previously laid bale to force the bales tightly together. Drive the stakes at least 18 inches into the ground.
- The straw bales do not need to be anchored if the bales are used on a relatively flat project area and the straw bale dike is inspected regularly. The trapped sediment should be removed when required, and repairs made promptly. The bales also do not need to be anchored if they are to be removed and replaced daily to facilitate construction or maintenance activities.

<u>Limitations</u>

- Installation can be labor intensive.
- Straw bale barriers are maintenance intensive.
- Degraded straw bales may fall apart when removed or left in place for extended periods.
- Can't be used on paved surfaces
- Shall not be used in areas of concentrated flow.
- Can be an attractive food source for some animals.
- May introduce undesirable non-native plants to the area.

<u>Inspection and Maintenance</u>

- The straw bale dikes shall be inspected weekly and after each significant storm (1 inch in 24 hr).
- Repairs and/or replacement shall be made promptly.
- Remove sediment behind the barrier when it reaches a depth of 6 inches.
- Remove the straw bales when the upslope areas have been permanently stabilized.



The dike in this photo is NOT effectively controlling sediment. If using straw bale dikes for sediment control, it is very important to install them correctly. The bales should be embedded into the soil at least 4 inches, and any gaps between bales should be filled with rocks, straw, or filter fabric. Straw bale dikes are suitable for sheet flow only.

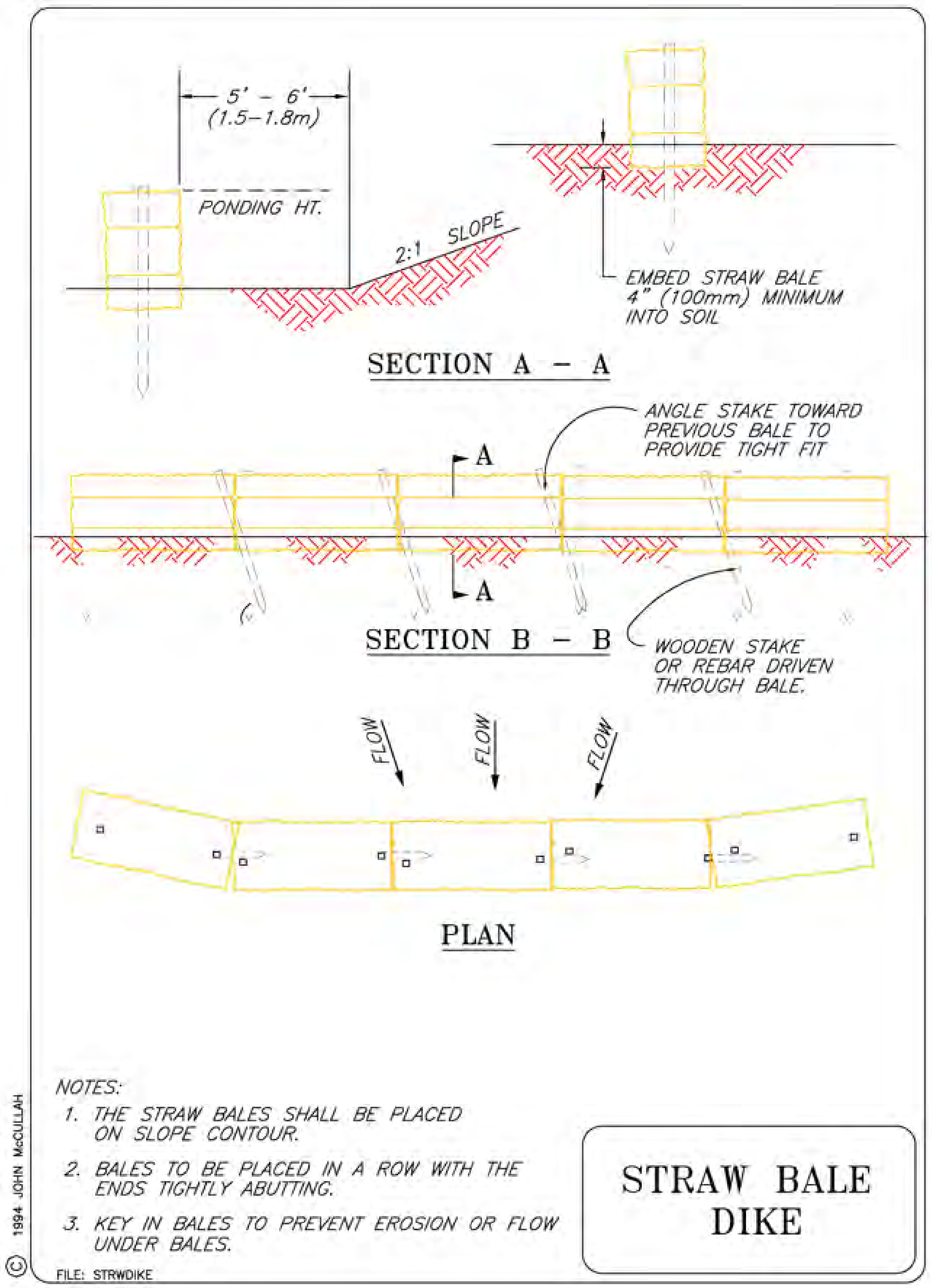


Figure 8-9. Straw Bale Dike.

SC-7 Compost Berms and Compost Socks

SWPPP Summary

A compost berm is a trapezoidal berm that intercepts sheet flow and ponds runoff, allowing sediment to fall out of suspension. Compost berms provide an environmentally-sensitive and cost-effective alternative to silt fence.

A compost sock is a type of contained compost berm, with the added benefit of better withstanding any machinery or other vehicle traffic. Compost socks are mesh tubes filled with compost, installed across a slope or small drainage swale to pond water and allow sediments to settle. Compost socks are also similar to fiber rolls in their applications.

Definition / Purpose

Compost berms sometimes offer a better solution than silt fence and other sediment control methods, because compost does not require any special trenching, construction, or removal, unlike straw bales or silt fence. This makes the technique very cost-effective.

The compost filter berm, which is trapezoidal in cross section, provides a three-dimensional filter that retains sediment and other pollutants (e.g., suspended solids, metals, oil and grease) while allowing the cleaned water to flow through the berm (Tyler and Faucette, 2005).

Compost socks also do not need to be trenched into the ground, and installing compost socks creates less soil disturbance than installing silt fence. Compost socks require a bit more installation than compost berms, and sometimes compost socks require removal.

- Compost berms can be easily and quickly fixed should something happen to them in the course of construction.
- Mechanical compost spreaders are commercially available and are widely used in the Pacific Northwest.
- Compost is organic, biodegradable, renewable, and can be left onsite. This is particularly important below embankments near streams, as re-entry to remove or maintain some sediment control BMPs can cause additional disturbance. Silt fence has to be disposed of in landfills and is often left abandoned on jobsites.
- With compost socks, only a small amount of material needs to be removed (the mesh), unless the mesh is biodegradable.
- Compost does not leach nutrients. Field tests in Connecticut (2001) have shown that run-off from compost treated sites has very low soluble salts, and all metals and nutrients are well within pollution leaching limits.
- When properly made, compost is full of nutrients and micro-organisms that stimulate vegetation. Compost binds heavy metals and can break down hydrocarbons into carbon, salts and other innocuous compounds.

Planning Considerations

Compost filter berms should be used at the base of slopes 2:1 or less. There are many types of compost, all with different properties, so it is best to determine what application the compost is being used for. Compost berms and socks can be vegetated or unvegetated. For compost berms, compost should generally have the following specifications:

- Compost needs to be stable and mature.
- Particle size: Compost should consist of both large and small pieces for maximum filtration. Finer grades (screened through 3/8-1/2") are better for vegetation establishment, long term plant nutrients, and increased infiltration rates. The coarser grades (screened 2-3") are better for increased filtration, and are less likely to be disturbed by rainfall and runoff. For berms, the ratio of coarse and fine material should be 1:1. No particle should be greater than 3".
- The recommended moisture content ranges from 20-50%. Compost that is too dry is harder to apply, while that which is too wet is heavier and harder to transport. In drier areas, use compost with a higher moisture content; in wet areas, use the drier compost, as it will absorb water.
- Organic matter content: The percentage of carbon based materials in finished compost should range between 40-70%. However, Texas DOT specifies no less than 70%.
- The pH should be between 5.0 and 8.5.
- Nitrogen Content: .5-2.0%.
- Compost should have a minimum of soluble salts, as these can inhibit vegetation establishment. These levels should be between 4.0 and 6.0 mmhos/cm.
- Compost must be weed and pesticide free, with manmade materials comprising less than 1%.

Slope	Slope Length (feet)	Sock Diameter (inches)
<50:1	250	12
50:1–10:1	125	12
10:1–5:1	100	12
3:1–2:1	50	18
>2:1	25	18

Table 8-1. Example Compost Filter Sock Slopes, Slope Lengths, and Sock Diameters (Oregon Department of Environmental Quality, 2004).

The diameter of compost socks will vary depending upon the steepness and length of the slope. Compost socks were used along this recreational trail project (Redding, CA).

Minnesota DOT erosion control compost specifications for "compost logs" (compost socks) recommends 30 to 40 percent weed-free compost and 60 to 70 percent partially decomposed wood chips, and that 100 percent of the compost passes the 2-inch sieve and 30 percent passes the 3/8 inch sieve.

Slope	Slope Length	Berm Dimensions (height x width)
<50:1	250 ft	1 ft x 2 ft
50:1 . 10:1	125 ft	1 ft x 2 ft
10:1 . 5:1	100 ft	1 ft x 2 ft
3:1 . 2:1	50 ft	1.3 ft x 2.6 ft
>2:1	25 ft	1.5 ft x 3 ft

Table 8-2. Example Compost Filter Berm Dimensions Based on Slope and Slope Length (Oregon Department of Environmental Quality, 2004).

Compost socks are much easier to install on rocky slopes with rough surfaces than some other sediment control BMPs.

Mechanical compost spreaders are available in most areas.

For compost berms, the basic rule of thumb is that the base should be twice the height of the berm.

<u>Construction Specifications</u>

Compost Berms:

- For slopes 3:1 or less, install a compost berm 1-2 ft high and 2-4 ft wide at the base. For maximum filtration properties, install the berm in a trapezoidal shape, with a 4-6 ft base, and a 2-3 ft wide top. Larger berms should be used for steeper slopes. The basic rule of thumb is that the base should be twice the height of the berm.
- Berms can be placed around the perimeter of affected areas, if the area is flat or the perimeter is on contour. Berms should be placed using 'smiles' and j-hooks.

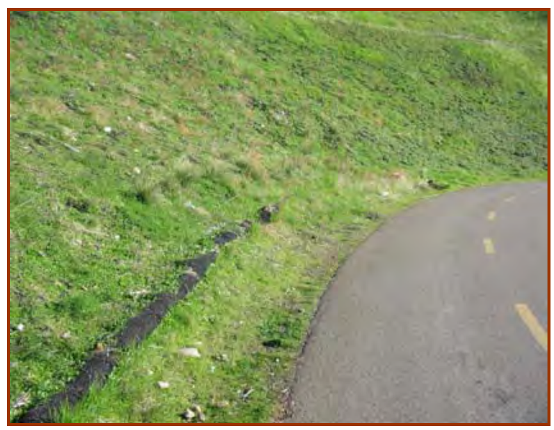
- Do not place berms where they cannot pond water.
- For steeper slopes, an additional berm can be constructed on the top shoulder.
- Compost can be seeded during application. However, field tests indicate that it is best to have only a thin layer of compost over the seed. Slopes seeded with 2- 4" of compost over the seed had less vegetation establishment than slopes with less compost over the seed.
- Do not use compost berms in areas of concentrated flow, as they are intended to control and filter sheet flow only.

Compost socks:

Compost socks are assembled by tying a knot in one end of the mesh sock, filling the sock with the composted material (usually using a pneumatic blower), and then knotting the other end once the desired length is reached.

A compost sock the length of the slope is normally used to ensure that stormwater does not break through at the intersection of socks placed end-to-end. In cases where this is not possible, the socks are placed end-to-end along a slope and the ends are interlocked. The diameter of the filter sock used will vary depending upon the steepness and length of the slope; example slopes and slope lengths used with different diameter filter socks are presented in Table 8-1.

- Compost socks are usually 8-24 inches in diameter, and may be round or oval in profile.
- Seed can be mixed into the compost prior to filling and installation.
- The ends of compost socks should be curved upslope to contain flow.
- Staking through the sock every 8-10 feet is usually sufficient to secure the sock in place.



This compost sock has become vegetated after two years and there is no need to remove it.

<u>Inspection and Maintenance</u>

- Compost berms and socks shall be inspected after each storm event and reapplied or repaired if necessary.
- Sediment retained by the berms and socks shall be removed when it has reached 1/3 of the exposed height of the berm or sock. Alternatively, the sediment and berm or biodegradable mesh sock can be stabilized with vegetation at the end of construction.
- Berms can be left onsite as a postconstruction BMP and seeded, or spread out in place as a soil enhancement. If mesh on socks is not biodegradable, cut the mesh open and spread the compost out on site, then properly dispose of the mesh.

The mix of particle sizes in the compost berm material retains as much or more sediment than traditional perimeter controls, such as silt fences or straw bale barriers, while allowing a larger volume of clear water to pass through the berm (silt fences often become clogged with sediment and form a dam that retains storm water).

The berms can be vegetated or unvegetated. Vegetated filter berms are normally left in place and provide long-term filtration of storm water as a postconstruction BMP. Unvegetated berms are often broken down once construction is complete and the compost is spread around the site as a soil amendment or mulch.

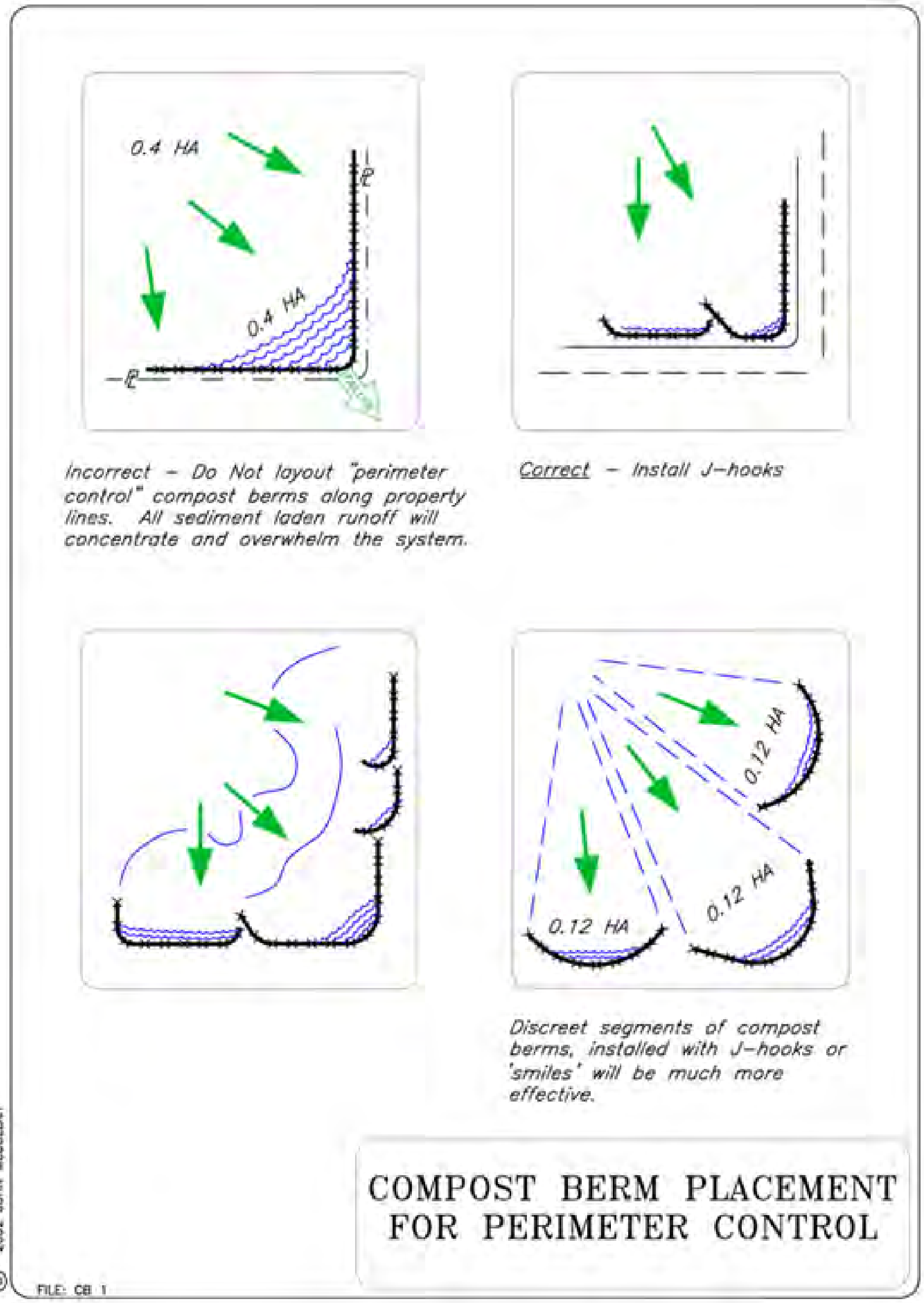


Figure 8-10. Compost Berm Placement for Perimeter Control.

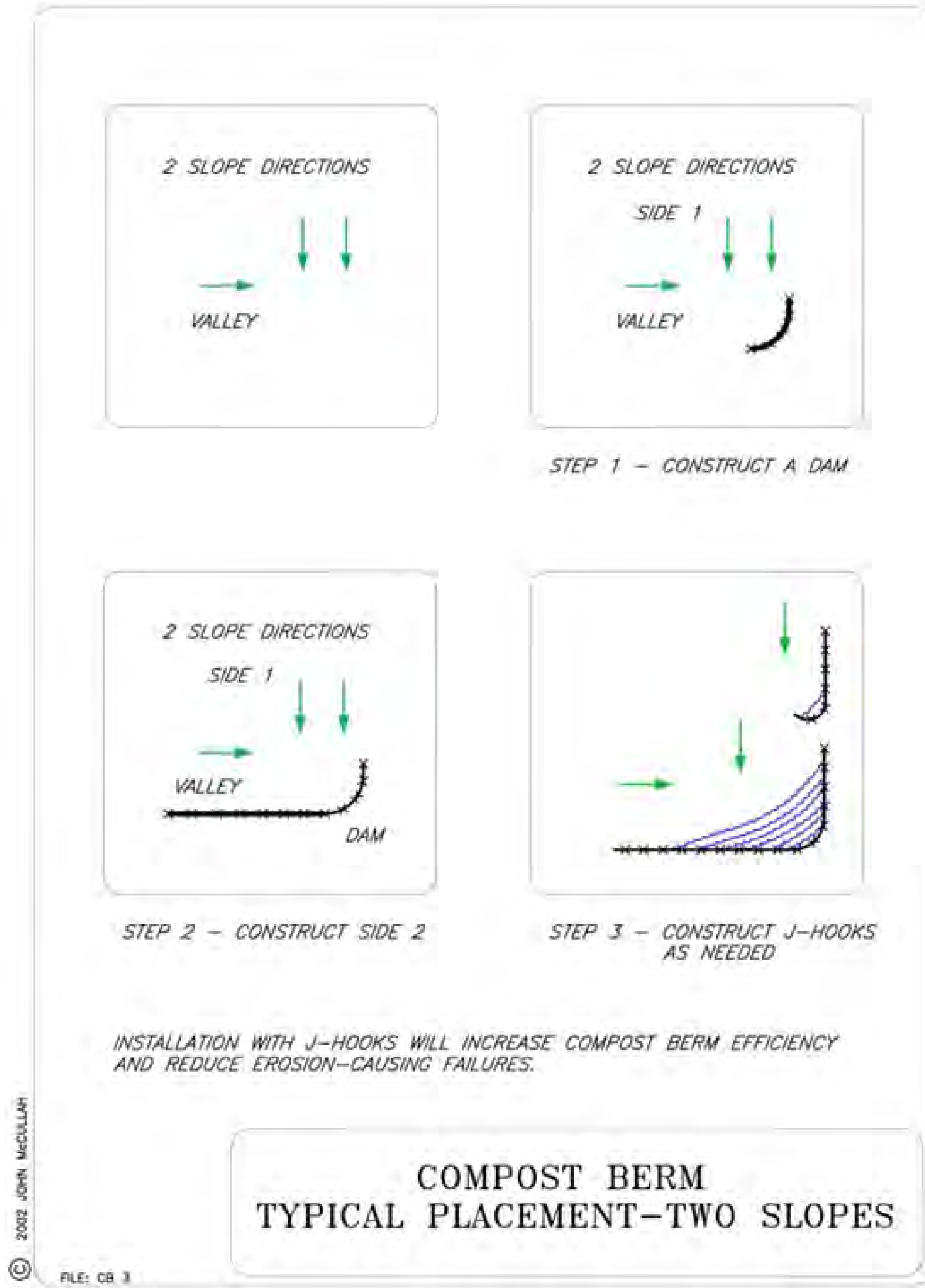


Figure 8-11. Compost Berm Typical Placement-Two Slopes.

9. ROAD AND TRAIL DRAINAGE (RT)

Low-Volume Roads and Trails: Planning and Design for Water Quality

The BMPs presented here are intended to be a guide to constructing and maintaining low-volume access roads and trails in a manner that reduces erosion, minimizes the alteration of natural hillslope drainage patterns, and thereby improves the water quality discharged to downstream waters. *Best Management Practices* (for low-volume roads and trails) are general techniques or design practices that, when applied and adapted to fit site specific conditions, will prevent or reduce pollution and maintain water quality (Keller and Sherar, 2003). These road and trail BMPs are intended to be implemented in watersheds where compliance with NPDES is critical and downstream resources are impaired or at risk of being impaired for sediment, sediment-related pollutants, or hydrologic impacts.

This section refers to, generally, all unpaved roads and trails, but more specifically to the low-volume service roads, emergency access roads, and the motorized OHV trails designated for recreation. Certain design practices such as rolling dips, outsloped roads, and low-water stream crossings are very cost-effective and practical but typically apply to low-volume, low-speed roads because of safety concerns, vertical alignment issues, or unacceptable traffic delays (Keller and Sherar, 2003).

Generally, on a watershed scale, the erosion, and certainly the sedimentation, caused by the actual OHV equipment is relatively minor compared to the problems caused by concentrated runoff and altered drainage patterns. An example of this might be a hill climb where motorcycle riding has been mechanically detaching soil particles and depositing them downslope for years. Those soil particles may never be delivered to "waters of the US" if they do not come in contact with concentrate runoff or channelized flows. That hill climb may not be a water quality problem until it diverts or generates concentrated runoff.

Unfortunately soil compaction (increased runoff) and altered hillslope drainage (concentrated runoff) go hand in hand with low-volume roads and OHV trails, and these roads and trails can cause water quality impacts unless the interaction of these processes (compaction, detachment, concentrated runoff) is well understood and proper drainage measures are implemented. Roadway surfaces need to be shaped to disperse water and move it off the road quickly and as frequently as possible. When doing so, always remember that the natural drainage patterns are the best as they have had eons of trials and adaptations.

The Three Most Important Principles Regarding Road and Trail Erosion: Drainage, Drainage, and Drainage

The concept of "control the water to control the erosion", while somewhat true for road surfaces and trail treads, needs to be re-considered in the context of watershed-scale erosion, sedimentation and NPDES rules. There is an overwhelming amount of documentation and evidence that controlling and concentrating runoff from roads and trails, on a watershed scale, with the conventional use of inboard ditches and culvert crossings (often insufficient quantity) will result in increased gully erosion. Draining low-volume roads in this way can result in a magnitude increase in erosion rates, multiply maintenance requirements, amplify sediment delivery, and commensurate increases in downstream sedimentation. Conversely, implementing BMPs that minimize alterations to the "natural" drainage patterns will result in less erosion, fewer gullies, less maintenance and reduced downstream sedimentation.

The Soil Conservation Guidelines/Standards for Off-Highway Vehicle (OHV) Recreation Management, Draft, 2005, (Soil Standards) describes the importance of "hydrologic disconnection" in BMP-RC-1 Hydrologic Disconnection: Keep water in its natural watershed by maintaining proper trail drainage, especially along drainage divides and at watercourse crossings.

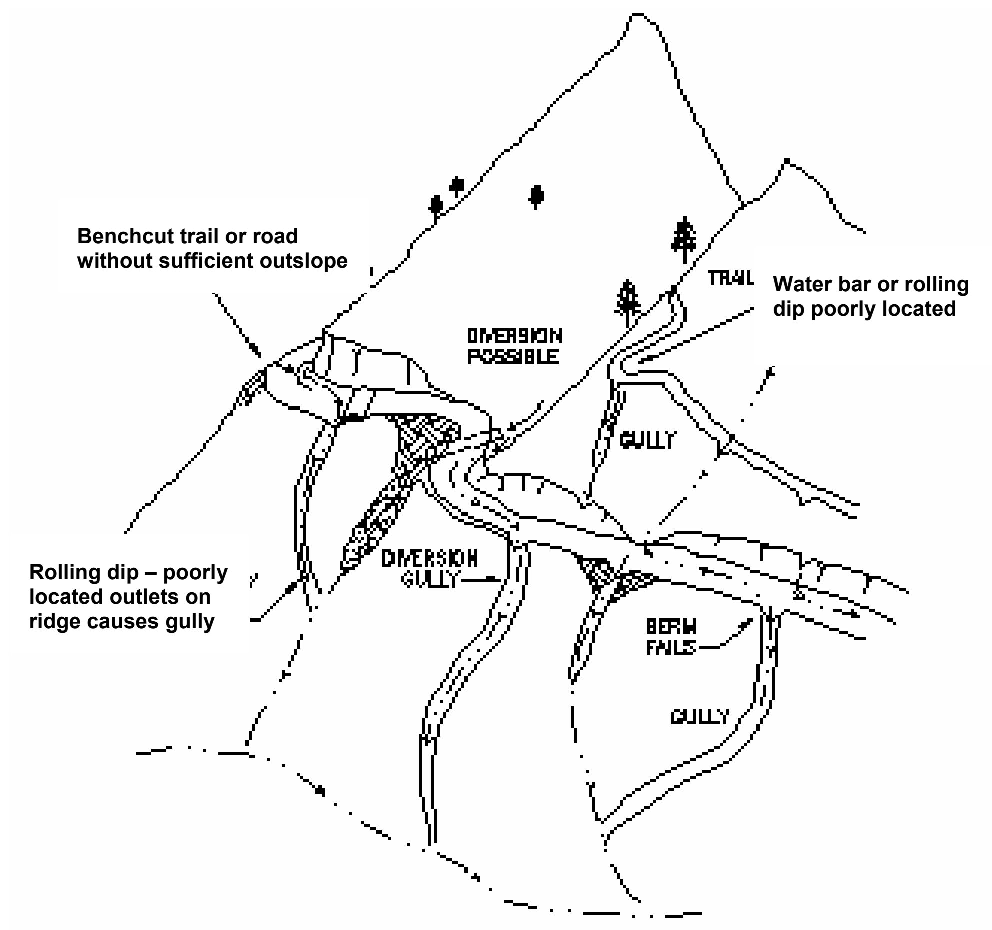
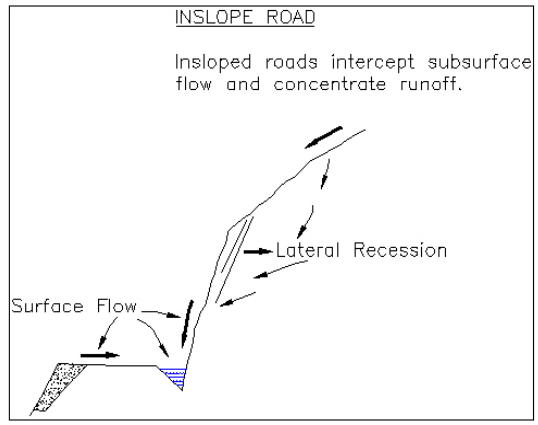


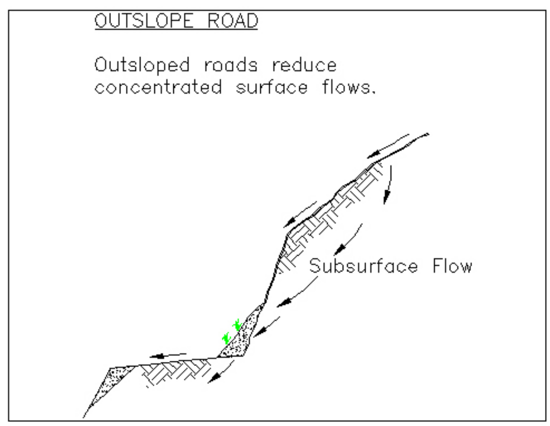
Figure 9-1. Roads and Trails, Hydrologic Connectivity, and Associated Erosion (from J. McCullah).

The Soil Standards also contain a publication for reference to the impacts of hydrologically connected roads. The publication, *Hydrologically Connected Roads: An Indicator of the Influence of Roads on Chronic Sedimentation, Surface Water Hydrology, and Exposure to Toxic Chemicals*, (Furniss et al., 2000), describes the concept of "hydrologic connectivity" whereby the use of inboard ditches, culverts, and other runoff "controlling measures" actually increase hydrologic connectivity, whereby upslope areas are effectively connected, hydrologically, to the downstream resources. Inboard ditches can be considered anthropogenic (human caused) streams. Building a stream or drainage ditch between the two most erosive and sediment producing road features – the cut slope and the road surface, will result in the most effective transport of sediment (and other road-associated pollutants) to the downstream receiving waters. This is hydrologic connectivity.

Low-Volume Roads: Service Roads and Emergency Access Roads

Altered Hydrology:





Obviously, roads increase impervious surfaces and reduce infiltration on a watershed scale. What is not so obvious is that roads with associated drainage ditches actually increase drainage density, increasing the overall stream lengths. Increased drainage density causes reduced time of concentration, increased peak flows, increased downstream flooding, and reduced base flows. A large portion of the precipitation and runoff that was naturally infiltrated into the watershed and stored as base flow is now discharged during the rainy season.

Wemple et al. (1996) describes a 55% change in hydrology due to conventional road building in forested watersheds. In the arid and semi-arid areas in California the precipitation falling in the winter is often stored as base flow. Some of that base flow may not reach the downstream riparian corridors until late autumn. During that critically dry period the base flows are necessary to maintain the health and vigor of the riparian trees and shrubs. Without healthy riparian trees and shrubs, the downstream channels are de-stabilized and less likely to sustain the more frequent and higher discharges associated with conventional road design.

From a watershed alteration, water quality, and NPDES perspective, roads built in a conventional manner, with inboard ditches and culvert crossings, will have the most negative impacts. However, road segments that are improved with more frequent cross drains, treatments to retard flows and sediments at cross drains, or road surface outsloping, can be considered "disconnected" (Furniss et al., 2000).

Therefore, roads that mimic the natural hillslope processes and minimize concentrated flows will have reduced impacts on water quality. The best designs for minimal-impact, low-volume roads will:

- Be located and built to conform to the natural terrain.
- Have more outsloped sections than insloped sections.
- Require the construction of ditches only when necessary.
- Roll the road grades to disperse the surface runoff.
- Have frequent rolling dips depending on gradient and soils, (an outsloped road can be thought of as an infinite amount of cross drains).
- Utilize armored terrain dips or armored low water crossings and minimize the use of culverts.

Culvert crossings are expensive and must be maintained because when they fail, plug and divert runoff, the impacts are often catastrophic. However, rolling dips and terrain dips are very cost-effective and can be installed at a frequency, determined by site conditions, that reduces negative impacts. Water bars are not recommended for permanent cross drainage as they are susceptible to failure when the soil bars break down (especially in the wet season) and/or they can be very unsafe if built too steep.

Therefore, the primary components of the Road and Trail Drainage BMPs are outsloping, rolling grades, and the rolling dip. Variations on the rolling dip include terrain dips and armored crossings. Outsloping is the first line of defense against tread erosion (USFS, 2004). With regards to low volume service and emergency access roads, restoring hillslope drainage is the most important principle for minimizing erosion, sedimentation and improving water quality.

Off-Highway Vehicle (OHV) Trails

For OHV trails, the outsloped trail treads may not be sustainable throughout the entire trail because, depending on the tread surface, type, and frequency use, the motorized OHV use will tend to fail the outslope with time. If and when the outsloping fails, or if no outsloping exists, the only protection against long gullies formed by concentrated flows is the rolling dip. Therefore, the rolling dip or natural terrain dip are the next most important Road and Trail Drainage BMP to reduce erosion and downstream sedimentation. The frequency of the rolling dips, the placement of rolling dips in relation to the natural terrain, and the amount of runoff each dip drains are all important factors affecting the erosion effectiveness and sustainability of the trail. The amount of runoff directed to each rolling dip is best addressed by the concept of "tread watershed", a term coined by Troy Scott Parker in *Natural Surface Trails by Design* (2004).

Therefore, for OHV trails the primary "tools" for reducing erosion, sedimentation, and maintaining "hydrologic disconnection" are:

1. Rolling dips
2. Rolling grades

3. Climbing turns
4. Applying the concept of "tread watershed"

Outsloping trails is a near-perfect solution for trails except that it is very difficult to sustain. Unsurfaced trails and roads (those with a natural surface tread) - especially OHV trails - are subjected to a combination of human and physical forces that are acting on them, relentlessly, day after day, year after year (Parker, 2004).

These physical and human forces include *compaction*, *displacement*, and *erosion*. While erosion tends to get the most attention, it is the interaction of these forces that impact the trails and subsequently watershed erosion and sedimentation. Even if a trail tread were outsloped, the forces of compaction, displacement and erosion will tend to "fail" the outslope.

On an OHV trail, vertical compaction force and horizontal displacement force always occur together and interact in specific ways:

- Over time, compaction and displacement tend to modify all tread shapes.
- Compaction hardens the tread and therefore reduces displacement. Soils with high clay content or other firm bonding can become resistant to displacement. Hence compaction is desirable.
- Compaction is limited but displacement can continue as long as the trail is in use. Displaced particles tend move downslope by both erosion and gravity. The steeper the slope, the faster the particles move downslope.

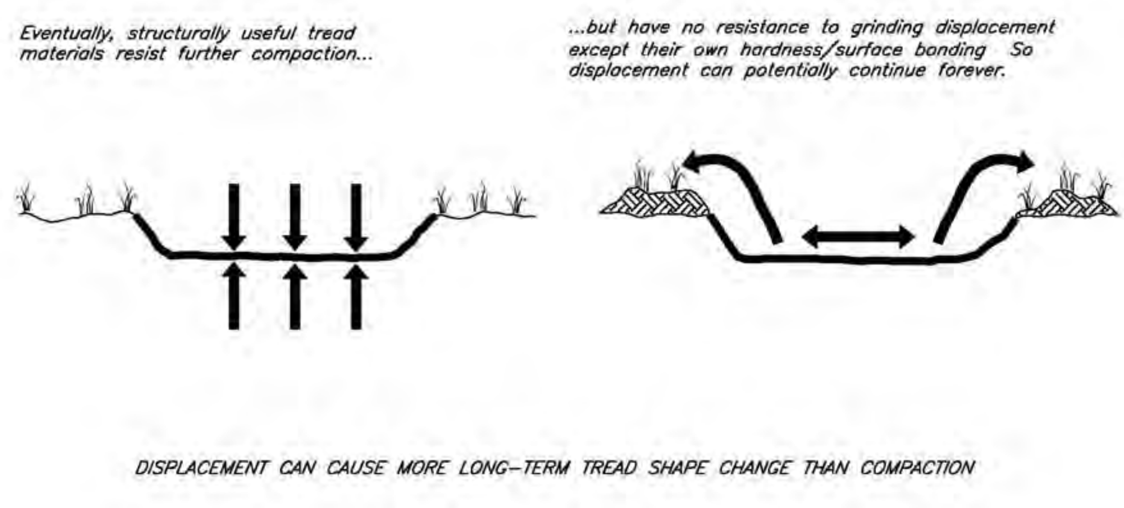


Figure 9-2. Displacement, Compaction, and Tread Shape (from Parker, 2004).

- On grades, displacement increase and compaction decreases. The steeper the grade, the more displacement will occur and the less the tread will be hardened by compaction.
- Tread material characteristics are a major factor in compaction and displacement. Some materials resist compaction and/or displacement better than others.
- OHV trail design tends to superelevate curves. *Superelevation* is an engineering term for a tread that pitches severely to the inside of the curve. Tight curves, fast travel, loose tread material, and high traffic all tend to increase "user-caused superelevation" (Parker, 2004).
- OHVs will displace materials by centrifugal force as the vehicle moves through a curve. Unless the curve is already banked, the material from the inside of the curve will be displaced to the outside of the curve, forming a banked curve over time. Once formed, superelevated curves can be very stable against further displacement and compaction. Centrifugal force can add to compaction force (beneficial) while displacement is greatly reduced. Superelevation uses physics to create a self-sustaining shape for the curves. Trail superelevation should be considered in the initial design so the trail and tread are more sustainable.

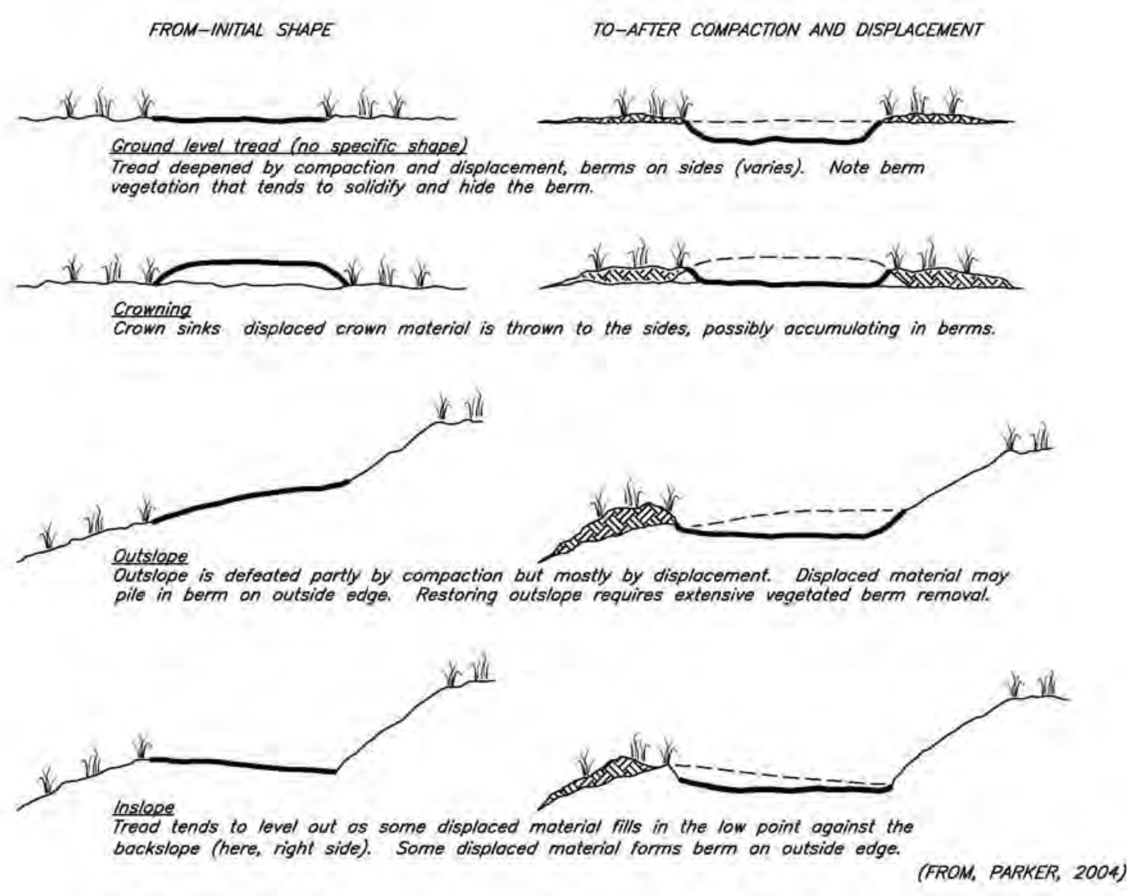


Figure 9-3. Compaction and Displacement on Trail Designs (from Parker, 2004).

Effective trail design for reducing erosion and sedimentation impacts to the watershed should integrate an understanding of these forces into the implementation of sustainable and environmentally-sensitive road and trail construction. For example, depending on soil type and slope gradient, an OHV trail might be constructed with an extreme outslope, knowing that compaction and displacement will tend to ameliorate the outslope.

The switchback turn might be insloped and superelevated such that the banked turn becomes stable through time. Such a superelevated "climbing turn" will have a tendency to reduce displacement and increase compaction, all beneficial for a sustainable trail. Such a trail will then go to outslope again with a rolling dip at the transition. And thirdly, placement of rolling dips will be strategic to remove the concentrated runoff before the volume accumulates.

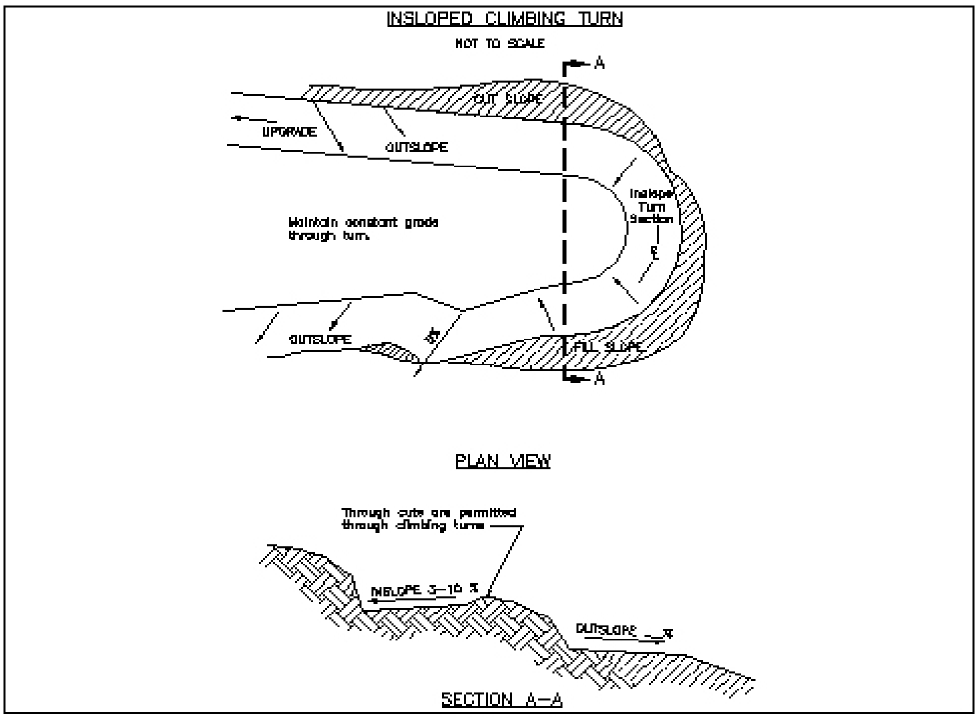


Figure 9-4. Insloped Climbing Turn.

Tread Watershed

A watershed is the land area that drains into a given water body or channel. The watershed area is bounded by the upslope ridgelines which "captures and sheds" the water to a single point. A *tread watershed* is a bit different. A tread watershed is the trail tread between a local high point (crest) and the next local low point (dip), plus the land area that drains into this tread segment (Parker, 2004). See Figure 9-5.

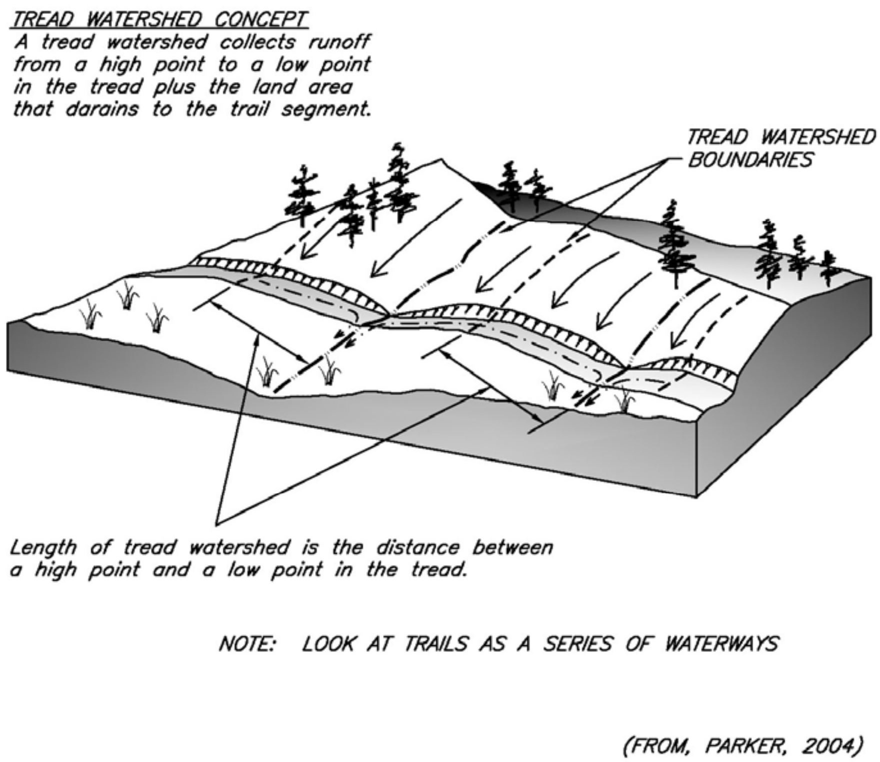


Figure 9-5. Tread Watershed Concept (from Parker, 2004).

The tread watershed concept looks at a trail as a series of waterways. Why? Because if and when the outslope fails, or if the outslope wasn't originally present – the tread becomes a waterway (diverts concentrated flow) when the runoff follows the tread rut. At that point, the tread drains solely through its dips. Since tread hardening is too expensive and goes against the spirit of why we're on the trail in the first place, that leaves *tread watershed control* as our major tool for hydrologic management.

Like a typical watershed, the *height* of the tread watershed is from the lower edge of the tread upward to the top of the topographic basin boundary. These features are fixed by the road location and the natural features. The tread watershed *length*, however, is the distance from the local trail crest to the dip. Crest and dip locations can be managed and modified by the trail designer. The dips and crests can be natural features, but if runoff erosion is occurring then there is probably too much water collecting and the tread watershed is too large. The designer can then reduce the tread watershed by adding drainage dips.

For legacy trails (those existing trails that are requiring maintenance), it is sometimes challenging make these dips "match the terrain". However, the use of Rolling Grades or Grade Dips (BMP-RC-2, Soil Standards) is recommended when designing and building new trails that have sustainable treads and are self draining with sufficiently small tread watersheds.

Full-Bench Cuts

Tread Watershed Size

The larger the tread watershed, the more stormwater it collects. Limiting the length of the tread watershed - by intentionally forming dips and crests into the tread alignment (rolling grades) – may be the only way to design OHV trails that; 1) have sustainable surface treads, 2) do not cause undue downslope erosion and sedimentation, and 3) are, therefore, hydrologically disconnected.

The Soil Standards (BMP-RC-4: Full-Bench Cuts) recommends using a full-bench cut for trails constructed on natural slopes of 50% or greater. The full-bench cuts are recommended to stabilize the trail bed and also reduce the risk of slope failure initiated by saturated fill slopes.

Depending on the hillslope steepness, full bench construction will generally have a higher and steeper cutslope or excavated backslope than partial bench construction. Generally, cutslopes are the most erosive feature in road or trail prism. This generalization is not true, of course, on motorized OHV trails or on roads or trails that are not adequately outsloped. In those situations the tread and off-trail gullies are the primary sediment sources. Cutslopes can range from near vertical in rock to 2H:1V in soils having little cohesion. Backslopes should not be constructed steeper than the exposed materials ability to remain stable (angle of repose) throughout the seasons (USFS, 2004). On trails constructed with cutslopes that exceed the parent materials angle of repose, the backslopes often fail, either by erosive and/or gravitational forces, and block the tread. If the trail is insloped or has concentrated runoff along the tread, the failed material will then be delivered to downslope water resources and increase watershed sedimentation.

The tread watershed concept looks at a trail as a series of waterways. A tread watershed is the trail tread between a local high point (crest) and the next local low point (dip), plus the land area that drains into this tread segment (Parker, 2004).

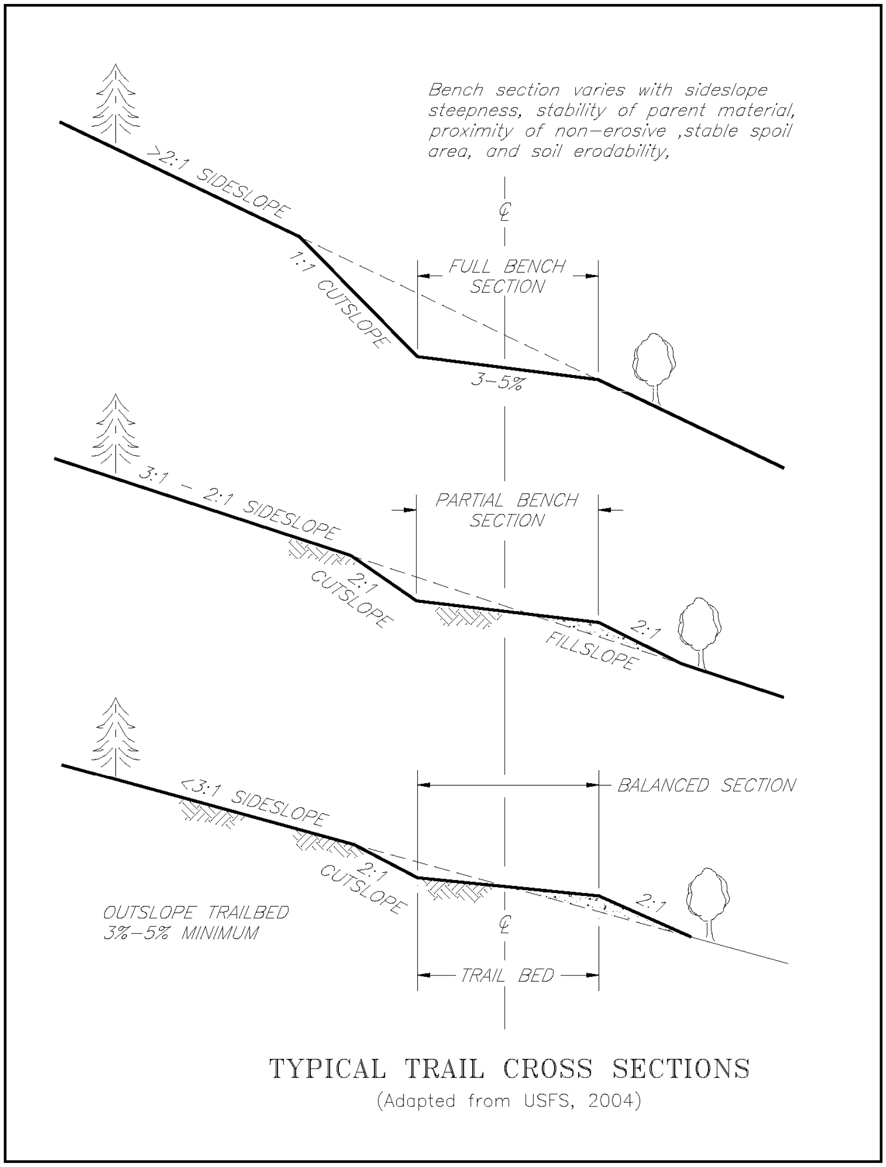


Figure 9-6. Typical Trail Cross Sections (adapted from USFS, 2004).

Summary of Recommended Practices for Low-Volume Roads (Adapted from Keller and Sherar, 2003)

General:

- Use minimum Road Standards needed for safety and intended traffic use.
- Roads should have gradients of 12% or less, short sections of 15% are acceptable when necessary. On steep roads, the drainage is difficult to control.

- Use road surface stabilization measures where needed and as often as possible.
- Use balanced cut-and-fill construction in gentle terrain. Use full-bench construction on slopes over 65% (50% recommended by Soil Standards for OHV trails) and end haul excavated material. Always avoid side-casting material when constructing or maintaining roads on steep ground.
- Maintain outsloped roads section by grading outer berms to the inslope, do not sidecast. Grading outsloped road surfaces is best accomplished by grading in an uphill direction to pull material to the inslope.
- Consider the use of retaining walls, Mechanically Stabilized Earth (MSE) and soil stabilization materials where applicable.

Drainage

- Outslope road surface 3-5% for road grades less than 10% on stable soils, using rolling dips and terrain dips for cross-drainage structures. In slippery soils, either inslope the road or add aggregate surfacing to the road.
- Construct ditches only when necessary. An outsloped road without ditches disturbs less ground, is less expensive to build and maintain, and is hydrologically disconnected.
- Construct rolling dips rather than culvert cross-drains for typical, low-volume, low speed roads with grades less than 12%.
- Construct rolling dips deep enough to provide positive drainage, angled 0-25 degrees from perpendicular to the road, with a 3-5% outslope , and long enough (45-180 feet) to pass the design vehicles and equipment.
- In soft soils, armor the mound and dip with rock or gravel, as well as the outlet.
- Inslope road surfaces 3-5% with a ditch section for road grades in excess of 10% or in areas with steep natural slopes, erodible or slippery soils with out aggregate surfacing, or on sharp turns.
- Roads making sharp turns or through-cut turns can be transitioned from outslope to inslope around the turn and then back to outslope again with a rolling dip at the lower transition (RT-7 Climbing Turn).
- Use a crown road section on a wide road with gentle and flat ground to prevent water from standing on the road surface. The crown segments should slope 3-5%.
- Roll grades or undulate the road profile frequently to disperse water, particularly into and out of stream crossings. Avoid long sustained road grades that concentrate flows. Undulate, don't concentrate!
- Maintain or provide vegetative filter and buffer strips between roads and drainage courses. Keep roads and streams disconnected!
- Use ditch relief cross-drain structures (rolling dips, culverts, terrain dips) frequently to move water across the road from the inboard ditch and all runoff from the road surface.

- Protect drain outlets with rock energy dissipators.
- Avoid out letting concentrated flows into areas other than natural drainages. Culverts outletted onto ridge lines (where water has never flowed) will frequently result in gullies running down the ridge!
- Install culvert cross drains in the bottom and middle of natural drainage courses so the installation causes no change in the natural channel alignment or stream bottom elevation. Replacement culverts should be placed as deeply into the natural channel as possible. Deep fills made on steep slopes may require slope or overside drains.
- Avoid the use of outside ditches or berms.

Road and Trail Drainage BMPs

The following BMPs are used - sometimes interchangeably - to drain roads and reduce road related erosion and sedimentation.

- RT-1 Crown
- RT-2 Outslope
- RT-3 Inslope
- RT-4 Road Surface
- RT-5 Rolling Dip
- RT-6 Terrain Dip
- RT-7 Climbing Turn
- RT-8 Culvert Crossing
- RT-9 Slope Drain or Overside Drain
- RT-10 Low Water Crossings

This low-volume road rolls across the terrain to minimize concentrated runoff. It is outsloped, has a terrain dip, and has a base rock surfacing.

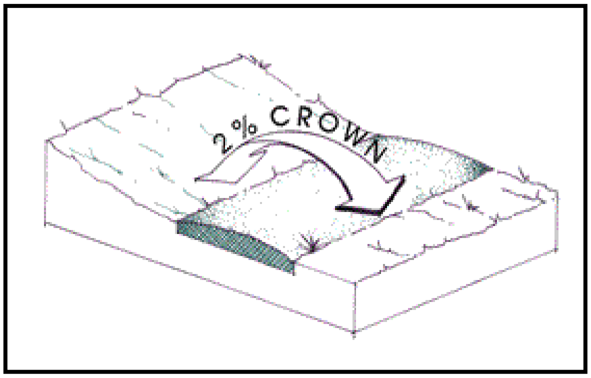
RT-1 Crown

SWPPP Summary

Crowned roads are designed to quickly drain road surfaces from the center of the road to side ditches. This technique helps to prevent water from standing on the road surface. Standing water results in road failures, destabilized sub-base, potholes, and erosion.

Definition / Purpose

Standing water on roads and trails will adversely affect the trail surface and decrease the life and quality of it. Crowning creates a high point in the center of the road so surface water will drain off on either side, preventing erosion of the road surface. Crowning is a method to effectively *disperse* (split) the road surface runoff – between the inboard and outboard areas.



Planning Considerations

Crowning is an especially effective technique to drain wide road segments traversing gentle gradients. Crown section roads are appropriate for higher standard, two lane roads on gentle grades. These sections also require a system of inside ditches and cross drains. It is difficult to create and maintain a crown on a narrow road, so a gently insloped or outsloped road drainage is more effective for rural roads (Keller and Sherar, 2003).

For relatively flat road segments, crowning is often the only feasible way to prevent water from standing on the road.

The crowned segments should have a pitch of 2%-5% (2% minimum) to the outer road edges.

Material shall be imported as necessary to crown the road or trail (import crown).

Construction Specifications

A general rule for level or gently sloping roads is ¼ inch of crown per foot (2%) of total road width. A crown of 3/8 – ½ inch per foot of road width (3-5%) may be necessary for steeper sections to counteract the tendency of water to travel downhill over the road surface.

This road would benefit from crown section.

Limitations

Crowned road segments, because of their relatively shallow drainage pitch, require annual (minimum) maintenance and re-grading. Crowned road segments tend to go from crowned (high point in the center) to flat with time and continued use. The road base or other natural road surface materials tend to migrate from the crown to the outer edges with time.

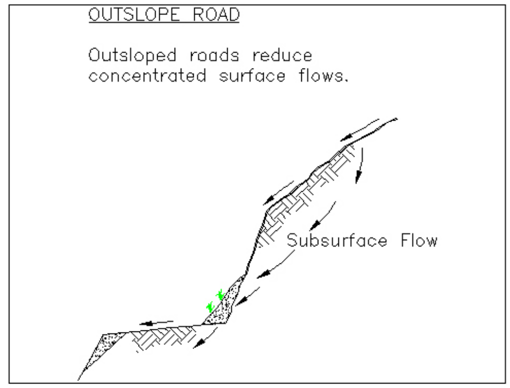
As the crowned road section deteriorates, standing water will begin to fail the road. Proper grading will prevent potholes from forming and provide a safer surface for travel.

Inspection and Maintenance

- Low-volume roads should be inspected annually to determine the condition of the road drainage.
- The roadside ditches, associated with crowned and insloped road sections, shall be inspected for erosion and/or sedimentation (plugging).
- Pot holes, washboards, and standing water on the road surface are all sign that the crowned road segment needs maintenance.
- Maintenance of crowned and/or insloped road segments should be done before the rainy season.
- Proper grading will prevent potholes from forming and provide a safer surface for travel. Just filling the potholes is not the solution. The cause of the potholes, e.g., poor drainage, should be ascertained and corrected.
- Crowned road segments must be maintained by making 3 or more passes with a grader. The first passes will pull material from the outer edges (where it migrated) back toward the center.
- Road grading shall be performed with sufficient moisture for proper compaction.
- Maintenance of crowned road segments should be done annually because, generally, vehicle use flattens the road over the course of a year.

RT-2 Outslope

SWPPP Summary



An outsloped trail is one that is lower on the outside or downhill side of the trail bench than it is on the inside or bank side. Outsloping lets runoff flow naturally, as uniform sheet flow, off the trail.

Not only does outsloping protect the trail or road prism from erosion, but it mimics and attempts to restore the natural hillslope processes and watershed hydrology which can greatly improve water quality.

Definition / Purpose

An outsloped trail or road surface is sloped to the outside so stormwater runoff no longer becomes "trapped" on the road prism. An insloped or poorly drained surface will actually collect and concentrate drainage, both surface flows and subsurface flows intercepted by the trail/road cut. Consequently, access roads may become impassable during the rainy season.

On newly constructed trails and roads, the road bench is sloped gently toward the outer edge to provide uniform sheet flow drainage. On rehabilitated or re-engineered roads the inside ditch is filled with material excavated from the road surface and the outer road embankment. This is referred to as a "pull back" where the outer edge (fill section) of the road prism or side-cast road material is pulled back into the road cut (cut section).

- Import Outslope: When there is insufficient road fill on the outer edge of the road prism to accomplish the outslope drainage then soil/road material will need to be imported, usually by dump truck.
- Export Outslope: When the road fill material removed ("pulled back") exceeds the capacity of the cut section then the excess material must be exported, sometimes to a nearby "import" road section. The presence of a spring or seep at the cut section of a road will require export as road fill should not be placed on or near springs.

RT-2 Outslope is a technique used to prevent concentration and channeling of stormwater by sloping a trail or road surface towards the downhill side, allowing sheet flow to occur.

Planning Considerations

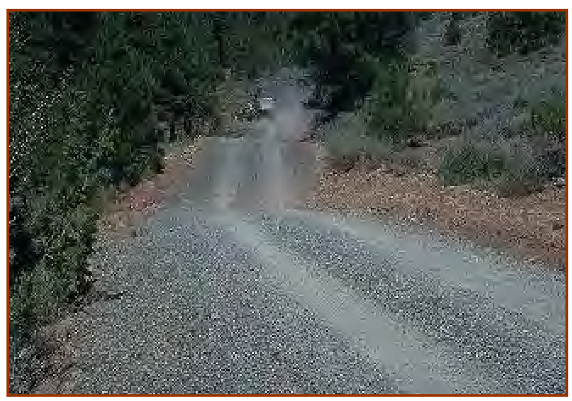
Outsloping of hillslope road segments is appropriate where water quality and sediment loading (sediment yield) is a concern. Outsloping provides for *hydrologic disconnection*, as per Soil Standards, BMP-RC-1.

Outsloped roads best *disperse* water and minimize road width - but may require roadway surfacing (see RT-4 Road Surface) and fill slope stabilization (usually grasses and/or shrubs). An outsloped road minimizes concentration of water, minimizes needed road width, avoids the need for an inside ditch, and, therefore, minimizes costs.

Outsloped Roads

- **Disperse the runoff as sheet flow to the downhill side.**
- **Best results are on roads with < 10% -12% gradient.**
- **Use with rolling grade breaks, rolling dips and terrain dips.**
- **Surface roads when feasible.**

- Outsloped roads with clay-rich, slippery road surface materials often require rock surface stabilization or limited use during rainy periods (see EP-2 Wet Weather Closure).
- On road grades over 10-12% on steep hillslope areas, outsloped roads are difficult to drain effectively and may feel unsafe. Try to limit the length of such road segments. Cross drainage (such as rolling dips) should be used wherever the local terrain allows a break in the oversteepened section.
- Roads or trails where the road surface has tire ruts and/or rills running down the length of the road are good candidates for outsloping.
- A re-engineered road or trail generally cannot be outsloped along its entirety. Instead, the various road segments will transition between outsloped and insloped, especially going around outer turns (traversing around a ridge node). These road turns at ridges are often exceptionally wide and relatively flat. Outsloping road segments around turns would require excessive soil translocation and can result in safety hazards. The transition from outslope to inslope (around the turn) and to back outslope will require a rolling dip at the transitions (see RT-7 Climbing Turn).



Outsloped roads and trails used in combination with dips can reduce maintenance costs, decrease soil erosion, and reduce sediment delivery and loading (sedimentation) to downstream resources.

- Outsloping performs optimally when used with rolling grades, following somewhat the natural topography of the hillslope. This breaks the road into distinct drainage areas or "tread watersheds". The degree of outslope should be based on the linear road grade and drainage requirement of each road segment and the outsloping can change as the road 'rolls" across the hillslope.

- If the linear road grade exceeds maximum allowable outslope grade, rolling dips, terrain dips, or other grade breaks should be included in the design. For roads with gradients steeper than 10%-12%, it is difficult to maintain the drainage. Steep road segments should be minimized in length, surfaced with well-stabilized and compacted road base, and drained with a rolling dip as soon as the topography allows such.
- Low-volume roads are generally outsloped at 3%-5% while trail segments can be pitched more (8%).
- Low gradient roads with a competent rock surface can achieve sheet flow drainage with a 2% outslope.
- During construction or the re-engineering of natural-surfaced roads and trails, it is recommended to increase the outslope gradient by 1-2% to allow for the inevitable settling, compaction, and detachment of the road surface.
- Adequate soil moisture or supplemental water is recommended to achieve compaction.

Low gradient roads with a competent rock surface can achieve sheet flow drainage with a 2% outslope.

- Service roads and emergency access roads will require surfacing. The minimum requirement for the tread surface is ¾-inch (minus) base rock laid down approximately 6-8-inches thick, graded smooth and uniform, and compacted to 94% (+/- 4%) on a relative Proctor scale
- Import outslope can often be cost-effectively implemented by importing material from nearby road segments with excess "cut" material, such as large crossings that are excavated and armored. Road fill cannot be placed against cut slopes with visible seeps or wet spots, so this material can be used as import.

Construction Specifications

- Conventional outsloping usually requires a dozer outfitted with rippers and a six-way blade. Sometimes the regrading can be accomplished with a grader. An excavator is recommended when it is necessary to retrieve the side-cast road fill and/or work between the existing trees and shrubs established on the fill section of the road prism.
- If the existing vegetation on the road edge is native and desirable, every attempt should be made to strip and stockpile the topsoil (top 2-3" organic soil layer) and/or duff for re-application later (see SS-2 Topsoiling and PO-5 Stockpile Management).

- Soil conditions should be moist. Adequate soil moisture or supplemental water is recommended to achieve compaction. For this reason, early spring or early fall are good seasons to consider re-shaping trails and roads.
- The existing inboard ditch shall be cleared of vegetation and ripped to eliminated the "drainage memory" and reduce future subsurface flow problems.
- The dozer, motor grader, excavator or back-hoe is used to cut the outer edge and reduce its elevation.
- If bedrock or large rock are exposed, imported fill will be required to achieve the desired outslope (import outslope).
- The "retrieved material" or imported soils are placed in the inboard ditch. The dozer shapes this material and compacts it with its tracks in maximum six-inch lifts. The dozer is also used to provide the initial outsloped road surface.
- Trees, stumps, roots, brush, and rocks (6 inches and larger) removed during excavation should be placed on the excavated slope below the road or at designated locations off the roadway. No organic material should be incorporated into the embankment, inboard fill, or the road surface.
- Excess organic material can be placed on the final soil surface as erosion control and to "naturalize" the area.
- A single drum 10 to 15 ton vibratory roller is used to compact the filled areas and road surface. If a compaction by vibratory roller is not possible then increase outslope pitch by 1-2% to allow for settling, compaction and displacement.

In certain weather conditions outsloped roads can be hazardous.

Limitations

- Outsloping may require roadway surfacing (see RT-4 Road Surface) and fill slope stabilization (usually grasses and/or shrubs).
- The presence of a spring or seep at the cut section of a road will require export of the outslope "cut" materials – as road fill should not be placed on or near springs.
- It is not safe to use outsloped roads located above the snow fall elevation (snow line) in the winter months, even if the road is rock-surfaced.

Inspection and Maintenance

- Maintenance of outsloped road segments should be done annually because, generally, vehicle use flattens the road over the course of a year.
- Rill formation on the road surface is an indicator that the outsloped road segment needs maintenance.

- The loss of outslope pitch from erosion, displacement, compaction, and/or the presence or gradual build-up of an outer berm is an indicator that outslope maintenance or road closure is needed before the next rainy season.
- Maintenance of outsloped road segments is best achieved by starting downhill - grading in an uphill direction so the berm material can be "pulled inboard". Maintenance usually requires two such passes minimum.
- Rolling dips are to be approached with caution as the grader blade must be reversed in direction so the dip is not destroyed.
- For gravel roads, routine grading and shaping will suffice. Retain the appropriate outslope of the road. Avoid leaving a berm that channels water down the road.
- On base rock surfaced roads the coarser gravels will separate with time and come to the surface, usually forming gravel ridges or outer berms. These roads should ripped with a toothed (1-2'' teeth) grader, re-graded, and then re-compacted
- To reduce maintenance, avoid using roads during wet periods if such use will damage the road or negate the effects or the erosion control feature.

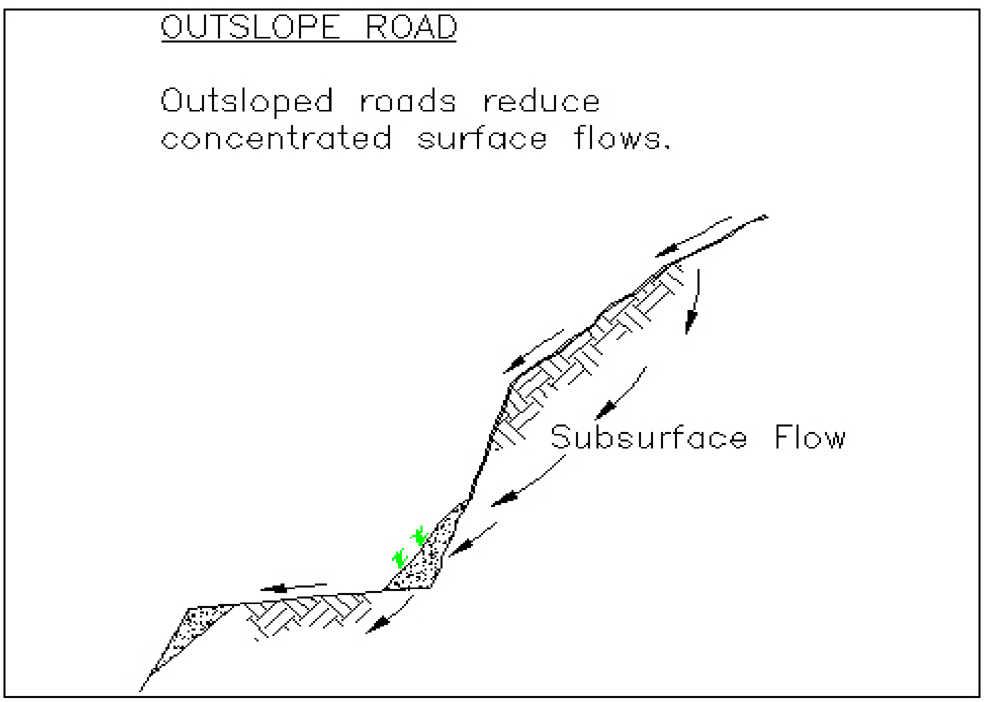
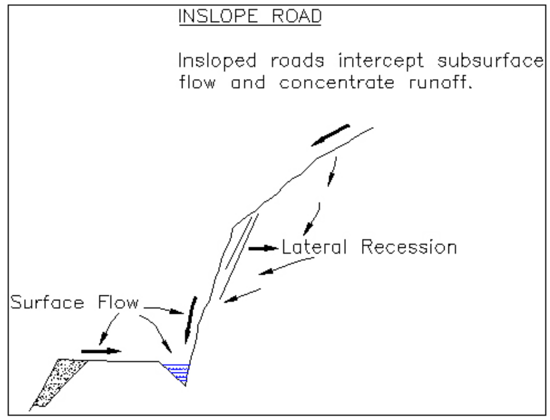


Figure 9-7. Outsloped Road.

RT-3 Inslope

SWPPP Summary

Insloping is a road shape where the road surface is lower on the inside (slope side) of the road. Insloping collects surface runoff into an inboard ditch system.



Definition / Purpose

On insloped roads, the traffic surface slopes down to the uphill side of the road. Insloped roads usually require a ditch and a cross-drainage culvert to move water to the other side of the road.

Planning Considerations

Insloped roads are safer and may be preferable when roads are built on side slopes with slippery soils and/or in steep terrain, especially on low-volume roads without stable road surfacing.

A well designed low-volume road will probably integrate both inslope and outslope sections. A rolling dip or armored dip (or other cross-drain) is required when making the transition from insloped segment to outsloped segment (when traversing the road in a downhill direction).

Insloped roads collect runoff from the road surface and accumulate subsurface flows from the hillslope. Therefore, insloping requires:

- **A system of drainage ditches.**
- **Extra width to accommodate the ditches.**
- **Cross drain or culvert construction.**
- **Maintenance and "erosion-proofing" of the drainage ditches.**
- **Replacement and maintenance of the culverts or cross-drains.**
- **Erosion control and energy dissipation at the cross-drain outlets.**

Insloped roads can best control the road surface runoff, but insloping concentrates water and accumulates subsurface flows from the cutslope face. The concentration of surface water has many drawbacks (limitations):

- Insloped roads require a system of ditches, cross-drains and the extra road width necessary for the ditch.
- The drainage ditches must be treated for erosion prevention, if necessary.
- The side slopes of the drainage ditch should be 2:1 maximum on the road side and 1:1 maximum on the cut slope side. Steeper side slopes will require additional stabilization and/or reinforcement.
- The drainage ditch must be treated and maintained for sedimentation in order to maintain positive drainage.

- Every time the ditch is maintained (pulled or cleaned out), the remaining disturbed and loose soil is highly erodible and susceptible for delivery to downstream resources.
- The cross-drains (ditch relief culverts) will require regular inspection and maintenance. Culverts will require replacement depending on the type of culvert.
- Energy dissipation and/or overside drains will be necessary to prevent erosion at the outlets.

Culvert cross-drains are most frequently used to move ditch water across the road. They are most appropriate for high-standard roads where a smooth road surface profile is desired. Because pipes are expensive, the tendency to install relatively small culverts must be weighed against the susceptibility to plugging and required cleaning (also see RT-8 Culvert Crossing).

The cross drains, ditch relief culverts, or broad-based dips (usually requiring armoring because of concentrated flows and vehicle wear) must be spaced frequently enough to remove water before erosion occurs. This spacing, in actuality, is difficult to determine because it should also consider the impacts of downslope erosion. Culvert cross-drains are relatively expensive; so cost, rather than need, is often a primary determinate of culvert spacing.

Recommended Maximum Distance (feet) Between Ditch Relief Culverts		
Road Grade %	**Low to Non-Erosive soils** (1)	**Erosive Soils |** (2)
0-3	360	225
4-6	270	150
7-9	225	120
10-12	180	100
12+	150	90

(1) Low erosive soils = coarse rocky soils, gravel, and some clay
(2) High erosive soils = fine, friable soils, silt, and fine sands

Table 9-1. Recommended Maximum Distance (feet) Between Ditch Relief Culverts. [From Keller and Sherar, (2003), adapted from Packer and Christensen (1964) and Copstead, et al., (1998)]

Construction Specifications

For insloped roads, plan ditch gradients steep enough (generally greater than 2 percent), but less than 8 percent to prevent sediment deposition and ditch erosion. The higher gradients may be suitable for more stable soils; use the lower gradients for less stable soils.

- The insloped pitch is usually between 3-5% unless the road is paved or surfaced.
- The ditch gradient should be between 2% and 8%. Steeper gradients will require armoring (see RC-4 Turf Reinforcement Mats/Grass-lined Channels, and SS-9 Cellular Confinement Systems).
- The side slopes of the drainage ditch should be 2:1 maximum on the road side and 1:1 maximum on the cut slope side. Steeper side slopes will require additional stabilization and/or reinforcement.

Limitations

- Insloped roads require more road width to accommodate drainage ditch.
- Insloped roads are relatively expensive due to drainage ditch system and frequent cross-drainage requirements.
- Insloped roads are "hydrologically connected", see Soil Standards BMP-RC-1 Hydrologic Disconnection.

Inspection and Maintenance

- Maintenance of insloped road segments should be done annually before the rainy season.
- Roadside ditches shall be inspected for erosion and/or sedimentation (plugging).
- Cross-drains need annual inspections to ensure they are operating. Inspections during runoff-producing storms are beneficial for determining whether culverts or ditches are plugged.
- Inspect overside drains and cross-drain outlets for erosion.
- Rolling dips are to be approached with caution as the grader blade must be reversed in blade angle so the dip is not destroyed.
- For gravel roads, routine grading and shaping will suffice. Retain the appropriate inslope (3%-5%) of the road.
- On base rock surfaced roads the coarser gravels will separate with time and come to the surface, usually forming gravel ridges or outer berms. These roads should be ripped with a toothed (1"-2'' teeth) grader, re-graded, and then re-compacted.
- To reduce maintenance, avoid using roads during wet periods if such use will damage the road or negate the effects of the erosion control features.

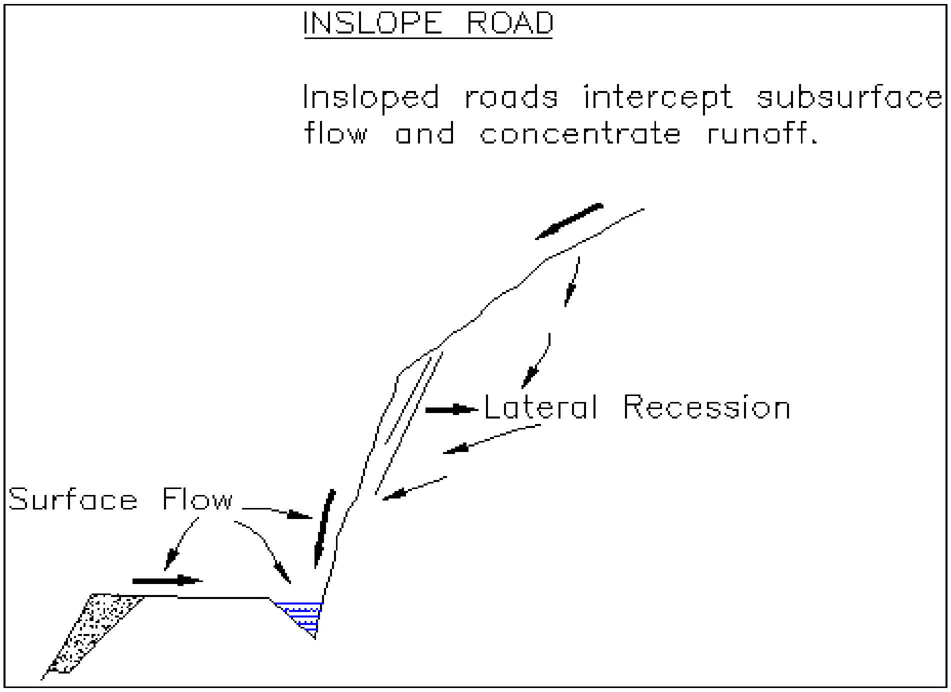


Figure 9-8. Inslope Road.

RT-4 Road Surface

SWPPP Summary

Surfacing the native roadbeds (and trail surfaces) with gravel, crushed aggregate and/or base rock improves the structural support and reduces road surface erosion. Low-volume roads intended for all-weather use shall be stabilized by surfacing with gravel.

Benefits of aggregate surfacing include:

- **Improved structural support and maintain drainage**
- **Improved traction and safety**
- **Reduced road surface erosion**

Definition / Purpose

Road surfacing most frequently consists of placing gravel, crushed aggregate, or base rock (4-6" thick minimum), on a newly prepared or approved roadbed. Emergency access roads and/or service roads should be surfaced so there can be all-weather access and prevent erosion and sedimentation from the road surface.

Roads and trails that have been re-engineered and/or re-graded for erosion control and hydrologic disconnection (outsloping, rolling dips, and rolling grades) should be seriously considered for RT-4 Road Surface. Un-surfaced roads, even those properly drained, can revert to rills, gullies, and increased diversion potentials if not protected from compaction, displacement, and tire rutting, especially if used during the wet season.

Planning Considerations

A stabilized road surface improves traction and safety, and offers erosion protection as well as structural support. Road surface erosion can be fairly significant; it is commonly estimated that the erosion rates on roads with rills evident can be as high as 10-20 tons/ac/yr. However, the gully erosion and fill slope failures which result from roads capturing, concentrating, and diverting runoff can be one to two magnitudes higher than the road surface erosion rates. Additionally, the sediment delivery potential (sediment yield) for the gully erosion is nearly 100% because the volume of water involved also has the energy needed to transport the sediment to the downstream resources.

Therefore, the role of surfacing materials in maintaining the proper road drainage is even more important than reducing the road surface erosion. Always stabilize the road surface in sensitive areas near streams and at drainage crossings.

For road segments where funding, time, or cost-effective rock delivery are limiting factors, rock surfacing can be "spotted", whereby limited rock is laid in or on the most critical areas only. The most critical areas for surfacing are often steep segments where traction and stability are crucial, drainage crossings (terrain dips, low water crossings, etc.), and roads adjacent to streams or other sensitive areas. Conversely, roads segments with gentle gradients traversing the ridge tops may perform well without surfacing.

Subgrade or Structural Section:

Always stabilize the road surface in sensitive areas near streams and at drainage crossings!

The condition of the subgrade is critical to the performance of road surfacing. The shape of the subgrade plays a central roll in providing road drainage. Do not rely on producing the surface shape (crowned, insloped, or outsloped) of the road by shaping the rock surfacing alone. The subgrade should be at or near the optimum moisture content for proper compaction and shaping prior to surfacing. The ditch, if required, should be shaped and clear prior to applying surfacing (Oregon Department of Forestry, 2000).

A range of options exist for improving the structural capacity of the roadway in areas of soft soils or poor subgrades (Keller and Sherar, 2003). These commonly include:

- Compacting the native soil to maximum density.
- Adding high strength material, such as crushed aggregate or gravel, over the soft soil.
- Improving the in-situ soils by mixing with stabilization additives such as lime, cement, asphalt, or chemicals.
- Bridging over the soft soils with geotextiles and/or articulated concrete blocks.
- Removing the poor soil and replacing with high quality soil or rocky material.
- Limiting use of the road (closure) during wet weather.
- Keeping moisture out of the soil with effective drainage.

Surfacing Materials:

Aggregate (crushed gravel), pit run rock, or select base rock are the most common and cost-effective materials used on low-volume roads. The various stabilization additives may be used to improve the material properties of the in-situ soils. However, most of these materials still need some type of durable "wearing" surface.

The surfaced road must have a stable sub-base. Roads built over deep clay soils may require several inches of rocky sub-base laid before laying the base rock course. Angular rock is best but generally any rocky aggregate will work for the sub-base.

Perennially wet seeps, springs, or deep clay soils may require additional reinforcement with the use of geogrids and/or geotextiles placed under the aggregate. These geotextiles are manufactured from polypropylene, either woven or non-woven, and will form a structural bridge and prevent the fine soil particles from "pumping" up through the aggregate and causing failure.

Type	Used as	Thickness	Comments
Base Rock* ¾-inch minus	Final surface	8" minimum compacted to 6"	Angular, well graded. Must have strong sub-base. Is the easiest to grade to a smooth durable surface. Reduced traction on steep sections and > 4% outslopes.
Base Rock* 1½-inch minus	Final surface armored crossings **	8" minimum compacted to 6"	Angular, well graded. OK on weaker to moderate sub-base Better traction in wet season.
¾-inch aggregate** (drain rock)	Sub-base and/or final surface *	varies	Angular, well sorted, poorly graded, can be useful on shallow soils with fine clay and silt fractions.
1½-inch aggregate** (drain rock)	Sub-base and/or final surface * armored crossings	Varies to 4" minimum	Angular, well sorted, poorly graded, can be useful on shallow soils with fine clay and silt fractions. This aggregate can make a good sub-base for wet soils with high fraction of "fines". Can provide good wet season traction.
River gravel	Generally unscreened useful as sub-base	Varies to 6" minimum	Gravels to small cobbles should be slightly rounded to sub-angular. Gravel with > 50% sand and > 5% silts recommended.

* useful only if there are sufficient and appropriate "fines" (5-15%) for binder.

** The armored crossing should have a relatively wide, flat bottom, well compacted over a stable sub-base.

Table 9-2. Types of Aggregated Rock and Recommended Applications.

There are many types of aggregated rock useful for structural sub-base and road surfacing:

a) Base rock is the best performing surface material; comprised of crushed angular rock that is well graded (full range of gradations available). The mixture is usually about 20-50% coarse gravels (by weight), 5-15% silts (fines passing #200 sieve), and the rest sands (coarse to fine). Select base rock mixtures allow maximum grain-to-grain contact with increased resistance to deformation, maximum compacted density, low permeability, and high stability.

b) Aggregate is crushed or angular rock with little or no fines. It is preferable for use as sub-base but may serve well as surfacing material if mixed with fines containing some plasticity. Aggregate is difficult to compact, has variable density, and ravels easily.

c) River gravels usually have a high amount (>30%) of fines and is slightly rounded. Such gravels have: poor grain-to-grain contact, decreased density, lower stability and strength, but is easy to compact.

Construction Specifications

Before the road is surfaced, the road drainage must be corrected with outsloping, terrain dips, armored crossings, etc. Make sure all of the road bed is structurally stable. The subgrade shall be compacted at optimum moisture conditions.

Important! If the road is outsloped and intended to be surfaced, the final road base elevation must be flush with the unpaved soil surface (shoulder), especially the inboard (shoulder) section of the road. It is imperative that the sheet flow running down the slope and across the shoulder does not become diverted and concentrated by the edge of an elevated base rock surface. This may require an 'over cut' of the road surface just prior to surfacing or stockpiling extra soil material along the inboard edge of the road for final grading of a uniform outsloped surface.

Hillslope drainage shall sheet flow, unimpeded by the surfacing material, across the road or trail.

- Do not perform construction operations or permit heavy traffic during wet or rainy periods on roads with clay-rich, fine-grained soil surfaces that form ruts.
- For heavy traffic on soft subgrade soils, use a single thick structural section of at least 8-12" aggregate.
- "Spot-stabilize" local wet areas with 4-6" of coarse rocky material. Add more rock as needed.
- Compact the embankment material, road surface material, or aggregate during construction and maintenance to achieve a dense, smooth road surface that will reduce water soaking into the road.
- Trucking the road base or aggregate can present the most problems and costs. Road segments that can be "rocked" with large trucks that can make circular round trips (do not need to turn around) for short distances will be the most cost-effective, followed by road segments with "turn-arounds" situated where the trucks can dump going downhill.
- Delivery with belly dumps, dumping downhill can be very cost-effective.
- Road surfacing projects that start "at the bottom" and have the gravel spread before the next truck traverses the finished segment can be very stable. The trucks can, in this way, provide significant compaction as they travel over each successively laid section of base.

- Keeping the road base at optimum moisture content will be essential for good compaction. Some way of providing supplemental water (water truck) will probably be necessary.

- Proper mixing, watering, shaping, and compaction of the rock should be done to allow the surface rock to set up correctly.

- Rock accounting and measurement procedures must be followed to ensure the quality and quantities specified are delivered and installed. Several methods are appropriate; from measuring depth of rock laid to collecting "weigh tickets". Collecting weigh tickets or rock load receipts are useful if aggregate is purchased from commercial sources. The provider can also monitor and report moisture content.

20T of base rock dumped in a downhill direction with a "bellydump" is ready for spreading.

Limitations

- Aggregate can be relatively expensive with the biggest variable being the distance to a source of acceptable material.

- The ability to transport the surfacing material in a cost-effective manner can be a limitation.

Inspection and Maintenance

- Generally, roads should be inspected for erosion and stability problems prior to the rainy season. Inspections after or even during runoff-producing storms can ascertain drainage problems; however, these inspections should only be performed if there is *no* risk of damaging the driving surface.

- Grade or maintain the roadway surface before significant potholes, washboarding, or ruts form. Pot holes, washboards, and standing water on the road surface are all signs that the road segment needs maintenance.

- Maintenance of surfaced road segments should be done annually before the rainy season. For Mediterranean climates, the moisture conditions may be optimal for re-grading and compaction in the spring season.

- Maintain a 3-5% road cross-slope with insloping, outsloping, or a crown to rapidly move water off the road surface.

- For gravel roads, routine grading and shaping will suffice. Retain the appropriate outslope of the road. Avoid leaving a berm that channels water down the road.

- On base rock-surfaced roads the coarser gravels will separate with time and come to the surface, usually forming gravel ridges or outer berms. These roads will need additional maintenance work to re-incorporate the aggregate with the fines. The surface, probably every two years, should ripped with a toothed (1"-2'' teeth) grader, re-graded, spread, moistened, and then re-compacted.

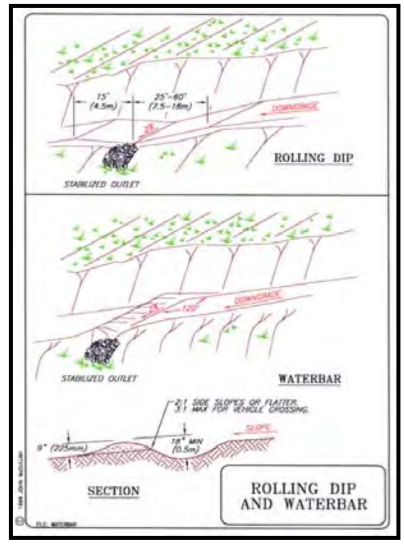
About every two years, base rock-surfaced roads should be ripped with a toothed grader and then re-graded, spread, moistened, and re-compacted.

Maintenance of surfaced roads should be done annually before the rainy season.

RT-5 Rolling Dip

SWPPP Summary

Rolling dips are gently sloping excavations running diagonally across the road surface. They limit the accumulation of erosive volumes of stormwater on roads by diverting surface runoff off the road at pre-designed intervals.



Definition / Purpose

Rolling dips (also called broad-based dips) are shallow, outward-sloping dips or undulations that collect surface runoff on roads and trails, and convey it across the road or trail surface.

RT-5 Rolling Dip is a road drainage BMP. The use of rolling dips will provide hydrologic disconnection (as per BMP-RC-1 Soil Standards). The rolling dip is a cost–effective way to control road and trail drainage while minimizing erosion and the alteration of the natural drainage patterns.

RT-6 Terrain Dips or "*critical dips*" are specially-located rolling dips constructed at drainage crossings. Terrain dips have a secondary function of reducing "diversion potentials" and, thence, large hillslope gullies.

Critical dips are built over, or adjacent to, culvert crossings. Critical dips are designed to reduce the likelihood of diversions down the road if the culvert clogs or fails.

Rolling dips and rolling grades for OHV trails have slightly different design criteria. Refer to the Soil Conservation Guidelines/Standards for OHV Recreation Maintenance (CARC, 2005, "Soil Standards") for more details on OHV trail layout, design, and construction criteria.

Planning Considerations

Because they are actually built by excavation, rolling dips are more appropriate for winter use than water bars, which can become damaged in wet weather. Water bars are also a hazard to riders. The main failure mechanism for dips is sediment deposition. Sufficient bottom gradient (5%) is required so they are "self-cleaning".

Frequent rolling dips and rolling grades are often preferable (both economically and hydrologically) to improperly spaced road drains such as culverts. For low-volume roads it is not economically feasible to install culverts as needed. As culvert spacing increases, road drainage, water quality and hydrologic connection problems also increase.

Rolling dips are recommended for wide range of uses:

- When the road gradient exceeds the outslope pitch (gradient), rolling dips are required. Concentrated runoff must be taken off the road surface before excessive volumes accumulate, and the rolling dip is the most cost-effective way to accomplish this.

- Rolling dips are effective on long inclines to keep storm water from flowing directly down the road, where it may cause rills, gullies, and other damage to the road/trail surface.
- Critical dips, rolling dips, and terrain dips are the primary methods to reduce diversion potentials and hillslope gullies.
- In soft soils, the mound, dip, and outlet shall be armored with gravel, rock, or aggregate.
- Avoid locating the outlet onto soft soils or unstable fill materials.

Shape:

Rolling dips can be relatively long (from 40 ft to over 100 ft) for a low-volume road. They are broad-based with a 2-6 foot wide bottom depending on the type of vehicle they are designed to pass. They are excavated into the road surface with a reversed grade and a slight mound at the downhill edge of the dip. The uphill grade out of the dip should be longer than the reversed grade entry length (generally 2-3 times) to allow smooth vehicular transition through the dip. The Soil Standards BMP-RC-3 (Rolling Dips) recommends a reverse grade of 15-20 feet minimum. Therefore, the uphill grade shall be approximately 30-60 feet long.

- Rolling dips shall be excavated deep enough to provide adequate drainage. The bottom of the dip should be deep enough to ensure the upstream flow cannot be "captured" by the road and form a diversion gully, and it must be deep enough to reduce erosion at the outlet end. Another way of looking at this is to reduce the amount of road fill placed in the channel.
- The bottom of the terrain dip should be as wide as possible and the bottom gradient should dip at least 5% so it does not fill with sediment.
- The bottom is angled at 90-120 degrees (0-25 degrees from perpendicular) and pitched outslope at 3-5%. Angled bottoms are preferred hydrologically but long-framed vehicles may have trouble negotiating highly angled dip. Adjust angle depending upon intended use and environmental sensitivity.

Armored Dips:


An armored dip.

Rolling dips should be surfaced whenever possible (RT-4 Road Surface). *Armored Dips* are rolling dips or terrain dips that have additional stabilization; a relatively thick section of compacted aggregate, cobbles, or gravel that can resist the tractive forces of flowing water. The bottoms of armored dips are usually over-excavated 6"-10" to accommodate the armor section. For example a 8-inch thick armored dip would be excavated an additional 8" below the final grade. Then there would be placed 4"-6" of well-compacted aggregate for a structural section followed by 2"-4" of surface rock, smoothed and compacted. Angular aggregate, combined with 5-15% fines (for binder) is often used for both the structural section and surface section because it will resist erosion and still provide a drivable surface (see RT-4 Road Surface).

Spacing of Dips:

<u>*Tread Watershed*</u>

Spacing of the rolling dips is a function of the road grade, soil types, and, most importantly, the amount of runoff collected and accumulating in the drainage area ("watershed") above the road. The concept of "*tread watershed*" should be considered and understood before making decisions about rolling dip spacing. If the tread watershed is too big, i.e., the runoff accumulating on the road will likely cause erosion, then the designer can then reduce the tread watershed by adding drainage dips. The dips and crests can be natural features, but if runoff erosion is occurring, there is probably too much water collecting and the tread watershed is too large.

<u>*Conventional*</u>

Table 9-3 below can provide general guidance for rolling dip spacing:

Recommended Rolling Dip Spacing (feet)	
Road Grade %	**Low to Non-Erosive soils** (1)
0-5	250 - 360
4-6	180 - 270
7-9	140 - 225
10-12	100 - 180
12+ *	** - 100

* Road lengths with gradients steeper than 12% shall be minimized.

** Traction may be a problem on steeper gradient roads; the road gradient coming out of the dip (uphill) is steeper.

Table 9-3. Recommended Rolling Dip Spacing (feet). [Adapted from N. Carolina Forestry BMP Manual, (2006), Keller and Sherar, (2003), Packer and Christensen (1964), and Copstead, et al., (1998)].

<u>*Terrain Dips*</u>

The spacing of terrain dips is dictated by the natural topography. It is imperative that terrain dips shall be placed where any discernable drainage course (headwater swale, intermittent stream, ephemeral stream, etc.) crosses the road. See RT-6 Terrain Dip.

Construction Specifications

- Stake the location for the inlet and outlet of the rolling dip bottom. Try to avoid outletting the dip onto unstable fill material.
- Determine the desired bottom elevation (invert) of the inlet section. This elevation may be determined by the bottom of an existing inboard ditch but usually it is 6”-18” below the road elevation at the inboard section. Pull a string line or survey a line to determine the average road elevation at the inboard edge of the road.
- Begin excavating the bottom of the dip at the inlet (inboard edge) to the design elevation; 6” to 18” below road elevation. Excavate the bottom so it has a broad bottom, 2 ft wide minimum.
- Angle the dip as designed, 90-120 degrees (0-25 degrees from perpendicular).
- Continue excavating the bottom of the dip toward the outer edge, giving the bottom the desired outslope gradient (pitch). This pitch should be 3-5% with enough slope to be self-cleaning. Dips with steeply outsloped bottoms will have less soil at the outlet, approaching “natural ground”, but the steeper pitch may cause erosion and make it difficult for vehicles to traverse; they may lose traction climbing out of the dip and/or drag a bumper if the dip is too deep.
- The length of reversed grade segment (entry) should be about 15-20 feet (Soil Standards BMP-RC-3). The uphill grade out of the dip should be longer than the reversed grade entry length, generally 2-3 times, to allow smooth vehicular transition through the dip. Construct and compact a slight mound (hump) across the downhill edge of the dip. The crest of the mound will also outslope and may become non-existent about mid-road.
- The excavated material can be “spoiled” and compacted against the down gradient cutslope, thereby outsloping the down-gradient road and reducing diversion potential.
- For an armored dip, over-excavate the bottom as per design (generally 6”-10” for structurally sound soils) and bring back to grade with compacted aggregate. Aggregate, mixed with 5-15% fines for binder and compacted makes an adequate armored dip.
- Place and compact road surface material (see RT-4 Road Surface).

Inspection and Maintenance

It is imperative that these drainage features are operational during the rainy season. Inspect the road and drainage features:

- In the fall prior to the rainy season.
- After rainfall events resulting in runoff.
- During periods of prolonged rainfall. **

** The roads must be sufficiently dry and safe before inspection and maintenance can be performed.

- Inspect the roads (including the rolling dips) annually. Inspection during the rainy season or early spring will help to ascertain problems with the road drainage. Rill formation on the road surface is an indicator that the road segment needs maintenance. Failure of the rolling dip or significant erosion at the outlet may indicate that the spacing is too large or the tread watershed is too big.
- Maintenance of outsloped road segments and rolling dips should be performed before the rainy season.
- Maintaining outsloped road segments is best achieved by starting downhill, grading in an uphill direction so the berm material can be "pulled inboard". Maintenance usually requires two such passes minimum.
- Rolling dips are to be approached with caution as the grader blade must be reversed in direction so the dip is not destroyed.
- For gravel roads, routine grading and shaping will suffice. Retain the appropriate outslope of the road. Avoid leaving a berm that channels water down the road.
- On base rock-surfaced roads, the coarser gravels will separate with time and come to the surface, usually forming gravel ridges or outer berms. These roads should ripped with a toothed (1-2'' teeth) grader, re-graded, and then re-compacted. This maintenance may be required every two or three years depending upon traffic use.
- To reduce maintenance, avoid using roads during wet periods if such use will damage the road or negate the effects of the erosion control features.

This outsloped recreational trail was designed with rolling dips and terrain dips. (Gold Run Creek Trail, Redding, CA)

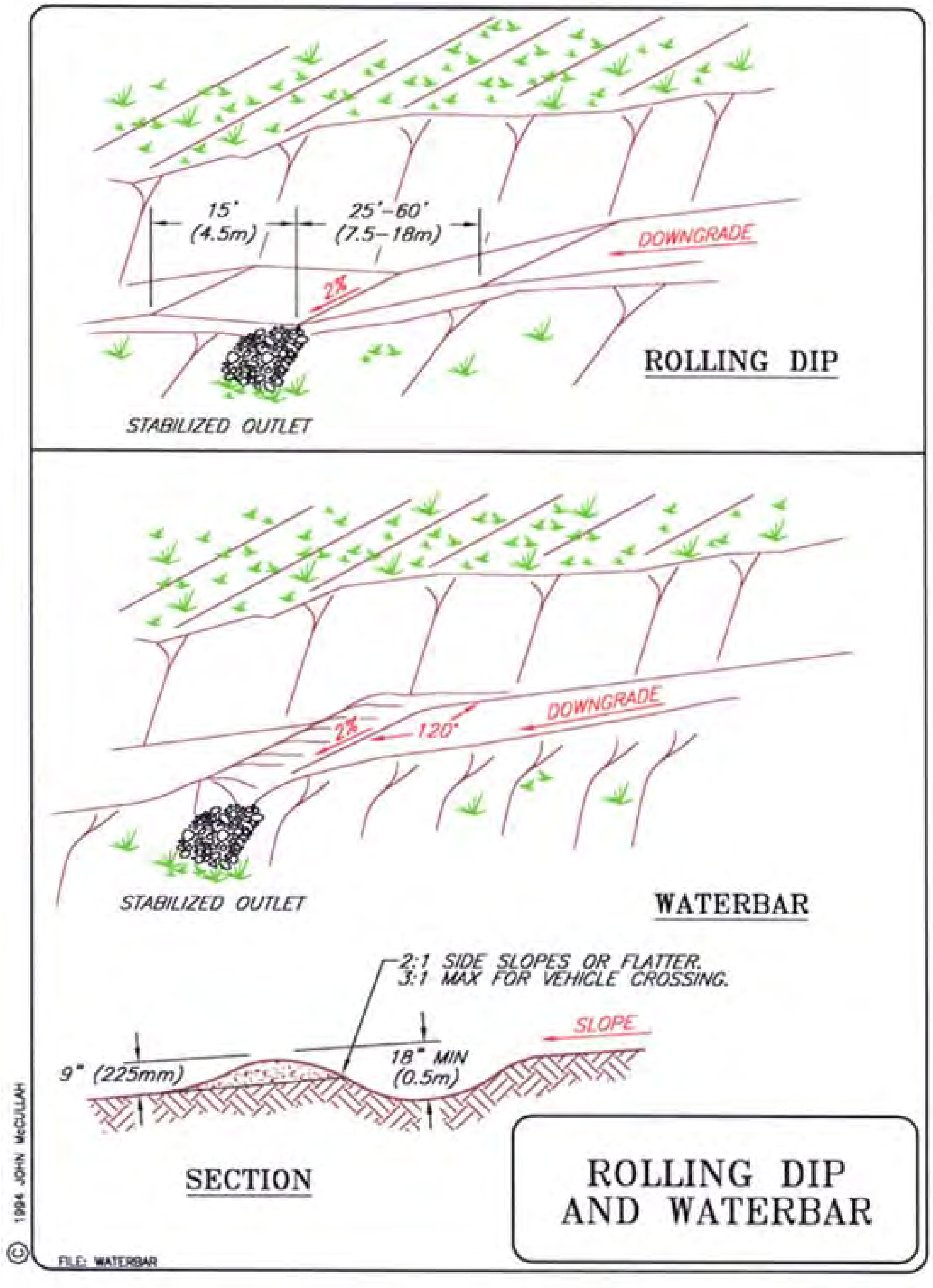


Figure 9-9. Rolling Dip and Waterbar.

RT-6 Terrain Dip

SWPPP Summary

A terrain dip is a specially designed rolling dip that is placed at the intersection of a road (or trail) and a natural drainage course or swale in order to allow runoff from the upslope swale to exit the road in its pre-disturbance location.

Definition / Purpose

The RT-6 Terrain Dip is a specialized rolling dip which is designed and configured to allow the natural upslope drainage way, swale, or headwater swale to flow unimpeded across the road/trail and exit the road at its pre-disturbance location.

Terrain dips are one of the most important techniques used to reduce modifying and negatively impacting the natural hillslope processes when building or maintaining cross slope roads or trails.

Planning Considerations

Terrain dips are employed on cross slope roads and trails. The quantities of terrain dips required are dictated by the slope and watershed morphology. Sub-watersheds with dendritic drainage patterns, for example, will require many terrain dips as the road/trail crosses the many drainage features.

SS-6 Terrain Dip allows a natural drainage feature, e. g., swale, headwater swale, etc., to flow unimpeded across the road and exit at its pre-disturbance location.

Rule of Thumb…

Watch the cutslope height and when it decreases or disappears, that is the place to install an RT-6 Terrain Dip.

The cross-section, shape, and armoring requirements of the terrain dips will be influenced by the upslope drainage area and drainage characteristics.

- On existing trails and roads across hillslopes, watch the cutslope. Generally a relatively high cutslope indicates the road is bisecting a ridge feature. Conversely, the cutslope narrows or disappears when the road/trail crosses a swale.
- RT-6 Terrain Dips shall be located at locations where the cutslope disappears.
- Is the drainage area small (< 2 ac), medium (2-5 ac), or large (5-10 ac)? A small drainage area on steep ground is often referred to as a "headwater swale". A medium drainage area is generally indicated by a swale, while a large drainage area would probably have a well-defined channel bottom which may be naturally-armored with rock.
- Is the drainage ephemeral or intermittent? These crossings will require armoring.
- Looking upstream, is there evidence that the drainage has flowed in the recent past? Headwater swales may be grass-lined and relatively undisturbed, or they can be slightly scoured with runoff-deposited leaves, sediment, or detritus evident. Generally, large swales or intermittent drainages will show evidence of recent runoff,

the channel bottoms will be incised, scoured, and devoid of much surface vegetation (grasses).

- The orientation (angle crossing the road) and cross-sectional area of the terrain dip should mimic the upslope drainage. The bottom width must be at least as wide as the upslope swale and the ingress and egress of the drainage crossing should match the existing terrain.
- The bottom of the terrain dips should be deep enough to ensure the upstream flow cannot be "captured" by the road and form a diversion gully, and it must be deep enough to reduce erosion at the outlet end. Another way of looking at this is to reduce the amount of road fill placed in the channel.
- The bottom of the terrain dip should be as wide as possible and the bottom gradient should dip at least 5% so it does not fill with sediment.
- For terrain dips draining medium or large sub-watersheds the bottom of the dip may need to be armored. This is often accomplished by "over-excavating" the bottom section and bringing it back up to grade with sufficiently sized, graded, and compacted rock (see RT-5 Rolling Dip, *Armored Dips*).
- After the drainage concerns are considered then the terrain dip must also be configured to pass the "design vehicle" (see RT-5 Rolling Dip).

The bottom of a terrain dip should be as wide as possible, and the bottom gradient should dip at least 5% so it does not fill with sediment. Terrain dips may need to be armored.

Construction Specifications

- Start excavation of dip at the inboard edge of the road, at the existing swale, trying to match the elevation and gradient with the existing watercourse. Sometimes the road/trail crosses near the confluence of two or more swales or weeps, or springs. At that time it may be necessary start the excavation of the dip at the downstream swale in order for one terrain dip to "pick up" all the drainages.
- Never start the dip excavation up-road-gradient from the natural swale.
- The dip must be deep enough so that the road or trail will never divert runoff down the road (reduced diversion potential).
- The excavated material can be "spoiled" and compacted against the down gradient cutslope, thereby outsloping the down-gradient road and reducing diversion potential.

Limitations

A culvert or alternative stream crossing may be required if:

- The sub-watershed drainage area is large.
- The depth and orientation required for the terrain dip does not allow vehicular passage.

Terrain dips are spaced according to the natural topography, and located where the trail or road cutslope decreases (or disappears). This terrain dip is also armored with rock found on-site.

Inspection and Maintenance

It is imperative that these drainage features are operational during the rainy season. Inspect the road and drainage features:

- In the fall prior to the rainy season.
- After rainfall events resulting in runoff.
- During periods of prolonged rainfall. **

** The roads must be sufficiently dry and safe before inspection and maintenance can be performed.

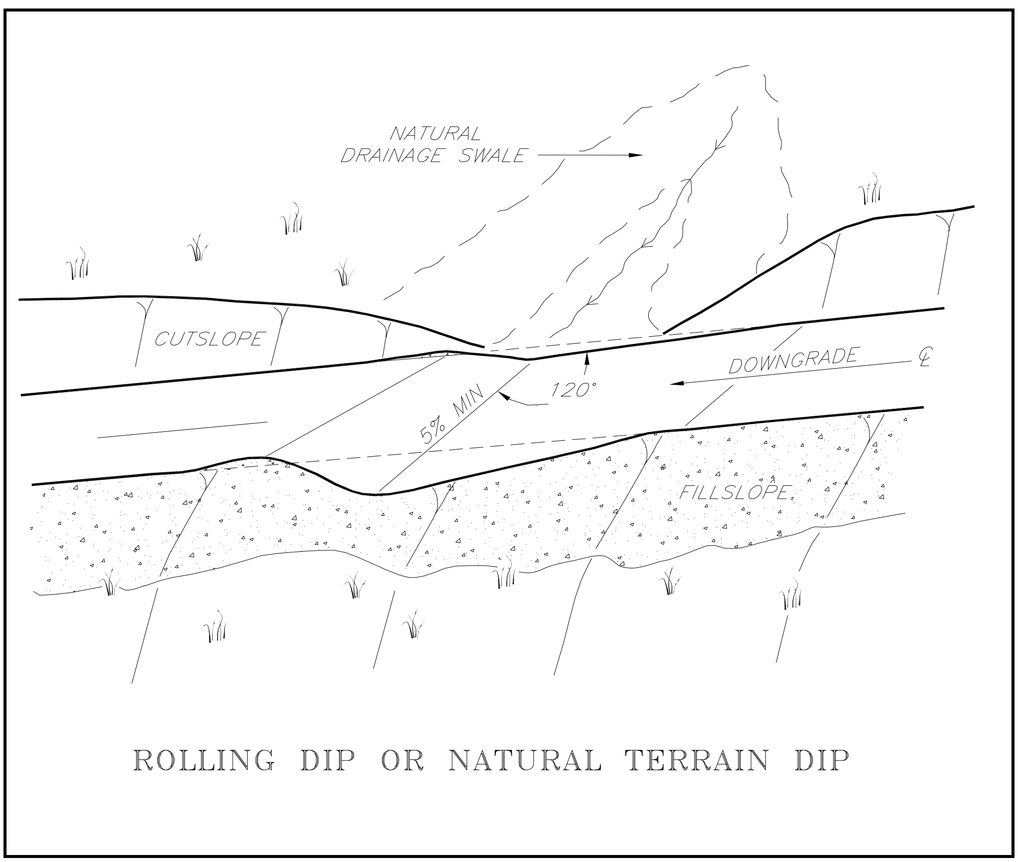
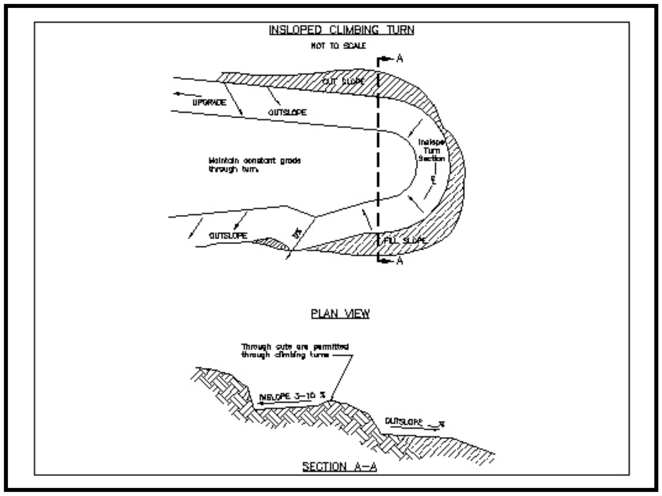


Figure 9-10. Rolling Dip or Natural Terrain Dip.

RT-7 Climbing Turn

SWPPP Summary

The climbing turn (switchback) is a road and trail design used to climb steep slopes in confined areas or make outboard turns (around a ridge node) with minimal erosion. From uphill to downhill the road drainage goes from outsloped to steeply insloped ("super elevation") and then to outsloped again. A strategically placed rolling dip is used to cross drain (relieve) the inboard ditch.



Definition / Purpose

RT-7 Climbing Turn and the "switchback" turn are similar. A climbing turn is an effective design for outboard turns on low-volume roads, recreation trails, ATV, or motorcycle trails. A climbing turn usually refers to designs with a larger turning radius associated with ATV trails and low-volume roads; a "switchback" is similar, but the term is used for sharp turns of about 180 degrees used on trails designed for motorcycle use. Both are used to develop a viable road or trail route through steep areas of difficult construction and/or to gain elevation in confined areas. If properly constructed, the switchback can provide an interesting riding experience (CARC, 2005).

For low-volume roads, RT-7 Climbing Turn is primarily a road drainage BMP, providing guidance on how to effectively drain road segments that go around ridge nodes or switchbacks. These outboard turns are sometimes relatively steep and can accumulate erosive concentrations.

Planning Considerations

ATV or Motorcycle:

The location and design of climbing turns should be developed by someone with knowledge of both trail building and OHV recreation. Refer to the Soil Conservation Guidelines/Standards for OHV Recreation Maintenance (CARC, 2005) for more details on OHV trail layout, design and construction criteria.

- Locate the climbing turn on a bench (8'-10' wide) or terrain with the least slope. Lay out the curves with a smooth, even radius; staking trail centerline at 4' intervals. Use the lowest grade feasible for 5'-10' before the turn begins to 10' beyond the turn.
- Locations where the trail turns left when going downhill are preferred as the rider can place the left foot on the ground for balance while keeping the right foot on the brake pedal.

- For ATV climbing turns, the turn should have an 8'-10' radius, with the tread width 60 inches at the apex of the turn, and widening to 72 inches. Refer to the CARC (2005) "Soil Standards" for more information.
- Avoid the use of tread armor. The super elevation on the turn will reduce displacement of the native materials. Mechanical compaction may be required to harden the trail during construction.
- Design a barrier of native materials to prevent trail cross-cutting.

This section of a rehabilitated low-volume road is insloped. At the climbing turn in the background, the road transitions to outslope.

On this same road, just before the transition from inslope to outslope, a rolling dip is constructed to take runoff from the inslope section off the road.

Low-volume Roads:

The climbing turn-type road design refers to the road drainage as it transitions (traveling downhill around the outboard turn) from outsloped section to insloped section and then back to outsloped section again. The best road design is one that will minimize the length of the insloped section. Insloping will concentrate water, and insloped roads require drainage systems. Therefore, transitioning the insloped climbing turn section back to outslope before erosive amounts of runoff can accumulate will be the most cost-effective and environmentally-sensitive design.

- Locate climbing turns at switchbacks or outboard turns around ridge nodes; on a bench or on terrain with the least slope.
- The pitch of the insloped section should be relatively steep (5-10%) so the turn is well drained.
- Keep the insloped section as short as possible. The section ends at the downslope end with a rolling dip; sometimes the optimal location and critical placement of this dip sets the required length of inslope segment.
- The downslope dip may need armoring to accommodate the accumulated runoff in a non-erosive manner.

- A stabilized outlet and/or overside slope drainage protection may also be necessary.

Construction Specifications

- It is important to outslope the road (2-6%) heading into the turn from the uphill direction in order to minimize or remove any concentrated flows before the turning segment. A rolling dip may be necessary, but caution is advised as any concentrated runoff released here will emerge again, below the switchback, onto the lower road segment.
- At the turn the road becomes "naturally insloped" with an inboard ditch. For motorcycle tracks this inboard slope can be built quite steep because the "superelevation" will help the rider power through the turn (climbing turn). The inboard pitch will help to overcome the mechanical erosion from the torque applied by wheels.
- Now the designer and road builder must "take the concentrated water off the road" as soon as possible. The concentrated runoff generated at the inboard turn can be minimized by keeping the inboard ditch length as minimal as possible.
- The road drainage is transitioned from inslope to outslope by the use of a rolling dip. The dip may need to be located where it can collect any concentrated road runoff that has traveled overland from the road segment above the switchback.
- The bottom of the dip shall be angled down from perpendicular at 5 to 45 degrees (depending upon the type of road/trail). The bottom of the dip must be outsloped (pitched) at least 5% to allow the dip to "self clean". The dip may fail if sediment accumulates in it.

Refer to the Soil Conservation Guidelines/Standards for OHV Recreation Maintenance (CARC) for more details on OHV trail layout, design, and construction criteria.

Inspection and Maintenance

It is imperative that these drainage features are operational during the rainy season. Inspect the road and drainage features:

- In the fall prior to the rainy season.
- After rainfall events resulting in runoff.
- During periods of prolonged rainfall. **

** The roads must be sufficiently dry and safe before inspection and maintenance can be performed.

- Grade or maintain the roadway surface before significant potholes, washboarding, or ruts form. Potholes, washboards, and standing water on the road surface are all signs that the road segment needs maintenance.
- Maintenance of surfaced road segments should be done annually before the rainy season. For Mediterranean climates, the moisture conditions may be optimal for re-grading and compaction in the springtime.
- Maintain a 3-5% road cross-slope with insloping, outsloping, or a crown to rapidly move water off the road surface
- For gravel roads, routine grading and shaping will suffice. Retain the appropriate outslope of the road. Avoid leaving a berm that channels water down the road.
- On base rock-surfaced roads, the coarser gravels will separate with time and come to the surface, usually forming gravel ridges or outer berms. These roads will need additional maintenance work to re-incorporate the aggregate with the fines, The surface, probably every two years, should ripped with a toothed (1"-2'' teeth) grader, re-graded, spread, moistened, and then re-compacted.

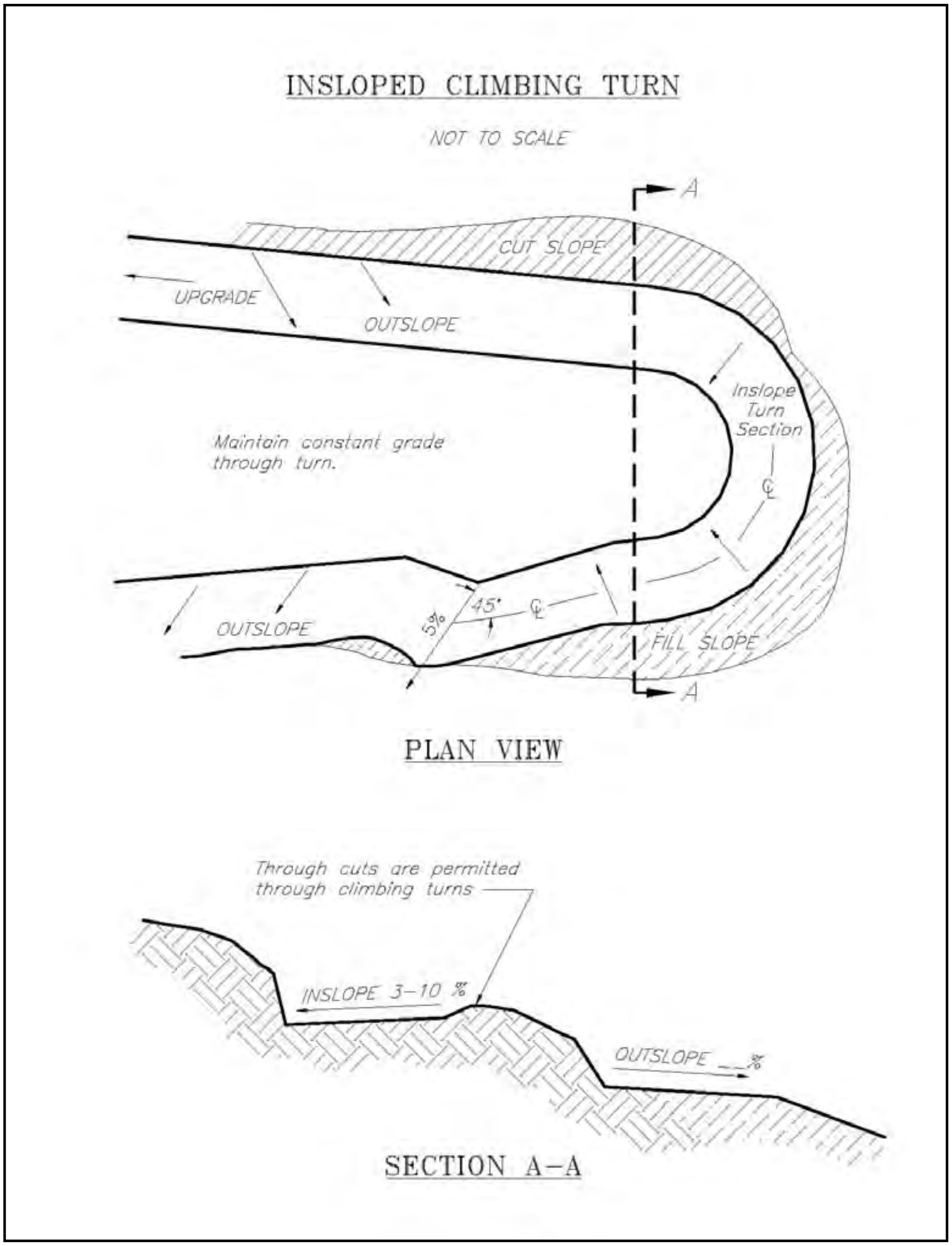


Figure 9-11. Insloped Climbing Turn.

RT-8 Culvert Crossing

SWPPP Summary

Culverts shall be installed and maintained in order to convey water where a stream or drainage intersects a road or trail, if a culvert is the only drainage option. The use of culverts shall preserve road base by draining water from ditches along roads. Culverts shall be properly designed and installed in order to prevent erosion problems. Culvert inlets and outlets shall also be properly designed to stabilize soil, prevent scour, and improve flow efficiency.

Definition / Purpose

A culvert is a closed conduit used to convey water from one area to another, usually from one side of a road to the other side. Culverts are used both as cross-drains for ditch relief and to pass water under a road or trail at natural drainage and stream crossings.

Planning Considerations

Natural drainages need to have pipes large enough to pass the expected flow plus extra capacity to pass debris without plugging. Fish and wildlife passage may also be a design consideration. Discharge will depend upon the watershed drainage area, runoff characteristics, design rainfall intensity, and return period (frequency) of the design storm. Culvert design typically uses a minimum storm even of 20 years, and may design for as much as a 100-year event, depending upon local regulations and the sensitivity of the site (such as with endangered species).

There are advantages and disadvantages with various pipe types. Steel culverts are strong and have an estimated service life of 30 years, but are subject to corrosion. Aluminum culverts are very light weight, and resist corrosion, but can be easily damaged.

This culvert was determined to be inadequate at passing stormwater runoff and associated debris. As part of good best management practices, culverts should be regularly inspected and kept clear and free of debris so that water can pass unimpeded at all times.

Replacement of culverts may be necessary. Head wall "wings" (extensions) help mold and direct channel flow and protect the area around the inlet and outlet from scour. Head walls may be riprap, gabions, logs, bagged concrete, concrete blocks, or poured concrete.

Construction Specifications

Culverts need to be properly sized and installed, and protected from erosion and scour.

One advantage of concrete culverts is an estimated life of 75 years.

- Install pipe culverts long enough so road fill does not extend beyond the ends of a culvert. Ensure a slope of 5% or greater to allow for positive drainage flow.
- Install permanent culverts that are large enough to pass flood flows and are a minimum of 12 inches in diameter. Culverts that are too small can plug up with debris and result in the road washing out or in flooding upstream.
- Culverts shall be installed so there is no change in the stream bottom elevation. Culverts shall not cause damming or pooling.
- Culverts shall be installed with 10% of its diameter below the streambed. This will minimize undercutting at the inlet or outlet. If the outlet is more than 6 inches above the natural stream channel, an energy absorbing structure shall be placed at the outlet.
- Culverts shall be installed during periods of low water flow. In live (flowing) streams, appropriate measures shall be taken to inhibit flow when possible (sandbags, etc.) and a pump shall be used to convey water around the excavation/work site. Pumped water shall be discharged onto a stable outlet to prevent scour.
- With live stream flows which cannot be impounded, flow shall be diverted to one side of the culvert alignment. Enough room shall be allowed to properly excavate the entire pipe trench and bed for the entire culvert. Disturbance to the surrounding soil and vegetation shall be minimized.
- One method of properly installing a culvert is to start at the outlet end, lay the culvert up-slope, properly bedding each joint as installation proceeds. The first section or "joint" is critical, and special attention shall be given to proper installation, grade, and alignment to reduce the potential for scour and erosion from water discharge, and, to ensure the whole culvert is aligned properly.
- Firmly compact fill material around culverts, particularly around the bottom half. Cover the top of culverts with fill to a depth of one-third of the pipe diameter or at least 12 inches, whichever is greater, to prevent crushing (Montana Department of State Lands, 1992.)
- Use riprap around the inlet of culverts to prevent water from eroding and undercutting the culvert. For permanent installations, use filter fabric under the riprap.

- Headwall structures should be flush with the end of the culvert.
- Seed and mulch all disturbed areas.
- A professional engineer, experienced in hydraulics and culvert dynamics, shall be consulted determination of actual culvert grades when dealing with peculiar alignment of laying conditions, and upon deviation from normal and usual installation procedures.

Use fords for crossing dry streambeds or where fording would cause minimal water quality impacts (see RT-10 Low Water Crossings).

Limitations

Professional engineers may need to be consulted in some instances. Permits may be required prior to the commencement of work.

Inspection and Maintenance

Despite the best efforts to keep culverts free and clear, they may become clogged with eroded soil, sticks, and leaves. The best way to keep culverts working properly is to inspect them on a regular basis, at a minimum of every spring and fall, and after heavy storms. During a rainstorm is a good time to check all of the road drainage systems. This way, small problems can be noted before they become big problems.

- Each spring and fall, and after heavy storms, inspect culverts for damage and debris.
- Remove obvious blockage (trash, brush, and other debris).
- Use high pressure flushing to effectively clear most plugged culverts.
- Be sure to clean outlet ditch after flushing.
- Repair damaged riprap headwalls and energy dissipators.
- Mark all drainage culverts to insure they are not missed during inspections.
- Trim brush around culvert ends and revegetate if necessary to control erosion.

Reasons to Replace a Culvert
1. End crushing due to errant vehicles.
2. Corrosion from acid soils.
3. Erosion due to high flow velocities carrying sand and gravel.
4. Pipe capacity insufficient for runoff needs.
5. Poor headwall or slope treatment resulting in embankment loss.
6. Poor culvert bedding resulting in settlement, or structural failure.
7. Danger of catastrophic failure due to old age.

Table 9-4. Culvert Replacement Criteria.

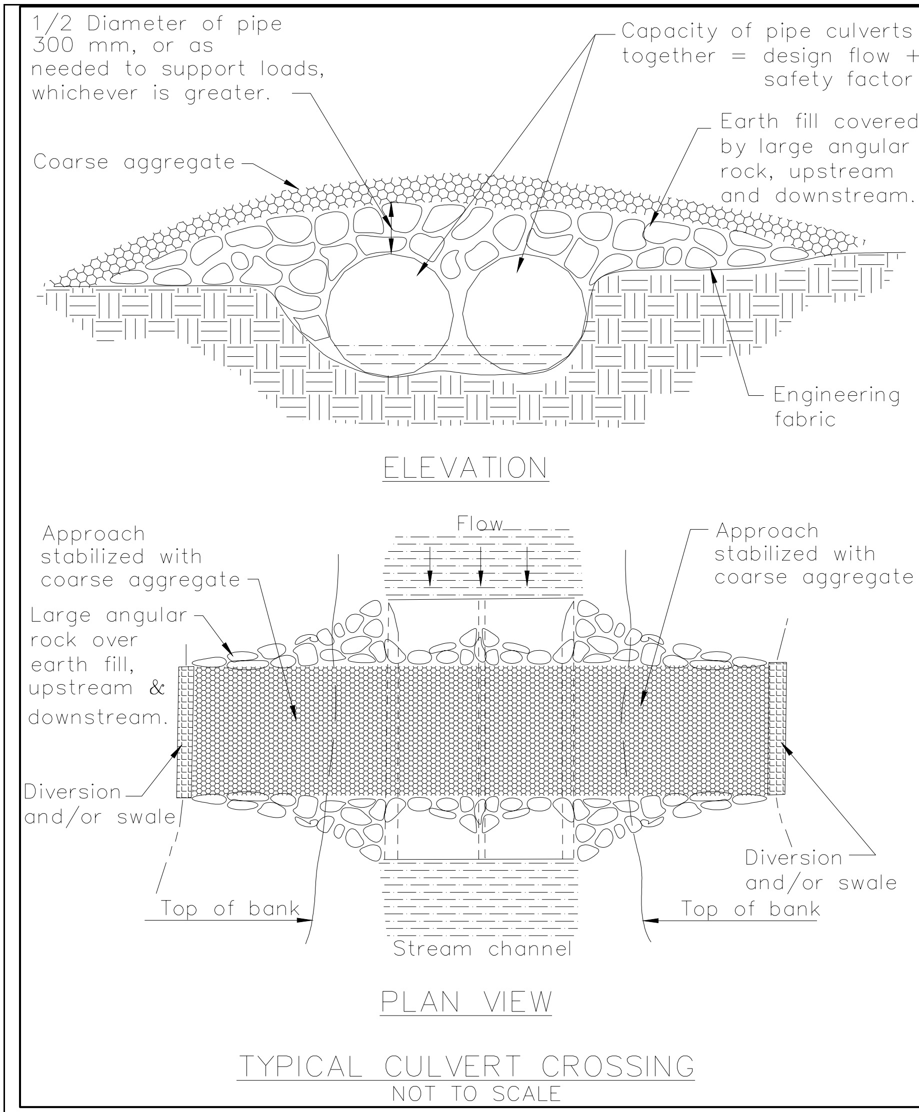
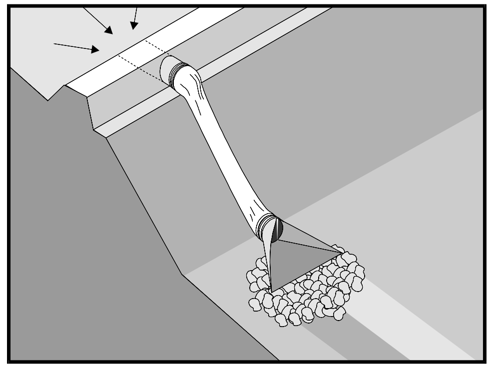


Figure 9-12. Typical Culvert Crossing (from Caltrans, 2003).

RT-9 Slope Drain or Overside Drain

SWPPP Summary



A slope drain is flexible tubing or a pipe, overside drain, or other conduit extending from the top to the bottom of a cut slope, fill slope, or other steep slope needing protection from runoff that cannot be diverted elsewhere. Slope drains shall be installed to convey concentrated runoff down the face of the slope without causing erosion.

Definition / Purpose

Constructed slopes (such as new roads) are often exposed to erosion between the time they are graded and permanently stabilized. During this period, the slope is very vulnerable to erosion, and RT-9 Slope Drain or Overside Drain, used together with RC-5 Diversion Dikes and Diversion Swales, can provide valuable protection.

Planning Considerations

This practice applies to areas where stormwater runoff above a newly constructed cut or fill slope will cause erosion if allowed to flow over the slope. Slope drains or overside drains may also be recommended when rehabilitating roads on steep erosive soils, or when other options of dealing with concentrated flows are not possible.

It is very important that slope drain structures be sized, installed, and maintained properly, because their failure will usually result in severe erosion of the slope. The entrance section to the drain should be well-entrenched and stable so that surface water can enter freely. The drain should extend downslope beyond the toe of the slope to a stable area or appropriately stabilized outlet (see RC-1 Energy Dissipator).

Overside drains convey runoff safely down slopes. This new "Scour Stop" material withstands high velocities and can also be vegetated.

Construction Specifications

Design Criteria:

- Capacity: Peak runoff from the 10-year storm.
- Pipe size: Unless they are individually designed, size drains according Table 9-5.

Maximum Drainage Area per pipe	Pipe Diameter inches
0.50 ac.	12
0.75 ac.	15
1.00 ac.	18
>1.00 ac*	as designed

*Inlet design becomes more complex beyond this size.

Table 9-5. Pipe Sizing for Slope Drains.

- Conduit: Construct the slope drain from heavy-duty, flexible materials such as non-perforated, corrugated plastic pipe, or open top overside drains with tapered inlets, or CMP. Install reinforced, hold-down grommets or stakes to anchor the conduit at intervals not to exceed 10 feet with the outlet end securely fastened in place. CMP or corrugated plastic pipe must have one (1) anchor assembly for every 20 feet of slope drain. The conduit must extend beyond the toe of the slope.
- Entrance: Construct the entrance to the slope drain of a standard flared-inlet section of pipe with a minimum 6 inch metal toe plate. Make all fittings watertight. A standard T-section fitting may also be used at the inlet. An open top flared inlet for overside drain may also be used.
- Diversion: Generally, use an earthen diversion with a dike ridge or berm to direct surface runoff into the slope drain. Make the height of the ridge over the drain conduit a minimum of 1.5 feet and at least 6 inches higher than the adjoining ridge on either side. The lowest point of the diversion ridge should be a minimum of 1 foot above the top of the drain so that design flow can freely enter the pipe (also see RC-5 Diversion Dikes and Diversion Swales).
- Outlet Protection: Protect the outlet of the slope drain from erosion with an energy dissipater (see RC-1 Energy Dissipator).

A common failure of slope drains is caused by water saturating the soil and seeping along the pipe. Proper backfilling around and under the pipe haunches (with stable soil material and hand compacting in 6 inch lifts) to achieve firm contact between the pipe and the soil at all points will reduce this type of failure.

- Place slope drains on undisturbed soil or well-compacted fill at locations and elevations shown on the plans.

- Slightly slope the section of pipe under the dike toward its outlet.
- Compact the soil under and around the entrance section in lifts not to exceed 6 inches.
- Ensure that fill over the drain at the top of the slope has a minimum depth of 1.5 feet and a minimum top width of 4 feet. The sides should have a 3:1 slope.
- Ensure that all slope drain connections are watertight.
- Ensure that all fill material is well-compacted. Securely fasten the exposed section of the drain with grommets or stakes spaced no more than 10 feet apart.
- Extend the drain beyond the toe of the slope and adequately protect the outlet from erosion.
- Make the settled, compacted dike ridge no less than 1 foot (300 m) higher than the top of the pipe inlet.
- Immediately stabilize all disturbed areas following earthwork.

Limitations

Points of concern include failure due to overtopping from inadequate pipe inlet capacity and lack of maintenance of diversion channel capacity and ridge height.

Inspection and Maintenance

Inspect the slope drain and supporting diversions after every significant rainfall and promptly make necessary repairs. If the protected area has been permanently stabilized, slope drain measures may be removed, materials disposed of properly, and all disturbed areas stabilized appropriately.

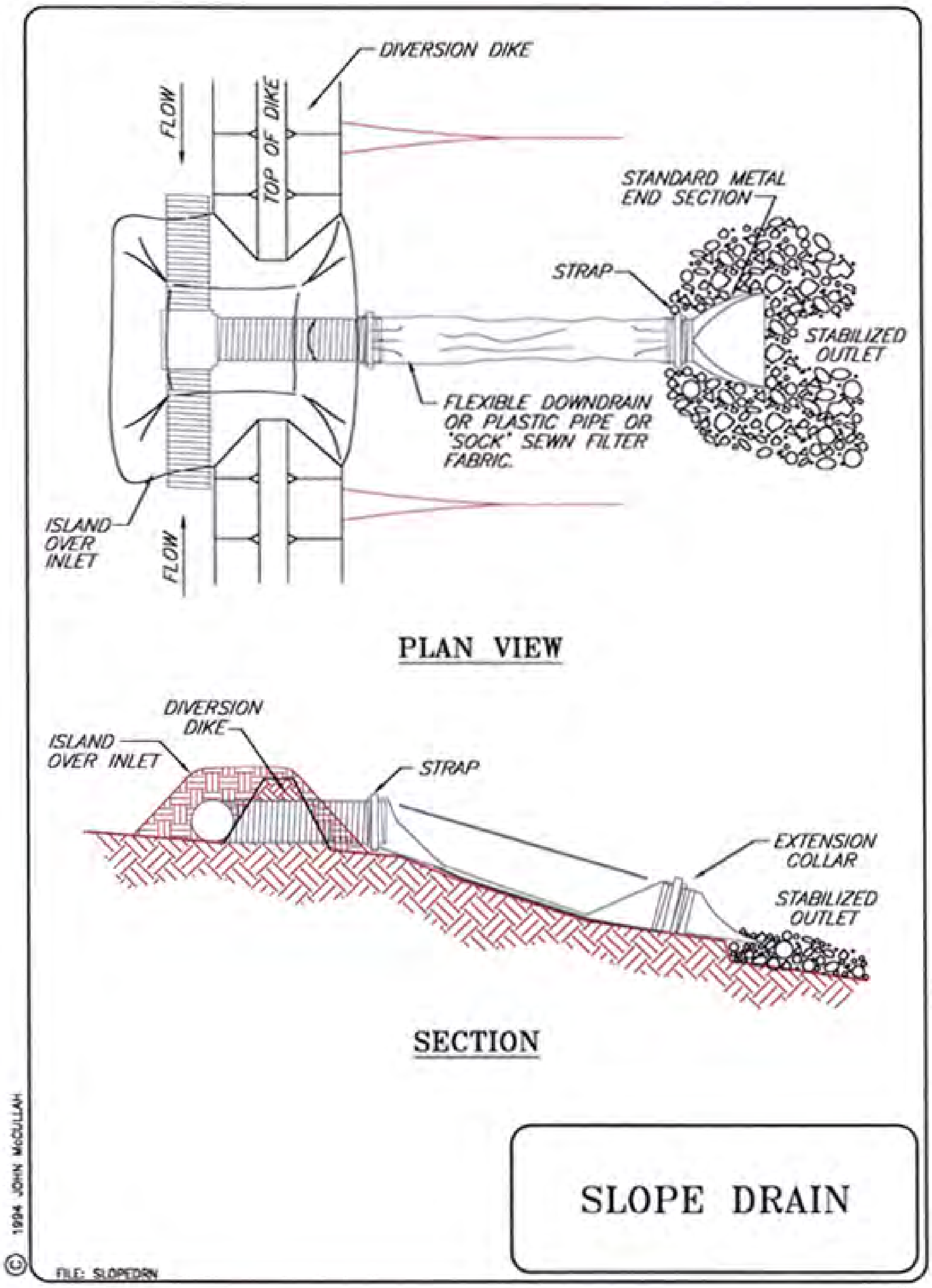


Figure 9-13. Slope Drain.

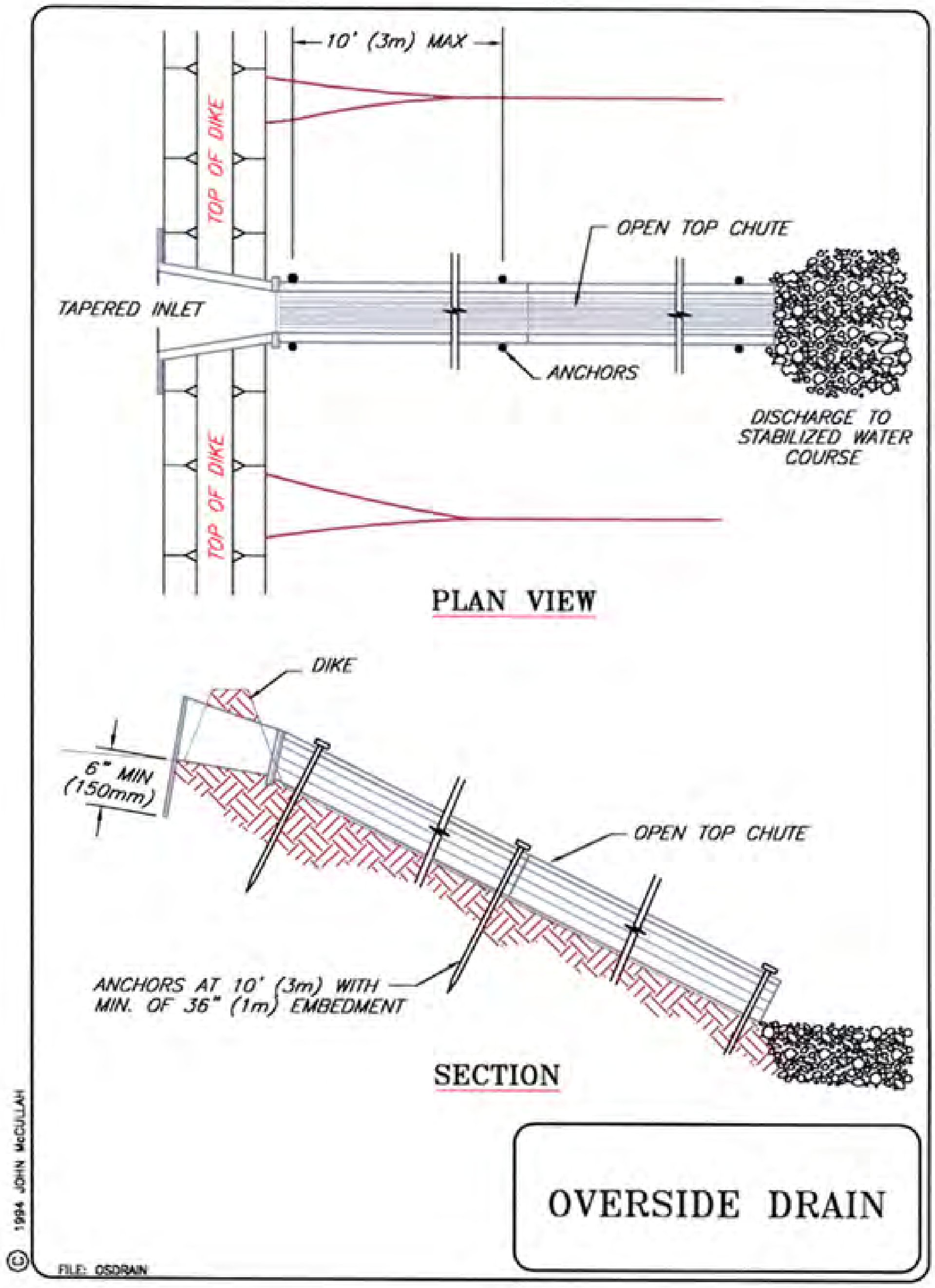


Figure 9-14. Overside Drain.

RT-10 Low Water Crossings

SWPPP Summary

Low-water crossings are BMPs used allow to vehicular access across streams and drainage ways while protecting the channel. A well designed low water crossing will protect the channel bottom and banks from erosion and sedimentation.

This low water crossing, designed for recreation and heavy equipment, is constructed from Articulated Concrete Blocks (ACBs). (J. McCullah photo, 2007)

Definition / Purpose

RT-10 Low Water Crossings are intended to reduce bank erosion, displacement of soil, destruction of channel bottoms, and the discharge of sediments to channels by vehicles crossing streams.

Stream crossings that are poorly located and/or have unprotected stream bottoms may erode streambanks and cause channel erosion. Stream crossings must be designed, constructed, and maintained to safely handle expected vehicle loads and to minimize disturbance of streambanks, channels, and aquatic organisms.

Planning Considerations

RT-10 Low Water Crossings can be a temporary BMP or a permanent feature. An important consideration will be the intended use, duration of need, and the "design vehicle". Is the crossing intended for temporary construction access, seasonal access, or permanent all-weather crossings? The designer must consider what kind of vehicle will use the crossing – OHVs, recreation vehicles, or emergency vehicles?

Low water crossings are often preferable to culvert crossings as they allow a more natural flow, reduce impacts to stream function, and they do not plug. However, operating equipment or allowing vehicular access in perennial or intermittent stream channels may add sediment directly to streams and/or disturb the existing substrate, leading to increased turbidity.

The designer must consider:

- Streambed (substrate) material.
- Stream size, width, planform, and gradient.
- Storm frequency, intensity, duration and discharge.
- Intensity of use (permanent or temporary).
- The passage of fish or other habitat and biotic concerns.

Sometimes permanent crossings can also act as grade control structures, preventing an incising stream system from headcutting.

Low water crossings shall be constructed during dry months when the stream is dry or water level is as low as possible.

As roads approach a stream crossing, proper drainage is critical to avoid sedimentation in streams.

A ford is simply an excavated low crossing in the streambed. Use fords for crossing dry streambeds or where fording would cause minimal water quality impacts.

Low-water crossings are the most common and cost-effective practice for low-volume roads or trails which cross seasonal or intermittent streams. They can be designed to have minimum impact on water quality, and are certainly a great improvement over simply driving through the streambed (with no protective measures).

This ford or "armored dip" has a well-compacted structural sub-base (large cobbles) and then armored with stone. (J. McCullah photo, 2007)

Low-water crossings can be constructed by:

- Locating fords and low-water crossings where streambanks are low.
- Simply excavating a ford in an appropriate area that has a stable, shallow banks and a stable bottom.
- The streambed should have a firm rock or gravel base. If needed, install stabilizing material such as cobbles, articulated concrete blocks (ACBs), crushed aggregate, a cellular confinement system filled with clean aggregate or concrete, or construct a concrete apron.
- If installing a rock-armored or ACB crossing, over-excavate the streambed to accommodate the layering of clean, durable rock under the ACB. Placing a geotextile fabric first will add stability and prevent "pumping" and displacement of fine materials.

Construction Specifications

Before installing or constructing a low-water crossing structure across any intermittent or perennial stream, contact the appropriate agencies to acquire necessary permits.

- Install stream crossings using materials that are clean, non-erodible and non-toxic to aquatic life.
- Install stream crossing structures at right angles to the stream channel to minimize length of structure.
- Minimize channel changes and the amount of excavation or fill needed at the crossing. Limit construction activity in the water to periods of low or normal flow. Keep use of equipment in the stream to a minimum.

- Divert road drainage into undisturbed vegetation, so that the drainage does not directly enter the stream (see RC-5 Diversion Dikes and Diversion Swales).
- Stabilize approaches to bridge, culvert, and ford crossings with gravel or other suitable material to reduce sediment entering the stream.
- Use Soil Stabilization (SS) practices at stream crossings.
- Use seed and mulch and install temporary sediment control structures (such as fiber rolls) immediately following construction in order to minimize erosion into streams. Maintain these practices until the soil is permanently stabilized. Refer to the Soil Stabilization (SS) section of this manual.

Limitations

Explore all other alternatives before deciding to cross a stream. Stream size, bank height, substrate or velocity may limit the use low-water crossings.

Inspection and Maintenance

RT-10 Low Water Crossings shall be inspected routinely and repaired as needed. Temporary crossings should be removed when no longer needed.

Armored crossings can withstand high velocities without eroding. (J. McCullah photo, 2007)

This emergency (rocked) crossing was constructed by "over-cutting" the banks 6-9 inches and laying well-compacted "gabion rock" (4-6 inch) as a structural base. The structure in the creek is a cross vane weir designed for fish passage. (J. McCullah photo, 2007)

Roads entering channels should be adequately stabilized. The photo above shows no protection.

The temporary crossing shown above has geotextile underlying clean, angular aggregate.

Geotextile is placed over compacted sub-base to provide stability and prevent "pumping" of fines.

Some ACB systems are pre-cabled for installation with a spreader bar and a large excavator.

The leading edge of the cabled mat is placed in a “cut-off trench”.

Same crossing after several winter storms and daily traffic.

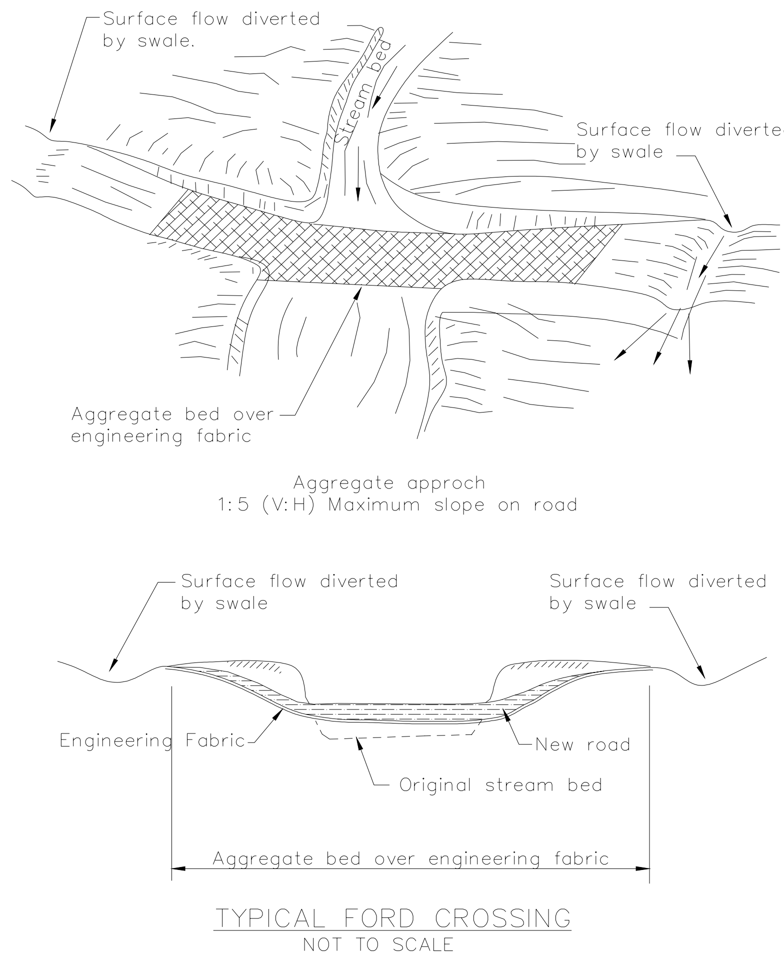


Figure 9-15. Typical Ford Crossing (from Caltrans, 2003).

An ACB system is installed here by hand over a well-prepared subgrade and geotextile. These blocks are also available pre-cabled for placement by equipment. ACBs are immediately stable and able to handle heavy loads. (J. McCullah photos, 2006)

This ACB system is in-filled with ¼ inch granular aggregate to help lock blocks together.

The ACB low water crossing withstanding high flows.

A cabled ACB after one year and several big storm flows in a watershed restoration project.

Scour Stop ® can be vegetated. Here it is used for outlet transition and channel protection. (J. McCullah photos, 2006)

10. RESTORATION AND REHABILITATION (RR)

"Restoration and Rehabilitation" (RR) BMPs are watershed restoration activities. RR BMPs are designed to speed the recovery of natural habitat in areas that have been degraded by past and present resource management activities.

These BMPs utilize live vegetation to enhance habitat, control erosion, and provide geotechnical stabilization to slopes and streambanks. When vegetation is incorporated into construction and restoration projects, this is often referred to as "Biotechnical Erosion Control". Biotechnical erosion control is often a "mixed construction" approach to slope/streambank protection and erosion control; one that combines both vegetative and structural inert materials. The agencies whose task it is to ensure fish habitat recognize that the continued use of unvegetated gabions, riprap, and other inert streambank structures have long-term negative impacts on aquatic habitats.

Gathering and Handling Woody Cuttings

Cuttings comprise the main live materials used in soil bioengineering construction. Live cut plant materials for soil bioengineering work can be gathered in the wild, i.e., harvested from existing native growing sites, or obtained from commercial nurseries that stock suitable cultivars. Attributes of cuttings from these two sources are summarized briefly below:

Restoration and Rehabilitation (RR) BMPs are designed to speed the recovery of natural habitat and restore water quality. Live cut plant materials (such as willows) are often combined with inert engineering materials (such as riprap) in a technique called "Biotechnical Erosion Control".

Native sources:

Live cut plant material can be taken from existing, healthy, native growing sites. Such sites may be found within a few feet of the proposed treatment site, or could be located upwards of 50 miles away in some cases. Longer hauling distances require more careful project coordination and impose greater constraints on handling and storage. A mixture of species should be harvested whenever possible.

Nursery sources:

The USDA has released cultivars of Dogwood (*Cornus* spp*)* and Willow (*Salix* spp) species to commercial growers and nurseries that may be suitable for soil bioengineering stabilization work. These include "Streamco" purple osier willow (*Salix purpurea L.*), "Bankers" Dwarf Willow (*Salix X cottetii Kerner*), and "Ruby" Red Osier Dogwood (*Cornus stolonifera Michx.*). These cultivars were initially selected by the Natural Resources

Conservation Service for outstanding performance as streambank stabilization plants. They are easy to clone and produce roots readily when cuttings are placed in moist soils.

Collect cuttings during the dormant season (when the leaves are gone - generally late fall to early spring). Young wood (less than 1 year old) will sprout easily but older wood (2-5 years old) has greater energy reserves for long-term survival, and is also much stronger.

Plant Selection

Choose plant material adapted to the site conditions. When choosing live plant material for biotechnical erosion control applications, remember that young (less than 1 year old) wood or suckers will often sprout the easiest. However, older wood (2 to 5 years old) has greater vegetative (energy) reserves necessary to consistently sprout, and older wood is much stronger. If possible, mix younger wood with older wood for the biotechnical erosion control application such that a majority of the material is 2 to 5 years old.

Hardwood cuttings are generally divided into three categories:

1. Stakes: 3/4”-2” diameter, with a minimum length of 16”.
2. Poles: 3/4”-3.5” diameter and 6’-9’ in length.
3. Branch cuttings: can have some smaller diameter branches (no smaller than 3/8”), combined with medium diameter branches, and are 3’-9’ long depending on the application. Branch cuttings can be bundled for fascines, bundles, or slope drains or used for brush layering techniques.

Timing

Timing is an important consideration in biotechnical work. This is particularly true in Mediterranean climates (where there must be sufficient soil moisture present when cuttings are placed in the ground – in order to insure satisfactory root formation and plant establishment). For example, woody cuttings installed in Northern California in the early winter will have sufficiently moist conditions to prevent desiccation while the cutting is developing roots. By early summer, there will be significant roots and shoots growing in response to the increased photosynthesis. By the time the typical autumn drought conditions occur, the plant will have had nine months to grow roots. By this time, these roots should be deep enough to tap into permanent water table, moist bedrock joints or into the capillary fringe. A similar woody cutting planted in the late spring of the year may not have had enough time to grow sufficient roots to allow the plant to survive the first dry season.

Cuttings can be collected any time during the dormant season, from leaf fall to just before the buds begin to break in the spring. Cuttings can also be collected during the growing season if most of the leaves are removed from the stem prior to planting, although establishment success will be lower (Hoag, 1993).

Spring plantings in non-riparian zones will have reduced success unless additional moisture (seeps, springs) is available. Occasionally, a wet year may extend the planting window.

Summer plantings should be avoided because of hot temperatures and dry conditions (Allen & Leech, 1997).

Harvesting Cuttings

Pruning willows often invigorates the donor plant (avoid taking more than 2/3 of one plant).

Sources of willow include highway or road right-of-ways, ponds, and streams. Another possible source is along drainage or irrigation canals. Maintenance supervisors are often happy to have the willows harvested. Regardless of whether the source plants are considered a nuisance or a valuable resource, careful pruning will not permanently harm the shrub or tree. In fact, pruning often invigorates the plant and produces an abundant source of straight branches (whips) for harvest in a couple or years.

Choose live wood at least 2 years old. Avoid suckers of current year's growth as they lack sufficient stored energy reserves to sprout consistently.

The best wood is 2-5 years old with smooth bark that is not deeply furrowed. Select healthy wood that is reasonably straight. Try to remove cuttings from inside the crown of the existing plant and spread the harvesting activity throughout the stand to minimize visual impact. In general, one should avoid thinning more than 2/3 of the donor plant to avoid harming it.

Trim off all side branches from stakes and poles. Some side branches may be left on the branch cuttings intended for brush layering and fascines. Trim the terminal bud (the bud at the growing tip) so the plant energy will be rerouted to the lateral buds and adventitious tissue. There is some evidence that the terminal buds should not be removed on Cottonwoods. Schiechtl and Stern (1996) reports a high success (70-100% propagation take) using black poplar, which were end cuttings only (the terminal bud was left intact).

Cutting length is dependent on the application. Cuttings should be long enough to extend 6-8 inches into the permanent water table or capillary fringe for riparian plantings. At least 50-80% of the cutting should be below the ground surface to prevent desiccation. The cutting should extend above any competing herbaceous vegetation and should extend beneath the competing plant root mass.

Soaking and Storage

Research indicates that cuttings should be soaked for a minimum of 24 hours, whether they are stored, or harvested and immediately installed (Hoag et al., 1991). Some research recommends soaking the cuttings for as much as 10 to 14 days (Briggs & Munda, 1992; Fenchel et al., 1988).

Never let the cuttings dry out. Do not leave them exposed to direct sunlight. Cuttings may be stored in a cool, humid, dark place until ready to install. Platts et al. (1987) suggest a temperature of 24-32° F for cutting storage. Cuttings can be stored up to 6 months if the conditions are kept stable. Muhlberg & Moore (1998) recommend storage of refrigerated cuttings at 31-40° at 60 to 70 percent humidity.

Prior to planting, soak the cuttings in water for 5 to 7 days (minimum 24 hours). Soaking will stimulate rooting and increase success. Remove them from water before the root tips emerge - this typically takes 7-9 days (Peterson & Phipps, 1976). When the cuttings are removed from the water, they should be immediately transported to the site and planted.

Requirements for Woody Cuttings

A large proportion of biotechnical erosion control and slope stabilization techniques involve the use of woody species which form adventitious roots. The woody shrubs and trees that are extensively used are Willow (*Salix* spp.), Cottonwood (*Populus* spp.), and sometimes Dogwood (*Cornus* spp.). Assuming that soil substrate exists, these plants have the following needs in order to be effective in biotechnical projects:

Sunlight and Exposure:

Sunlight is necessary for plant growth. Willows and, to a lesser extent, cottonwood are dependent upon direct sunlight for proper growth. Given adequate moisture, willow does well on a south or west-facing slope. Willow grown on a northern exposure or in a deeply shaded riparian may not persist. In such a situation, keep in mind that the willow material may still stabilize the slope or streambank and thus allow natural recruitment to occur.

Soil Moisture:

As with any plants, woody cuttings require adequate soil moisture. A common misconception is that willows can only be used in riparian zones. Many grow at high elevations and in droughty areas. Additionally, upland willows grow well in California's Mediterranean climate, characterized by cool, wet winters and hot, dry summers.

A woody cutting can dry out if it hasn't properly established roots before the dry season. With sufficient roots, the cutting has a good chance of utilizing the available soil moisture. If an upland willow, started from a cutting, survives the first couple of seasons it will probably persist, especially if it has tapped into seeps in fractured bedrock. Its roots will have established sufficiently to survive any seasonal fluctuations in soil moisture and the water table.

The Vadose Zone, Capillary Fringe, and the Water Table:

The *Vadose Zone* is the soil horizon located between the ground surface and the saturated soil zone. Given a specific site, the zone fluctuates with changing hydrologic conditions (precipitation, subsurface drainage, flooding, etc.). With regards to biotechnical planting, the vadose zone is the soil elevation region with a beneficial environment in which to install cuttings, live stakes, and poles that will encourage root growth, uptake of nutrients, and the exchange of gases.

Capillary Fringe is the distance water is wicked upwards above the water table by capillary action. Roots of woody cuttings should be able to reach this capillary fringe. Try to plant cuttings such that the branch, stake or pole extends 6-8 inches into the capillary fringe.

Woody cuttings can also drown. Woody cuttings placed in the saturated soil zone, viz., below the ground water table, will suffocate. The plants require soil with sufficient aerated pore spaces to allow exchange of gases.

Inundation:

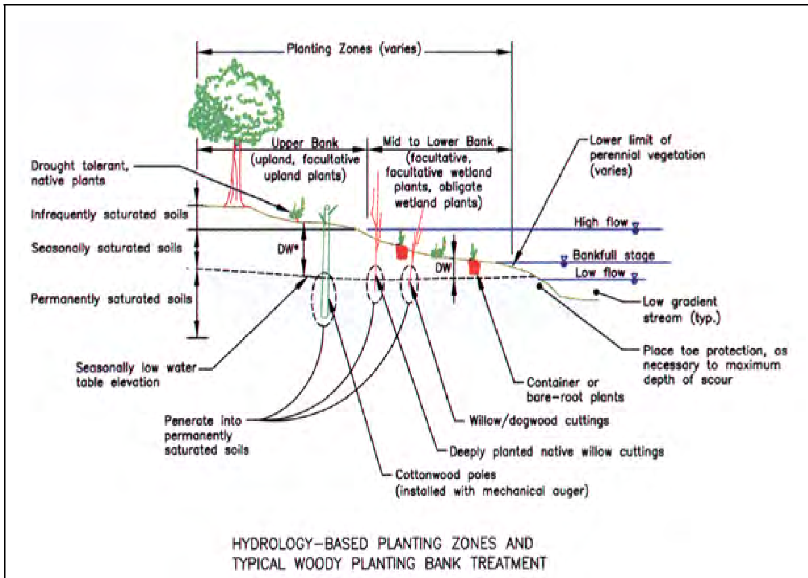


Figure 10-1. Hydrology-Based Planting Zones (from Washington State, 2003).

Flooding will produce an anaerobic environment surrounding the root system. The duration and type of flooding has different impacts on woody plants. These impacts are varied - depending on the plant's tolerance to flooding - which is in turn dictated by the growth of adventitious roots and new secondary roots under low oxygen conditions. Very tolerant species (*Willow, Cottonwood*) can maintain their "normal" roots (i.e., the root system that developed in an aerated medium) while producing new secondary and adventitious roots (Teskey & Hinkley, 1978). In fact, flood tolerant species generally have the ability to form adventitious roots in response to the anaerobic conditions. The new roots help the plant exchange oxygen for survival. Non-flood tolerant plants experience immediate die back.

Pre-Planting Soaking:

In flood tolerant species like willow and cottonwood, the formation of adventitious roots is triggered by waterlogged conditions in the rhizosphere (that portion of the soil in the immediate vicinity of plant roots). Interestingly, there is much evidence linking adventitious root growth with the oxygen content of the floodwater for tree species (Teskey & Hinkley, 1978). Adventitious root development has been shown to be much greater under moving water than under stagnant water conditions and would appear attributable to the higher oxygen and lower CO_2 concentrations in moving water (Hook et al., 1970).

These studies and others done subsequently by USDA (Hoag, 1993) indicate that woody cuttings (willow, cottonwood) should be soaked in water for 5-7 days (minimum 24 hours) prior to planting. The aforementioned studies indicate that water high in oxygen, such as a running stream, may improve adventitious root formation. Bentrup and Hoag (1998) state that soaking swells the root primordial, and may leach out natural anti-rooting hormones found in cuttings. Schaff, Pezeshki & Shields (2002) found that soaking Black Willow cuttings for 10 days improved growth, biomass production, and survival, while those soaked for 3 days did not show a significant response. They also noted that studies of the response to a longer soaking period have not been done, and could reveal that the optimum soaking period is longer.

RR-1 Revegetation

SWPPP Summary

Areas of rehabilitation and repair (revegetation) shall be closed to vehicular traffic. Closed areas shall be signed and fenced, and riders shall be educated to stay on established trails, and not blaze trails through vegetation. Native, locally-adapted plant species shall be used, and soil shall be amended as needed to promote growth.

Areas closed for plant rehabilitation should be signed and fenced.

Definition / Purpose

Certain areas of the Park have been damaged from recreational use. Park staff and volunteers replant these areas with native grasses and other native plants.

Many native grasses have deep, fibrous root systems. These grasses are extremely beneficial in revegetation efforts as they help overcome both the direct and indirect impacts of OHV activities on soil structure. Direct impacts of OHV activities on vegetation include reduced vegetation cover and growth rates, and increased potential for non-native grasses and pioneering species to become established, thus altering vegetation communities. Indirectly, OHV roads and trails also create edge habitats, which can generate conditions that promote the encroachment of non-native and invasive plant species (Ouren et al., 2007).

Planning Considerations

Environmental factors such as climatic zone, soil type, moisture availability, soil chemistry, light conditions, degree of compaction from OHV use, etc., must be taken into account when developing a planting design. Locally available, native plants are often the best adapted to conditions, and often provide broad-based environmental benefits, such as food or nesting sites for particular species, e.g., certain butterflies, or excellent adaptation to local weather extremes such as prolonged drought or flooding. Plants may need irrigation either for an establishment period or for the life of the project.

Plants always benefit from suitable high quality soil and organic amendments. Plants, (whether from seeds, cuttings or rooted container plants), are usually planted in combination with protective surface mulch. Mulch is a layer of organic material that is applied to the soil surface. Examples of mulch include blankets of wood chips or straw, or shredded wood waste or newspaper pulp that is sprayed on the ground by hydraulic mulching pumps. Mulch provides a protective cover against soil erosion and loss of small plants and seed, prevents rapid drying of soil and roots, and discourages growth of weeds that compete for light, growing space, and nutrients. Mycorrhizal fungi can also enhance nutrient availability and biological soil structure, encouraging native plant succession and discouraging invasive plant species (see SS-3 Mycorrhizae Inoculation).

Construction Specifications

Vegetation can be planted in the form of seed, rooted transplants (also called container plants), or cuttings. Seeding can be accomplished by hydraulic seeding (hydromulching), seed drilling, hand broadcasting, or mechanical broadcasting. Hydromulching sprays are mixtures of seed, mulch, and emulsifying/stabilizing agents that harden and provide temporary protection. Rooted transplants in containers are usually placed in prepared soil dug by hand as shown in Figure 10-2. Detailed information on planting methods can be found in Washington State, (2003). See for RR-2 Live Staking and RR-3 Willow Posts and Poles for more information on propagation with cuttings.

In all cases, the soil must be prepared properly, so that it provides a suitable horticultural medium. So-called "engineered-soils" are soils that have had organic material removed and are compacted to a dense, hard condition with poor aeration and water transmission properties. This is the opposite of typical horticultural needs of any plant, whether grass or an oak tree. Some areas may consist of subsoils that contain no topsoil at all.

Slopes which are to receive vegetative stabilization should be roughened prior to application of seed and fertilizers (SS-1 Surface Roughening). This promotes establishment of a healthy stand of vegetation, holds fertilizer, and increases infiltration. Tillage or other suitable implements may be used to create horizontal depressions on the contour, or slopes may be left in a roughened condition by not fine-grading them.

Sub-soils are typically dense, poorly developed soils that lack sufficient air, good drainage, and nutrients or organic matter - all of which are vital to successful plant growth. A typical compacted slope must be loosened near the surface and amended to allow plant roots to penetrate and for the plant to receive air and nutrients to prosper. Nutrient and water needs vary by plant type. See Section 3: Notes on Soil Compaction, Optimizing Soil Compaction and Other Strategies, in the Introduction to this manual, for different ways of ameliorating or circumventing adverse conditions associated with engineered or compacted soils.

Consistent with the Off-Highway Motor Vehicle Act of 1988, the condition of soils, wildlife, and vegetative resources shall be continually monitored by Park staff to determine if soil loss standards and habitat protection plans are being met. Habitat restoration, soil rehabilitation, and revegetation efforts shall include management policies such as rotating rider use areas, replanting closed areas with native plant species, and eradicating noxious weeds and invasive species.

Optimal application of straw mulch to prevent surficial rainfall erosion ranges from 1-2 tons/ac. A prospective user should not only have clear goals for the planting, but also work with an experienced local horticulturist to specify soil, soil amendments, fertilizers, plants, planting techniques, mulches, and irrigation needs. Refer to SS-1 Surface Roughening, SS-3 Mycorrhizae Inoculation, SS-4 Seeding, and SS-5 Straw Mulching for more information.

The following publications provide useful information and advice on soil and site preparation to maximize plant establishment and survival: Gray and Leiser, (1992); Washington State, (2003).

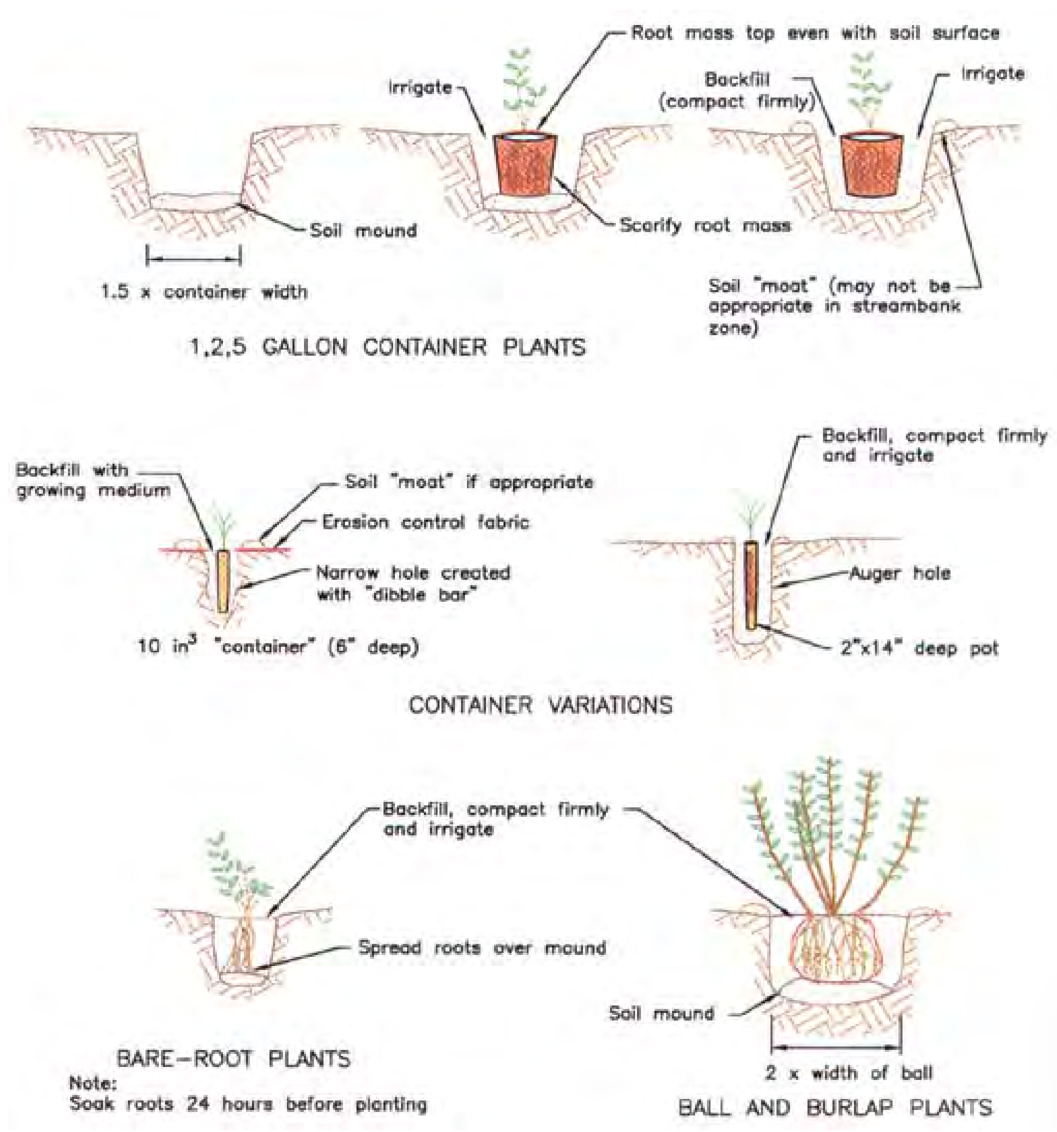


Figure 10-2. Woody plant installation using bare-root, ball and burlap, or container plants (from Washington State, 2003).

<u>Limitations</u>

Vegetation has strength limitations, particularly in its early stages, when the plants are not yet well-established. Additionally, vegetation is not as strong when used alone as it is when combined with other techniques or materials, such as erosion control fabrics and more structural procedures, such as biotechnical erosion control techniques. Plants minimize physical soil disturbance from such things as hooves or feet, however, plants used alone are vulnerable to heavy traffic and trampling.

It is imperative that riders stay on existing trails and avoid vegetated areas!

Many factors can contribute to or cause failure of plants to establish, thrive, and survive. Inadequate soil moisture (either too little or too much), insufficient soil nutrients, toxic soil conditions (high alkalinity or acidity), and inadequate light are all soil and site conditions that can influence plant health. Other common causes of failure include incorrect planting locations (see Figure 10-1), inability of plant material to reach the summer water table, damage by wildlife and livestock, excessive pedestrian use or unauthorized OHV traffic, and inability of installed plants to compete with naturally establishing riparian vegetation.

Inspection and Maintenance

Revegetation efforts do not end with initial installation and planting; monitoring and maintenance are crucial to project success as well. Some follow-up planting may be required to replace plants that did not survive the initial planting. Plants may need irrigation for an initial establishment period, but are not likely to (and should *not* require) continuous irrigation. Irrigation alternatives are described by Fischenich (2000). Plantings should be checked for browsing damage, and if necessary, measures taken to protect young saplings and emergent vegetation. Weed control may be necessary in some cases as well.

Monitoring should be conducted monthly during the first full growing season after installation, and can be reduced to single, annual visits thereafter (Washington State, 2003). Initially, survival of installed plants can be monitored by a physical count, but later on, as cover density increases, it may be necessary to use percent cover as an indicator of plant health and survival. Survival monitoring in a riparian zone should also take into account sediment deposition, which can affect survival of installed plants, but in the long run may be beneficial to the establishment of desirable native riparian species.

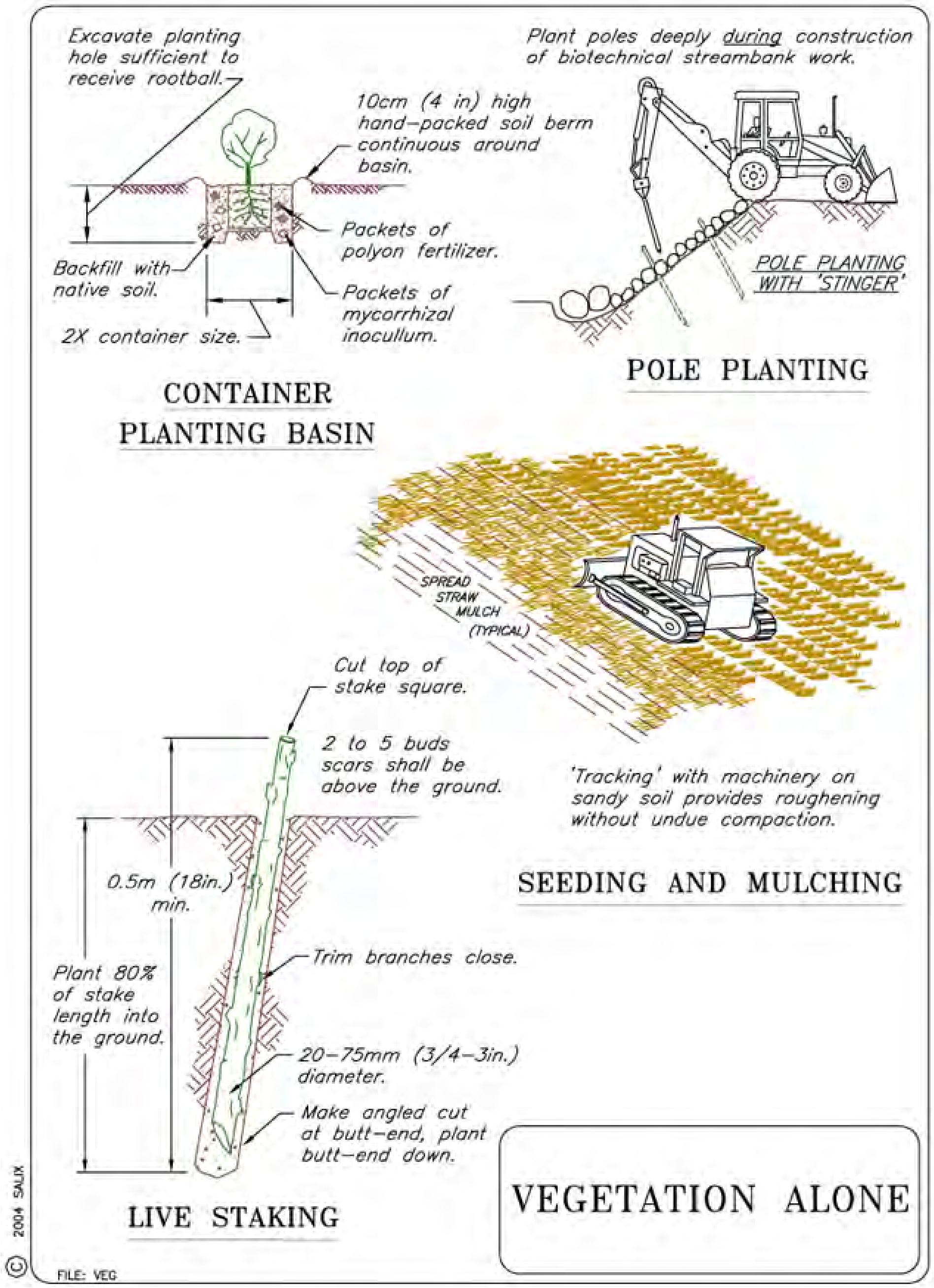
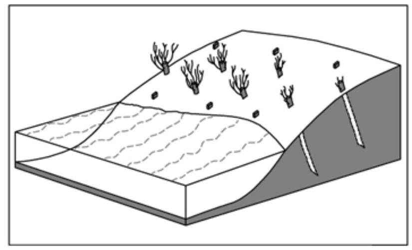


Figure 10-3. Vegetation Alone.

RR-2 Live Staking

SWPPP Summary



Live stakes are pieces of freshly cut woody plant stem planted in the ground or into erosion control or streambank stabilization structures.

Live stake cuttings can be used to repair small earth slips and slumps. The stakes can help buttress the soil and arching. Gullies and bare gully banks can benefit from live staking. Live stakes or poles can be inserted or driven through interstices or openings in gabions, riprap, articulated block, or cellular confinement systems (joint planting). Live stakes can be used to anchor and enhance the effectiveness of live fascines, fiber rolls, turf reinforcement mats, and other erosion control materials.

Definition / Purpose

The concept behind live stake planting is that the live, vegetative cuttings are placed into the ground to allow the stakes to root and grow. Even if the branches do not grow the stakes can provide (at least temporarily) reinforcement much like a wooden stake or steel rebar stake. Live stakes generally accomplish several purposes concurrently:

- The stakes grow vegetatively thereby providing cover and erosion control.
- The vegetative cover can provide improved aesthetics.
- The cover provides shade and canopy cover where thermal pollution may be a concern.
- The leaves, branches and insects living on them can provide carbon and nutrient cycling and are an important food source for aquatic organisms.
- The roots and branches provide for and improve geotechnical and soil stability. Using a system of live stakes creates a root mat that stabilizes the soil by reinforcing and binding soil particles together. Roots can also aid stabilization by extracting excess soil moisture, and by binding fill soils to existing native soils.
- Live stakes used as slope nails can stabilize slumps and slides through the mechanisms of "buttressing and arching".
- Leafy and brushy top growth benefits the streambank by increasing roughness, thereby reducing boundary shear stress underneath the canopy.
- RR-2 Live Staking can (especially when used in conjunction with biodegradable erosion control materials) enhance conditions for colonization of native species.

Planning Considerations

Live stakes are planted with the terminal buds or leaf nodes pointing up and the basal ends down into the soil. The buried portion of the cuttings develop roots, while the exposed portion produces branches and leaves. Depending on the species, the cuttings can grow into shrubs and/or trees. Because of its ability to root easily, the preferred plant species for RR-2 live staking is Willow (*Salix* spp.), but Cottonwood (*Poplar* spp.), Dogwood (*Cornus* spp.), Elderberry (*Sambucus* spp.), Coyote brush (*Baccharis* spp.), and others have been used successfully.

Live staking has been successfully used in many different climactic, soil moisture regimes and elevations. The possible uses for and benefits of live staking is vast; but the primary uses generally involve revegetation, anchoring, enhancing geotechnical strength (shear strength), or reducing erosion through increased cover (raindrop impact) and hydraulic roughness (reduced boundary shear). The practice is commonly used in combination with other practices to provide more stable site conditions and a more environmentally-sensitive design.

Willow planting can benefit from SS-3 Mycorrhizae Inoculation and slow release fertilization.

<u>Construction Specifications</u>

Live stakes should be cut with the planted end (butt end) angled, and the top end cut square. This helps identify the top from the bottom, so stakes don't get planted upside down.

- The stakes shall be harvested from relatively straight, disease-and-insect-free branches.
- Make clean cuts without splitting ends.
- Trim branches from cutting as closely as possible.
- Stakes shall be 3/4 inch to 3 inch diameter and a minimum of 18 inches long.
- The butt end of the cutting should be pointed or angled, and the top end should be cut square to help identify the top and bottom when planting. The top, square end can be painted and sealed by dipping the top 1 to 2 inches into a 50 to 50 mix of light colored latex paint and water. Sealing the top of stake will reduce desiccation, ensure the stakes are planted with the top up, and make the stakes more visible for subsequent planting evaluations.
- Stakes must not be allowed to dry out. All cuttings should be soaked in water for 5 to 7 days (a minimum of 24 hours) and planted the same day they are removed from water.
- A metal pilot bar and 2 to 3 lb sledge hammer may be necessary. A dead blow hammer or hard rubber mallet should be used to drive the live stake.

Planting Live Stakes:

Generally, the deeper the branch is inserted into the soil, the better the chance of vegetative success - and the greater the soil stabilization benefits. Therefore, the "80% Rule" must be strictly followed – at a minimum 80% of the branch shall be placed in the soil and with 20% protruding above. For instance, an 18 inch stake will be installed 14.5 inches minimum into the soil, and a 30 inch stake shall be installed 24 inches. Deeper planting also reduces the chance that stakes can be pulled out by deer or other wildlife. Limited browsing of willow by wildlife is generally not detrimental.

It is important not to damage the stakes during installation. Damaged and split stakes have increased incidence of dehydration, decay, and the introduction of disease. Most compacted soils or soils with rocks and gravel will require the use of a "pilot bar" to make a hole prior to driving the stake. The use of a polyurethane hammer or rubber mallet will reduce splitting damage to the stake. Using a high-powered water jet to pilot the holes is most favorable as the hole is also left well hydrated. The USDA-NRCS Plant Material Center has specifications for a water jet.

Use the pilot bar to make a hole in firm soil. Plant the basal ends into the ground, with the leaf bud scars or emerging buds always pointing up. Be careful not to damage the buds, strip the bark, or split the stake during installation. Ideally, the stakes should not be planted in rows or at regular intervals, but at random in the most suitable places at a rate of 2 to 5 cuttings/10 ft^2. However, if trying to control a group of people planting several thousand of these, it may be easier to specify an average set interval.

Set the stake as deep as possible into the soil, with 80% of its length into the soil. Deep planting will increase the chances of survival. The stake should never protrude more than one-quarter of its length above the ground level to prevent it from drying. The excess stake or any damage or split ends can be cut off after installation. At least 2 buds and/or bud scars should remain above the ground after planting. Add soil to the planting hole if necessary to ensure soil contact with the stem. It is important to tamp the soil around the cutting to ensure good soil-stem contact. The best installations, especially on droughty sites, will include "watering in" and slightly compacting the backfill or hole. "Watering in", much like transplanting a container plant, can successfully be accomplished by pouring one to two gallons of water into the soil around the stake and planting hole, then slightly tamping or otherwise jarring the soil. This procedure will ensure intimate soil to stem contact.

Limitations

Without temporary irrigation, stakes have the highest survival rate when installed during the dormant season, which may not coincide with the best time for construction of the rest of the project. Stakes do not become fully effective until one growing season after installation, and thus provide limited immediate and aerial stabilization unless combined with other practices.

Inspection and Maintenance

Stakes should be inspected every few weeks until well established, and irrigation, browse control (from livestock, deer, beavers, etc.), pruning, weed control, and fertilization should be implemented as needed.

Sometimes it takes one to two years for full establishment. A rule of thumb is - if the biotechnical planting survives one year - it will probably survive and sustain itself for many years.

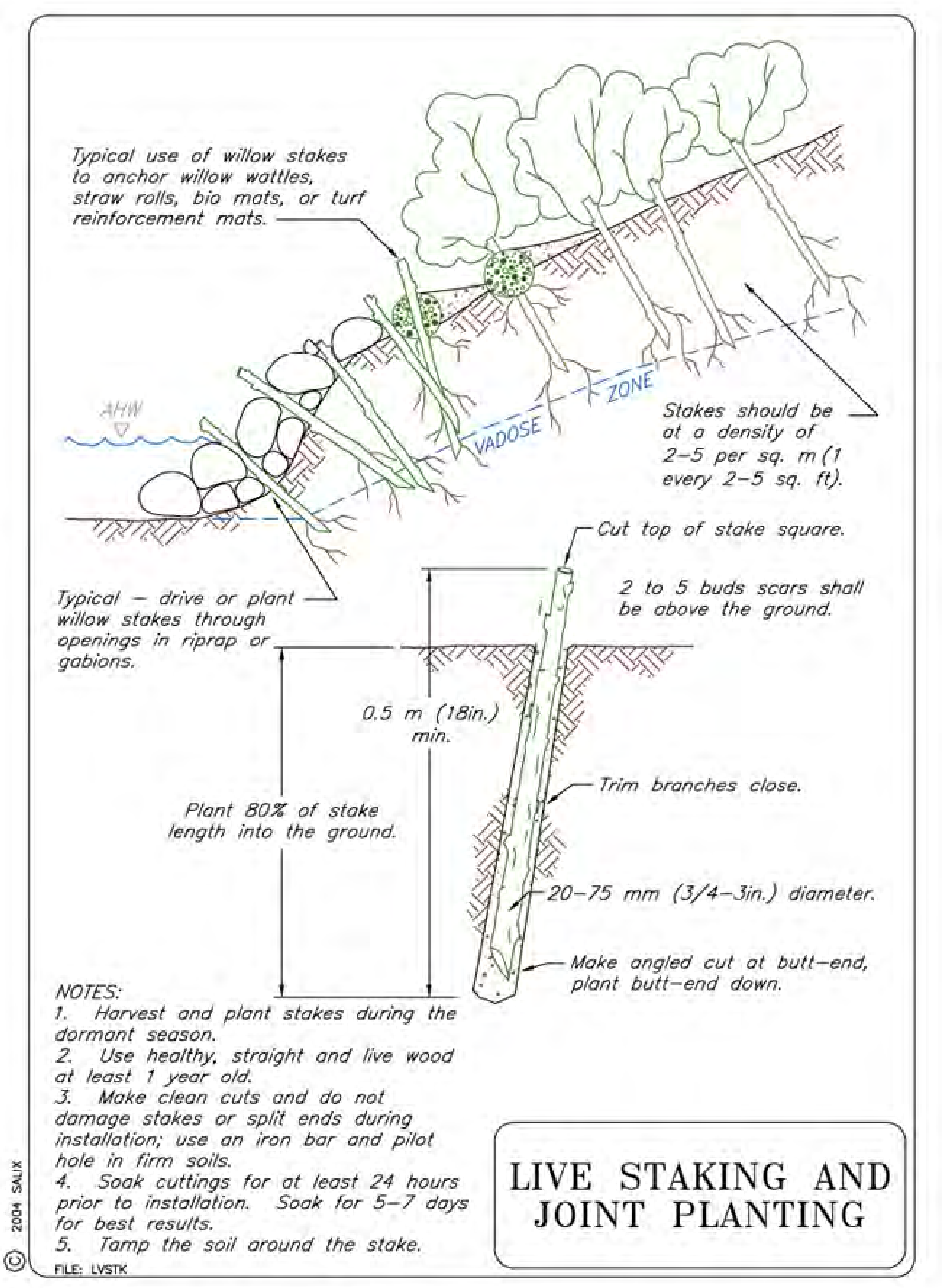
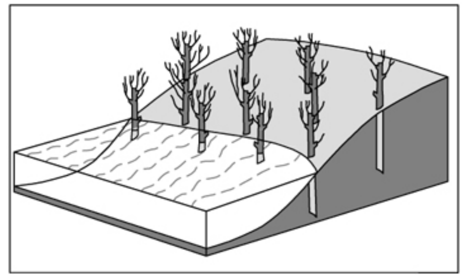


Figure 10-4. Live Staking and Joint Planting.

RR-3 Willow Posts and Poles

SWPPP Summary



RR-3 Willow Posts and Poles is a biotechnical erosion control technique whereby the use of vegetative components and structural materials are combined in a mutually reinforcing manner. Willow posts and poles are excellent additions to any technique that requires excavation, particularly when the depth and location of the excavation intercepts soils conducive to willow growth. Willow posts and poles may be inserted into stone or soil backfill and thus become incorporated with the structure as they root.

Willow species are lead pioneers in riparian zones throughout much of North America. Once established, they provide cover and create microhabitat conditions conducive to colonization by endemic native species that comprise the riparian community. Functional riparian zones provide habitats for a wide range of aquatic and terrestrial plants and animals, generally improve bank stability, mediate water quality, and improve visual resources.

Definition / Purpose

RR-3 Willow Posts and Poles may also be referred to as pole planting or dormant live posts. Larger willow materials (posts and poles), planted deeply and incorporated into the structures will grow much more vigorously and provide mechanical bank protection during the period of plant establishment. Dense arrays of posts or poles reduce velocities near the bank or bed surface, and long posts or poles reinforce banks against mass instabilities occurring in shallow failure planes. Willow posts are planted deeply, usually during actual construction. Deep planting will increase survival and increase establishment rates while providing enhanced geotechnical and ecological benefits.

Planning Considerations

Willow posts and poles can be incorporated into many techniques during construction (see RR-5 Vegetated Riprap and RR-6 Vegetated Gabions), and can be planted in the keyways of many structures.

When placed along a channel with perennial flow, willows generally will not survive when planted at the toe, but may serve as short-term sacrificial protection for plantings at higher elevations. If permanent protection is needed, however, structural measures like stone toe protection are recommended.

Workers in drier climates have stressed the importance of planting willow posts deeply enough to maintain contact with groundwater throughout the growing season.

Willow planting can benefit from SS-3 Mycorrhizae Inoculation and slow release fertilization.

Construction Specifications

- Willow cuttings should be planted while dormant, and care should be taken to prevent desiccation or dormancy break of cuttings between harvest and planting.
- Willow poles shall be approximately 2-6 inches in diameter, and 6-10 feet in length.
- Equipment for digging planting holes: Optimum equipment is a backhoe with "waterjet stinger", normal "stinger", or auger - but an excavator bucket can also be used effectively.
- Poles and posts should be deeply 3 to 7 feet, planted in holes created during construction using a backhoe or excavator. Sometimes willow and cottonwood poles can be planted "after construction is complete" by using a metal stinger mounted on a hydraulic hoe, or an auger. In this situation the auger hole and pole shall be well "watered in" using water and soil to ensure proper compaction and reduction of air pockets.
- Poles should be planted to such a depth that desiccation does not occur during the summer season (for sites with water tables lower than the stream) and to ensure that poles are not undermined by local scour during high flows.
- Good contact between the plant stem and soils is essential. Plant desiccation can occur if too much air surrounds the stem.
- Only a small portion of the pole should remain above the surface of the ground – about 80% of the cutting should be buried, to prevent desiccation and ensure good stem to soil contact.

Limitations

- Willow posts and poles have higher survival rates when planted during their dormant season, so planning should be adjusted accordingly when possible.
- Desiccation and browsing are the two biggest reasons for failure. Often, willow post installations need to be fenced for a year or so, especially in agricultural areas, to allow the willows to get established. Willows that are not planted deeply enough, have too much of their stem exposed, or do not have good stem to soil contact can dry out and die before getting established.
- Optimum stabilization is not achieved until the willows become established, typically at least one season after installation, although they provide some reinforcement immediately following installation.

Inspection and Maintenance

Willow posts should be inspected for vigor, dehydration, and animal browsing problems, and remedial action taken as necessary.

Sometimes it takes one to two years for full establishment. The rule of thumb is - if the biotechnical planting survives one year - it will probably survive and sustain itself for many years.

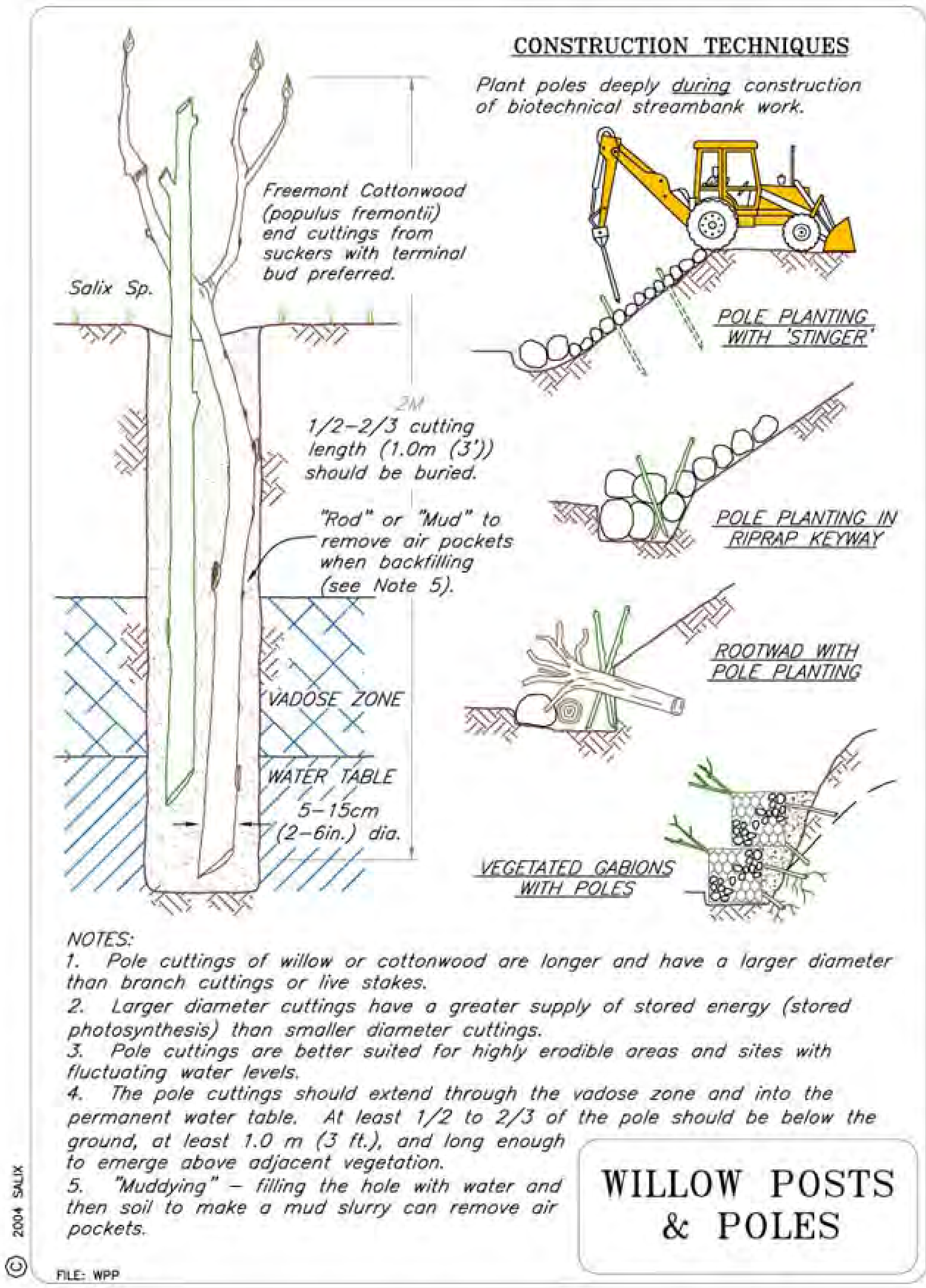
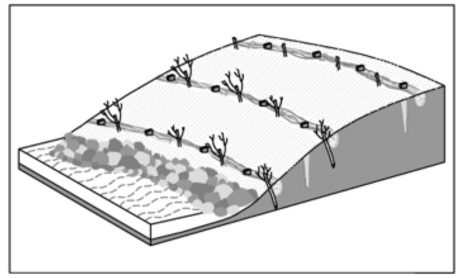


Figure 10-5. Willow Posts and Poles.

RR-4 Live Fascines

SWPPP Summary



Live fascines are also known as live brush (willow) bundles, or willow wattles. Live fascines are bundles of live branch cuttings placed in long rows in shallow trenches across the slope on contour, or at an angle. Fascines are used for biotechnical stabilization of slopes and streambanks. Live fascines may be used for erosion control and vegetation establishment on long slopes, road fills, road cuts, trails, gullies, slumped areas, eroded slopes, or eroding streambanks. Frequently, they are used to repair small earth slips and slumps or to protect slopes from shallow slides 1-2 feet deep. This technique is useful on slopes requiring other planting materials such as woody vegetation, transplants, seeded grasses, and forbs. Live fascines provide soil stability while promoting vegetation and cover establishment.

Vegetation establishment is enhanced because the bundles provide a suitable microsite for plants by reducing surface erosion, increasing infiltration rates, and by forming a series of terraces with shallower slope angles. As the riparian vegetation roots and grows, soil de-compaction, shading, and development of nest sites, food resources, and shelter occur.

Definition / Purpose

Fascines are utilized as a resistive measure to protect the toe and face of an eroding streambank, and they are also very effective for erosion control on long slopes. Fascines reduce effective slope length, dissipating the speed and energy of runoff moving down slope, and simultaneously trapping sediment. The branch cuttings, rope ties, and wooden stakes combine to provide structural elements that resist hydraulic forces acting on the slope. The terraces behind the fascines provide a stable platform for workers - or for access to steeper areas. Additionally, the terraces formed by the rows of fascines will trap sediment and detritus, promoting vegetative establishment. The partially buried bundles can root and grow, providing strong, long-term protection. Fascines provide excellent protection against surficial erosion; detaining runoff and increasing infiltration if aligned on contour, and directing drainage away from a slope area installed at an angle.

Some of the advantages of live fascines are:

- Large equipment is needed only for any necessary bank regrading.
- Economical where materials are locally available.
- Flexible, simple method requiring little soil disruption.
- Grows into durable, natural appearing bank or slope cover.
- A very effective stabilization technique once rooting is established.
- Live fascines are capable of collecting sediment.

Planning Considerations

This technique is applicable where immediate erosion protection is necessary, and works best where flows are sufficient to keep the base of the bundle wet during most of the growing season, but do not exceed the flood tolerance of the fascine (Sotir & Fischenich, 2001).

Fascines are made of long straight brushy branches 3 to 15 feet long and up to 1 ½ inches in diameter. The branches comprising fascines are harvested from tree and shrub species capable of propagating from cuttings, typically willow (*Salix* spp) species (McCullah, 2004). If adequate quantities of suitable material are unavailable, the fascines may be constructed from 50% of species unlikely to root, e.g., alder or birch.

Live fascines can be effective for erosion control on long slopes. Fascines reduce slope length, form terraces which trap sediment and native seeds, and promote vegetative establishment.

Construction Specifications

Tie cuttings together to form bundles, tapered at each end, 6-30 feet in length, depending upon site conditions or limitations in handling. The completed bundles should be 6-12 inches in diameter, with the growing tips all oriented in the same direction. Stagger the cuttings in the bundles so that the tips are evenly distributed throughout the length of the bundle. Compress and tightly tie the bundle every (1) foot with rope or twine of sufficient strength and durability. Hemp, jute, cotton, or other biodegradable rope may be used (McCullah, 2004).

Installation should progress from the bottom to the top of the slope. Install bundles into trenches dug into the slope on contour. Spacing of contour trenches (fascines) is determined by soil type, potential for erosion, and slope steepness. See Table 10-1 for general spacing guidelines:

Slope (V:H)	**Slope Length Between Fascines**	
	Cohesive Soils	*Non-Cohesive Soils*
1:1	3 ft[1]	NA
1:1 – 1:2	3 to 4 ft[1]	NA
1:2 – 1:3	4 to 5 ft[1]	3 to 4 ft[1]
1:3 – 1:4	5 to 6 ft	4 to 5 ft[1]
1:4 or flatter	6 to 8 ft	5 to 7 ft

[1] Recommended to be used with coir netting or ECB between fascine and bank.

Table 10-1. General Installation Guidelines (adapted from Sotir & Fischenich, 2001).

Trenches:

The trench should be shallow, about ½ the diameter of the fascine. The trench width should be 12-18 inches, depending on the slope angle, but should be at least 1 inch wider than the bundle. In non-cohesive soils, the trench should be lined with a coir erosion control blanket or netting prior to installation of the fascine (Sotir & Fischenich, 2001).

Staking:

Stake fascines firmly in place with one row of construction stakes on the downhill side of the bundle, not more than 3 ft apart. Place a second row of stakes through the fascines, near the ties, at not more than 5 ft apart. Overlap the tapered ends of adjacent bundles at least 18 in, so the overall thickness of the fascine is uniform. Use two stakes at each bundle overlap, such that a stake is driven between the last two ties of each bundle.

Live stakes, if specified, are generally installed on the downslope side of the bundle. Drive the live stakes below and against the bundle between the previously installed construction stakes. Repeat the preceding steps to the top of the slope, placing moist soil along the sides of the live bundles. When finished, all live stakes should be trimmed, such that a maximum 3 in of stake protrudes above the bundle (Sotir & Fischenich, 2001).

Keys:

Fascines should be keyed into the bank at least 3 ft on both upstream and downstream ends (Sotir & Fischenich, 2001).

Backfilling:

Proper backfilling is essential to the successful rooting of the fascine. Backfill bundles with soil from the slope or trench above. Work the backfill into the fascine interstices and compact behind and below the bundle by walking on it and working from its terrace.

Seed and mulch:

Shallow slopes, generally 3:1 or flatter may be seeded and mulched by hand. Steeper slopes may be hydraulically seeded, and the mulch anchored with tackifier or other approved methods.

Limitations

This technique should only be installed during the dormant season of the plant material used. Live fascines are only appropriate on slopes that are not undergoing mass movement and on streambanks above the annual high water (AHW) level. Live fascines do not penetrate the soil as deeply as some other bioengineering techniques (such as live staking or pole planting), so more desiccation is to be expected, especially in dry, hot climates.

Inspection and Maintenance

Inspections should occur after each of the first few flood events, and/or twice the first year. Monitoring should continue at least once each year thereafter. Toe erosion and/or flanking can cause loss of the structure, if not combined with a toe protection in areas where shear stresses and velocities exceed limits for the soils underlying the structure. Flanking can be caused by insufficient keying-in of the structure (Sotir & Fischenich, 2001).

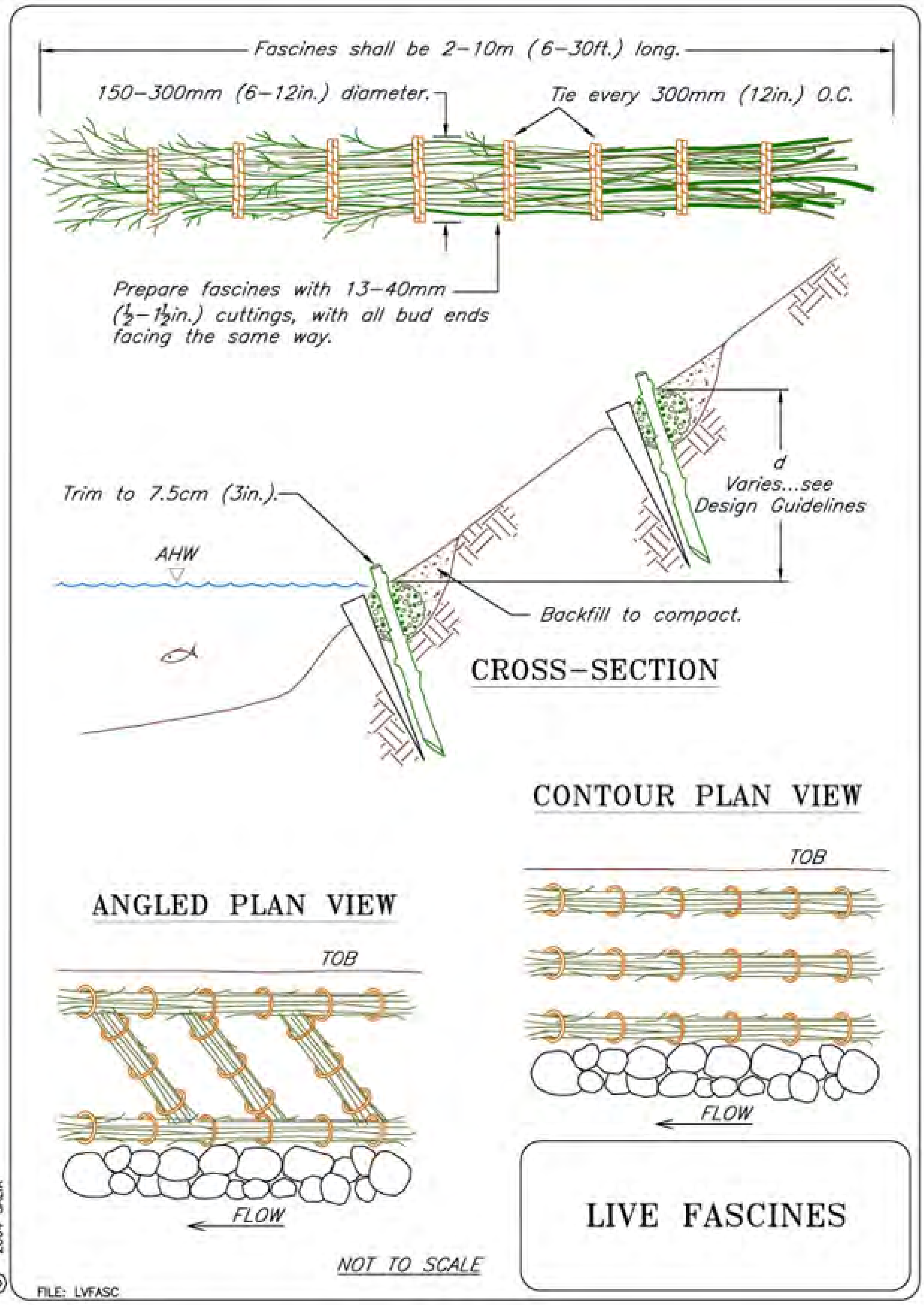
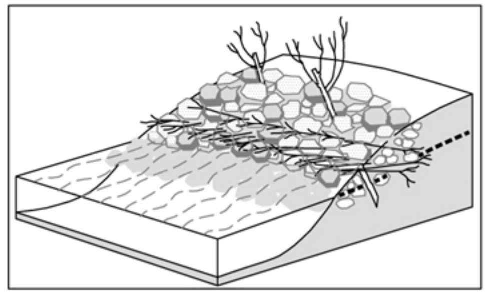


Figure 10-6. Live Fascines.

RR-5 Vegetated Riprap

<u>SWPPP Summary</u>



Correctly designed and installed, vegetated riprap offers an opportunity for the designer to attain the immediate and long-term protection afforded by riprap, with the habitat benefits inherent with the establishment of a healthy riparian buffer. The riprap will resist the hydraulic forces, while roots and branches increase geotechnical stability, prevent soil loss (or piping) from behind the structures, and increase pull-out resistance. Aboveground components of the plants will create habitat for both aquatic and terrestrial wildlife, provide shade (reducing thermal pollution), and improve aesthetic and recreational opportunities. The roots, stems, and shoots will help anchor the rocks and resist ‘plucking’ and gouging by debris. This technique can also be applied to stabilize slopes where habitat and aesthetic values are important.

<u>Definition / Purpose</u>

RR-5 Vegetated Riprap is also known as vegetated rock revetment, Vegetated Rock Slope Protection (VRSP), face planting, or joint planting. The negative environmental consequences of traditional riprap can be reduced by minimizing the height of the rock revetment up the bank and/or including biotechnical methods, such as; vegetated riprap with brushlayering and pole planting; vegetated riprap with soil, grass, and ground cover; vegetated riprap live fascines; and vegetated riprap with bent poles (McCullah, 2004).

Combining riprap with deep vegetative planting (e.g., brushlayering and pole planting) is also appropriate for banks and slopes with geotechnical problems, because additional tensile strength is often contributed by roots, stems, and branches.

<u>Planning Considerations</u>

Rock riprap is the most common and effective form of streambank protection. Rock can settle and conform if some scour should occur. Conventional riprap placement, however, does not increase wildlife habitat nor is it aesthetically pleasing. It often takes many years for riprap to become vegetated, if revegetation is not planned in advance and integrated with construction.

This practice applies whenever there is a desire to install riprap that is more attractive and has the potential to enhance, not degrade, fish and wildlife habitat. Additionally, woody vegetation establishment will prevent soil loss (piping) from behind the structures and increase pull-out resistance.

Vegetated riprap is appropriate where infrastructure is at risk, and where redirective and discontinuous bank protection measures have been rejected or deemed inappropriate (Derrick, 2002). Vegetative riprap techniques are sometimes considered mitigation for some of the impacts caused by riprap (Washington, 2003).

Filter Materials:

Some sort of filter material is typically used to prevent piping of fine soils from below the riprap, if "self-launching stone" is not used. There are two choices: filter fabric or graded filter gravel. Filter fabrics are *not* recommended for use in vegetated riprap, as roots have difficulty penetrating the fabric. If filter fabric is required, one can cut holes in the fabric where the vegetation is placed. Small slits in the fabric are especially appropriate with the bent pole method. This can, however, make placement much more labor-intensive.

Filter gravel is the preferred filter media for vegetated riprap. The following composition is an example of graded gravel that has been successfully used as a filter layer (see Table 10-2). The composition of all filter blankets should be based on site-specific conditions. Other filter designs can be found in Brown et al., 1989.

Rock Size:

There are two options for rocks – self-launching / self-filtering rock or standard riprap. The advantage of self-launching / self-filtering rock is that the revetment will build its own toe, by self-launching, in any scour hole that forms. In addition, the different sizes of rock act as their own filter medium, so no filter fabric or filter gravel is needed. This decreases cost, and also makes installation less labor-intensive for two of the three methods of installation. However, using self-launching stone is dependent on a source of graded rock, which is not always available.

Consult with an erosion control specialist for rock sizing guidelines.

Sieve Size	**Percentage Passing**
1 in	100
3/4 in	90-100
3/8 in	40-100
No. 4	25-40
No. 8	18-33
No. 30	5-15
No. 50	0-7
No. 200	0-3

Table 10-2. Example Composition of Filter Gravel.

Vegetation:

The vegetation obtained should be poles of adventitiously-rooting native species (such as willow, cottonwood, or dogwood), with a minimum diameter of 1.5 in, and be sufficiently long to extend into the vadose zone below the riprap.

Construction Specifications

Vegetated Riprap with Willow Bundles:

- Grade the bank to the desired slope where the riprap will be placed, such that there is a smooth base.
- Dig a toe trench for the keyway (if required) below where the riprap will be placed.
- Place 4-6 inch bundles on the slope, with the butt ends placed at least 1 foot in the low water table (see RR-4 Live Fascines, aka "willow bundles"). This will probably involve placing the poles in the toe trench before the rock is placed, if standard riprap rock is being used. Digging shallow trenches for the willows prior to placing them on

the slope will decrease damage to the cuttings from the rocks, and may increase rooting success because more of the cuttings will be in contact with soil.

- The bundles should be placed every 6 feet along the bank, and should be pointed straight up the slope. Once the bundles are in position, place the rock on top of it and to the top of the slope. The bundles should extend 1 foot above the top of the rock. If the bundles are not sufficiently long, they will probably show decreased sprouting success, and therefore, a different technique should be chosen.

Vegetated Riprap with Bent Poles:

- Grade back the slope where the riprap will be placed, such that there is a smooth base.
- Dig a toe trench for the keyway (if required) below where the riprap will be placed.
- If filter fabric is being used, lay the fabric down on the slope, all the way into the toe trench, and cut holes in the fabric about 2-3 feet above the mean low water level. Slip the butt ends of the willow poles through the fabric and slide them down until the bases are at least 6 inches into the perennial water table, or at the bottom of the toe trench, whichever is deepest.
- If using filter gravel, lay it down on the slope, and place a layer of willow poles on top of the gravel, with the bases of the cuttings at least 6 inches into the perennial water table, or at the bottom of the toe trench, whichever is deepest.
- Place the largest rocks in the toe trench. Ensure that they lock together tightly, as they are the foundation for the structure.
- Place the next layer of boulders such that it tapers back slightly toward the streambank.
- Bend several willow poles up, such that they are perpendicular to the slope, and tight against the first layer of rocks. Now place the next layer of rocks behind these poles. Placement will require an excavator with a thumb, as someone will have to hold the poles while the rocks are placed. As the poles are released, they should be trimmed to 1 foot above the riprap.
- This last step should be repeated until all the poles have been pulled up, and the entire slope has been covered.

Vegetated Riprap with Brushlayering and Pole Planting:

There are two methods of constructing brushlayered riprap; one involves building up a slope, and the other works with a pre-graded slope – neither method can be used with filter fabric.

Method 1:

- Lay the bank slope back to somewhat less than the desired finished slope.
- Dig a toe trench, if needed, and lay the key rocks into the trench. Pack soil behind these rocks, with filter gravel in between the soil and rocks. Continue installing riprap 3-4 feet up the bank.

- Slope the soil back into the bank at a 45° angle, such that the bottom of the soil slope is in the vadose zone. Place a layer of willow cuttings on top of the soil, with the butt ends extending into the vadose zone, and the tips of the branches sticking out 1-2 feet.
- Place the next layer of stones on top of the initial rocks, but graded slightly back, and repeat the soil and brush layering process. When finished, trim the ends of the willow branches back to 1 foot. Do not cut shorter than 1 foot, as the plant will have difficulty sprouting.

Method 2:

- Lay the bank slope back to the desired finished grade, and dig a toe trench if self-launching stone is not being used.
- Place the largest rocks in the key-way, and fill in behind with filter gravel and soil. Continue installing riprap 3-4 feet up the bank.
- Place the bucket of an excavator just above the layer of rocks at a 45° angle. Pull the bucket down, still at a 45° angle, until the water table is reached, or the stream is dry, to the elevation at the bottom of the key trench. Pull up and back on the bucket; this will provide a slot in the bank into which willow poles can be placed.
- Throw in some willow poles (about 6 poles per linear ft), ensuring that the butt ends are at the bottom of the trench.
- Release the scoop of earth, and allow it to fall back in place on the slope. Then place the next layer of rock on top of the branches, flush with the slope. If self-filtering stone is not being used, filter gravel should be placed behind the rocks. Repeat the process, beginning again with pulling back a scoop of soil. Continue this process to the top of the slope, or if preferred, use joint-planted riprap on the upper slope, where it is difficult to reach the perennial water table with the excavator bucket.
- When finished, trim the ends of the branches back such that only 1 foot extends beyond the revetment.

Limitations

- Vegetated riprap may be inappropriate if flow capacity is an issue, as bank vegetation can reduce flow capacity, especially when in full leaf along a narrow channel.
- In remote areas large rocks may be difficult to obtain and transport, which may greatly increase costs.
- Riprap may present a barrier to animals trying to access the stream (WRP, 1998).

Flanking, overtopping or undermining of the revetment due to improperly installed or insufficient keyways is one of the biggest reasons for failure of riprap. Improperly designed or installed filter material can also cause undermining and failure of the installation. Undersized stones can be carried away by strong currents, and sections of the revetment may settle due to poorly consolidated substrate. Vegetation may require irrigation if planted in a non-dormant state, or in extremely droughty soils. Also, vegetation may be limited by excess soil moisture (Pezeshki et al., 1998).

Photo series showing installation of Vegetated Riprap with Bent Poles.

Inspection and Maintenance

Riprap should be visually inspected following any 1-year return interval or greater flow, with focus on potential weak points, such as transitions between undisturbed and treated areas. Soil above and behind riprap may show collapse or sinking, or loss of rock may be observed. Inspect riprap during low flows annually, to ensure continued stability of the toe of the structure. Treat bank (or other slope) or replace rock as necessary.

Also note any channel or habitat impacts that result from riprap installation and treat as needed.

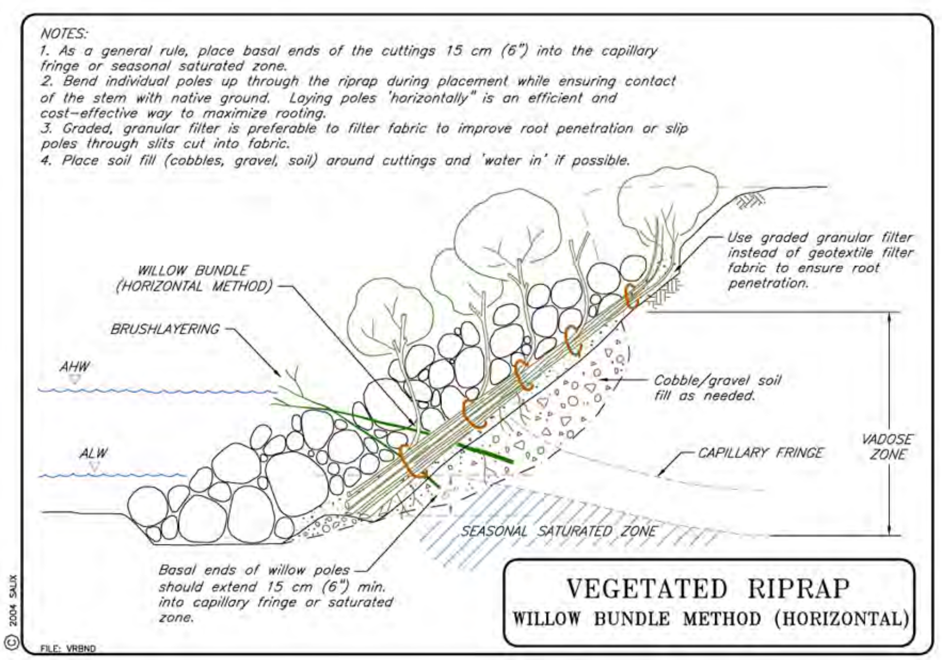


Figure 10-7. Vegetated Riprap, Willow Bundle Method (Horizontal)

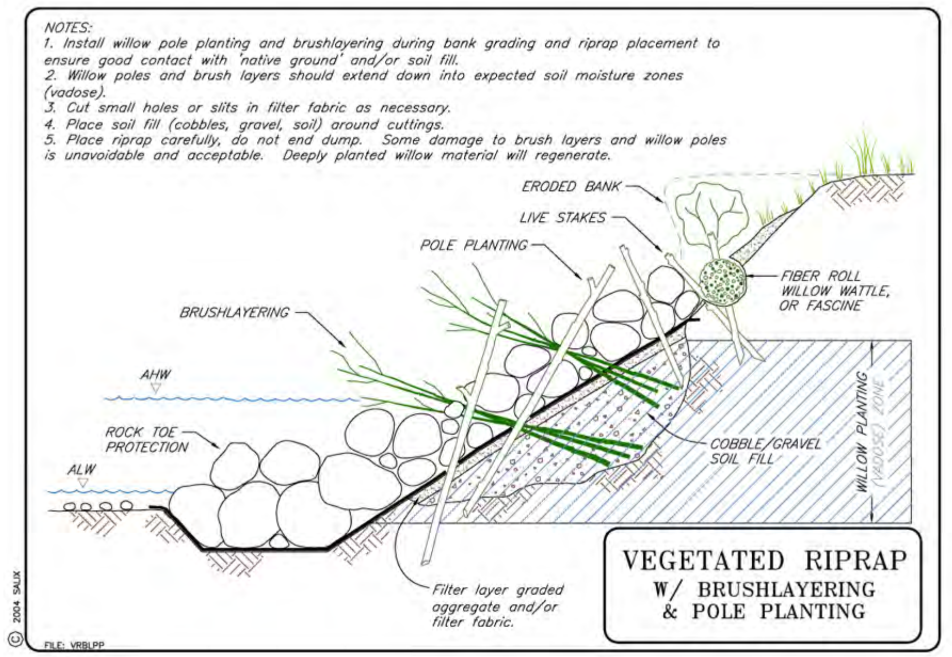
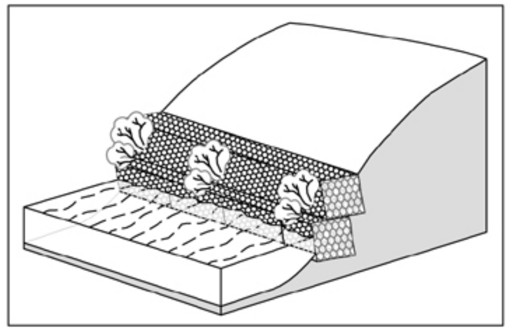


Figure 10-8. Vegetated Riprap with Brushlayering and Pole Planting.

RR-6 Vegetated Gabion Basket

SWPPP Summary



Vegetated gabions are used as pervious retaining and armoring structures, culvert outlet or inlet stabilization, and as flexible toe-walls that reduce the steepness of slopes or streambanks. This technique is typically used where large rock is unavailable, as gabion baskets filled with small rocks can resist higher tractive forces than the rocks would normally be able to withstand without wire reinforcement.

Vegetated gabions are mitigation for unvegetated gabions. Besides providing habitat enhancements, vegetating gabions with woody plants during construction will increase longevity of the structures.

Definition / Purpose

Gabions are rectangular baskets made of triple-twisted hexagonal or welded-wire mesh of heavily galvanized, and sometimes poly-vinyl chloride coated, steel wire. Gabions are delivered as flat wire panels that are folded into the basket form, filled with rock, and laced shut. Vegetation can be incorporated by placing cuttings through the mesh of the basket during filling, or between the baskets after the baskets have been laced shut (McCullah, 2004). These pervious structures can be used singly or stacked like building blocks.

Vegetated gabions are reinforced by the vegetative elements, have increased geotechnical strength, exhibit increased longevity (get stronger with time) and benefit the ecosystem by providing habitat, shade, cover, organic detritus, etc.

Biotechnical Stabilization:

Plant materials combined with structural elements in a *mutually-reinforcing* manner.

Live rooting branches may be placed between and through the rock-filled gabion baskets. This will anchor the gabions to the bank, and protect the wire from corrosion and abrasions while providing habitat and ecosystem benefits.

Planning Considerations

Gabions are often recommended for sites where either there is insufficient supply of large angular stone or where the bank must be constructed at an angle steeper than the angle of repose (greater than 1V:1.5H) therefore reinforcement is necessary. The gabion baskets can be stacked to construct relatively high banks. Gabions can also be used to armor the bed and/or banks of channels, or as deflectors or groins that divert flow away from eroding streambank sections. Gabions are useful where flow velocities exceed 6 ft/sec, and where vegetative streambank protection alone is not sufficient. These structures can also be used to stabilize culvert outlets or inlets, or to provide a flexible toe-wall and reduce steepness of slopes or streambanks.

> **Gabions are often specified if sufficient large rock is not available in the area. Gabions can be used to stabilize culvert outlets and inlets. It is best to incorporate vegetation into gabions as they are being constructed (not as an afterthought), as it is very difficult to vegetate them after they've been assembled and filled with rock.**

Other Considerations:

- Gabions are often specified if sufficient large stone is not available and/or when the final slope is too steep (>1:1) for rock without mechanical reinforcement.
- According to a Caltrans durability study, gabions, unprotected by woody vegetation, have an average life of 15 years. After that time abrasion and corrosion can combine to fail the wire. Vinyl coating increased longevity by 5-7 years (Racine and Hoover, 2001).
- If gabions are used below bank-full elevation, they will be subject to abrasion and should be protected when feasible by rock and or willow/cottonwood pole plantings.
- Gabions can support vegetation, especially willow pole plantings, if special construction techniques are employed.
- Gabions can be cost-effective when using local, commercially available stone fill.
- Gabions require less tonnage of stone than riprap – as gabion thickness is approximately 1/3 that of comparable riprap.
- They are flexible and durable if properly maintained.
- Gabions can be stacked to obtain near-vertical side slopes where right-of-way is limited.
- Gabions are flexible and can adjust to minor substrate settling.

Stability:

Gabion basket walls should be installed with a batter of at least 6° from the vertical into the slope. Two options are available for achieving this batter, as shown in Figure 10-11:

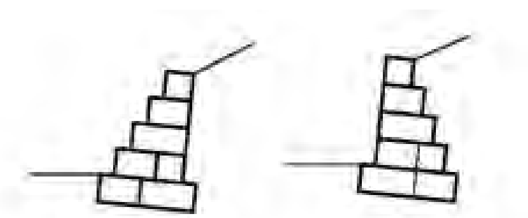


Figure 10-11. Front step and rear step gabion layouts (from Freeman & Fischenich, 2000).

Construction Specifications

Materials needed include gabion baskets, hog-ring staples and stapler, stiffeners or corner ties, rock for gabion fill, filter fabric or gravel, woody cuttings.

Filter Material:

An important consideration when installing gabion baskets is choice of filter material. Filter material prevents migration of soil through the installation, which could lead to undermining, settlement or flanking, and subsequent failure. The only time that filter material may be omitted is when the foundation material clearly does not need it (Freeman & Fischenich, 2000).

A 2001 Caltrans study (Racine and Hoover, 2001) indicated gabions last an average of 15 years until succumbing to the effects of corrosion and abrasion.

Vegetated (willow pole) gabions at the toe of a highway cutslope in Trinity Hwy 299W. The deeply planted willow pole plantings are at 3000' elevation and have survived four summer seasons (100° F plus).

Rock-filled gabion basket "check dams" failed after 15+ years in Corral Hollow Creek, Carnegie SVRA.

Gabion wire is abraded by stream sediment and corroded by water until the structures fail. (J. McCullah photos)

There are several choices for filter material; one can either use filter fabric, a gravel or sand filter, or a combination of these two. Filter fabric is commonly used; however, vegetative roots may not penetrate filter fabric. Therefore, a sand or gravel filter is the best material to use when installing vegetated gabion baskets or mattresses.

If using a filter fabric, it is important to use a non-woven fabric (6 oz is recommended), as woven fabrics have poor flow-through properties, and can actually lead to increased erosion from bank, due to fabric movement. The composition of all filter blankets should be based on site-specific conditions. Filter designs can be found in Brown et al., 1998.

Filter Material

It is *not* recommended, nor necessary, to use geotextile filter with pole-planted vegetated gabions. Use a "graded" permeable sand and aggregate filter that can allow root penetration.

Another important consideration when designing a gabion wall is how to protect it against scour. The bottom-most rank of baskets should ideally be placed below the expected maximum scour depth. If this is not feasible, gabion mattresses (scour apron) can be placed at the toe to drop (self-launch) into any scour holes that occur. The scour apron is generally made from a gabion mattress (12 in-thick) instead of a basket. It is critical that factors such as scour depth be determined for each particular project and be incorporated into project design. Overall height of gabion structures should not exceed 9 feet, including the toe.

Rock sizing:

Freeman & Fischenich (2000) and Racine and Hoover (2001) provide rock sizing guidelines.

Thickness	Filling Stone Range	D_{50}	Critical Velocity	Limit Velocity
1.5-3 ft	4-8 in	6 in	19 ft/s	24.9 ft/s
1.5-3 ft	5-10 in	7.5 in	21 ft/s	26.2 ft/s

Table 10-3. Rock sizing based on expected velocity. (From Freeman & Fischenich, 2000)

Wire type:

There are several different types of wire mesh available for gabions. The first choice to make is welded-wire vs. twisted wire. Racine & Hoover (2001) found that there was no significant difference between the two types in terms of load bearing ability, flexibility, or deflection. Another choice that must be made is whether to purchase PVC-coated wire, or zinc-coated (uncoated) wire. Table 10-4, based on 16 years of observation, indicates expected life-span of the two choices in a variety of conditions. The life-span was determined when the wires lost half of their strength, wires disintegrated, or other loss of function occurred. The designer should match the desired lifespan of the structure with site conditions to determine whether or not coating (and its accompanying higher costs) is necessary.

Site Conditions	PVC	Zinc
Vandalism (wires cut, rocks emptied)	1 year	1 year
Creeks, streams and arroyos with storm runoff that conveys abrasive soil particles and debris, corrosion (erosion of corroded compounds), or cyclic rising and falling water levels	9-15 years	9-15 years
Fresh water, stagnant pools with low dissolved oxygen	16+ years	10 years
Saturated soils	16+ years	10 years
Freshwater sites with intermittent, channelized storm runoff and/or streams that transport little or no suspended particles greater than 0.074 mm and/or low velocity water with low conductivity and high dissolved oxygen	16+ years	16+ years
Well-drained and/or dry soil	16+ years	16+ years
Atmosphere	16+ years	16+ years
Rock fall impact that could break wire	16+ years	16+ years

Table 10-4. Life-Span Comparison Between PVC-Coated Wire and Zinc-Coated Wire.

Vegetation:

There are two methods used to vegetate gabions; pole planting and brushlayering. Pole planting, where branches are inserted through the basket mesh during filling, helps to anchor the baskets to the slope, while simultaneously enhancing aesthetic appeal. Install 1 pole per foot, with a minimum of 3 poles per basket. Brushlayering, where branches are placed between the basket layers, is a very quick technique that enhances aesthetics and habitat. The gabion basket provides all geotechnical stability necessary for the slope, so for brushlayering, 2 branches per foot should be sufficient for aesthetic and habitat benefits.

Live materials consist of poles, branches or cuttings that are ½ to 1.5 inches in diameter and long enough to reach beyond the back of the rock baskets. Consider deeply planted Poplar sp. (cottonwood) when appropriate.

Design and install gabions on firm flat soil beds in accordance with manufacturer's standards and specifications. Include pole planting and brushlayering techniques during construction. Install the brushlayers between the gabions in such a manner that the branches extend beyond the baskets and the butt ends are in contact with the native soil behind the baskets. Live poles can be placed through the baskets, "toe nailed" into the slope, before the baskets are filled with rock. After inserting poles through the basket and into the slope, backfill the basket carefully and fasten the lid. Install another brushlayer between subsequent baskets.

The following further installation guidelines are derived from Gray & Sotir (1996); Freeman & Fischenich (2000); McCullah (2004); and USDA (1996):

1. Remove loose material from the foundation area, and excavate a footing area as deep as specified in plans (typically 2-3 ft). The key trench should be uniform, and slope down into the bank at least 6° from the horizontal.
2. Install filter material (fabric or gravel) as specified by manufacturer. Filter gravel should be installed to a uniform thickness; compaction typically is not necessary.
3. Assemble the gabions as specified by the supplier, and position them according to plans.
4. Once the gabions are in place, fill them halfway with rock and insert poles at the density specified. They should be inserted through the basket, with the growing tip higher than the butt end; the butt end should extend far enough into the substrate behind the gabions to reach the vadose zone. Fill the basket the remainder of the way with rock, close lid, and lace it shut.
5. Rocks should be placed carefully, so as not to damage gabion wires. If necessary, stiffeners or corner ties should be installed during filling. Typically, 1 foot of rock is placed; stiffeners are installed; the next layer of rocks is placed; and so on.
6. Once the first rank of baskets is installed, brushlayers should be placed at the designed density, with the butt ends extending far enough into the substrate behind the gabions to reach the vadose zone. The 6° minimum batter into slope will ensure that growing tips are elevated above butt ends.
7. Backfill behind the gabions and compact to ensure optimum stem to soil contact prior to installing the next rank of baskets. Baskets should be placed such that vertical joints are staggered (as shown in design guidelines).
8. Repeat this sequence until the wall is the desired height.

Limitations

Costs for gabion baskets are high. Installation is labor-intensive. Gabions are very difficult to vegetate after they have been assembled and filled with rock. It is moderately more difficult to plant the branches and staked through filter fabric. Use a filter layer of graded aggregate or sand instead of geotextile fabric, if possible.

Inspection and Maintenance

Baskets require significant monitoring and maintenance to identify wear before failure occurs. Gabions should be checked regularly for broken wires, and repaired immediately if necessary, to prevent loss of rock from the structure. The structure should also be monitored for signs of undermining or flanking. Should any damage be found, corrective measures should be taken. The area should also be monitored for any signs of geotechnical failure, such as shifting or bulging away from the bank or slope.

Morrow Creek, Morrow Bay, CA (March 1999). Scour apron being planted with Live Staking "after the fact". It is very difficult to plant gabions after construction.

July 2000. After the first winter the scour mattress "dropped" into place as designed and a few willow stakes successfully established.

This rock-filled gabion has a 10 year-old willow tree growing through it with no deformation or "lifting". There is ample proof that woody vegetation will only reinforce gabions, not cause structural compromise.

Vegetated gabions after only 4 months (Branciforte Creek in Santa Cruz County). The willow poles were inserted through the baskets during construction, then backfulled with rock. (J. McCullah photos)

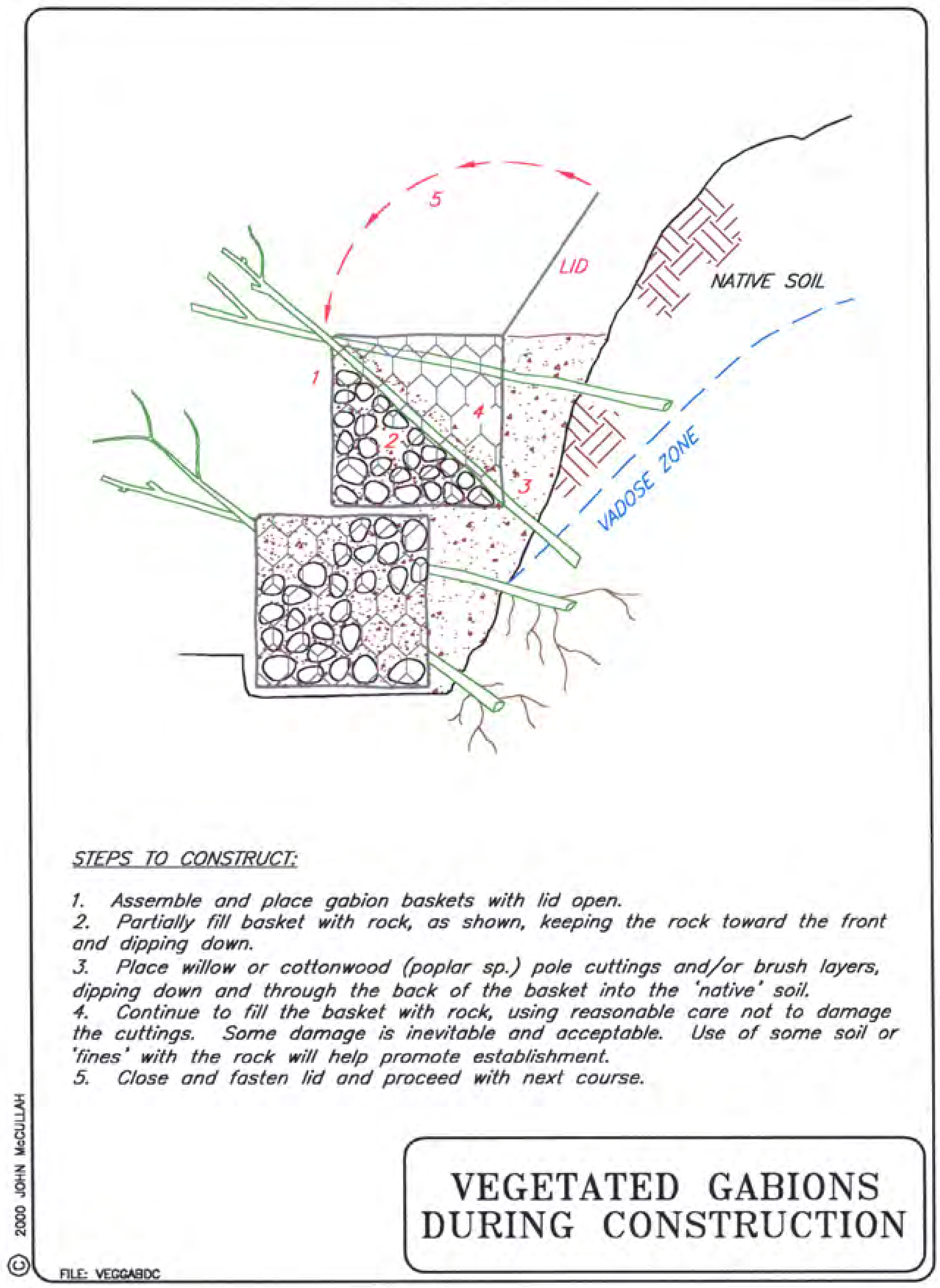


Figure 10-12. Vegetated Gabions During Construction.

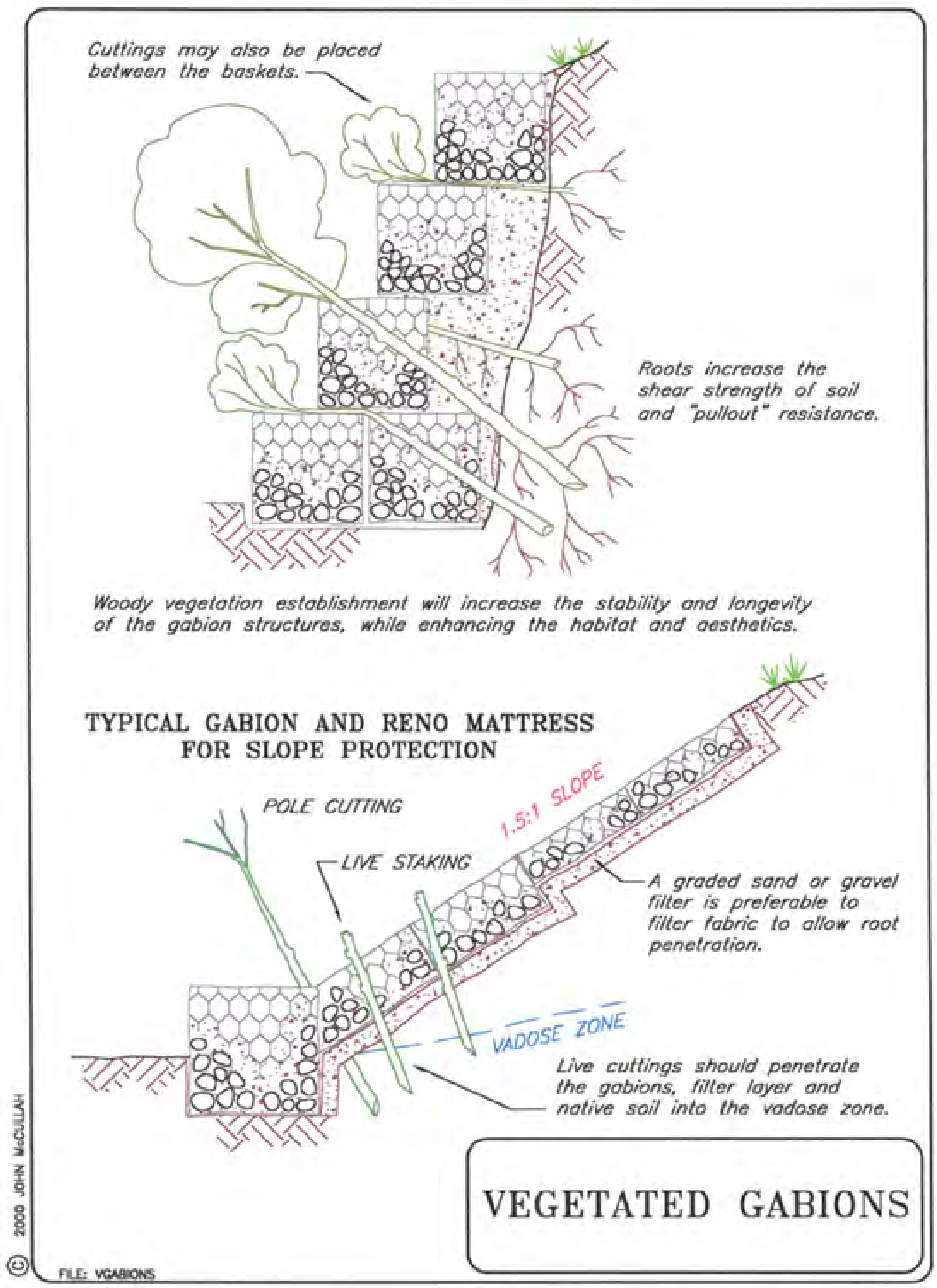
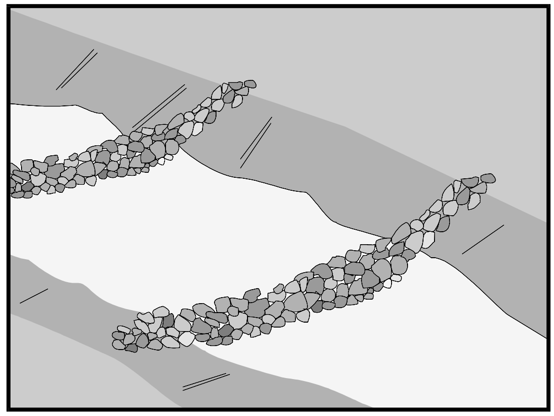


Figure 10-13. Vegetated Gabions.

RR-7 Gully Repair

SWPPP Summary

When gully erosion rates and sediment yeild are excessive, gully repair becomes imperative. Gullys are complex and RR-7 Gully Repair usually consists of a combination of techniques for stabilizing these eroding intermittent or ephemeral channels. These repair techniques include identifying and minimizing the source of concentrated flows, installing drainage measures as required, preventing further downcutting, grading the disturbed soils, and applying soil stabilization techniques.



Definition / Purpose

Gully repair (for the purpose of improving water quality) will necessarily focus on the erosion processes, relative erosion rates, and sedimentation or sediment yield. For instance, headcutting and downcutting have much higher erosion rates than raindrop, sheet and rill erosion of the gully sides. Moreover, gullies (even large gullies) that have been "de-watered" may have a greatly reduced sediment yield, such that extensive treatments may not be necessary.

Gully erosion involves multiple processes that can occur at the same time (Schumm et al., 1984). Gully erosion is caused by channel *downcutting* (incision), *headcutting*, and mass wasting (*widening*) of gully sides. Effective gully control and repair requires an understanding of each process acting individually and/or in tandem (Heede, 1976). The purpose of gully erosion control, in general, is to arrest and/or mitigate these degradational processes.

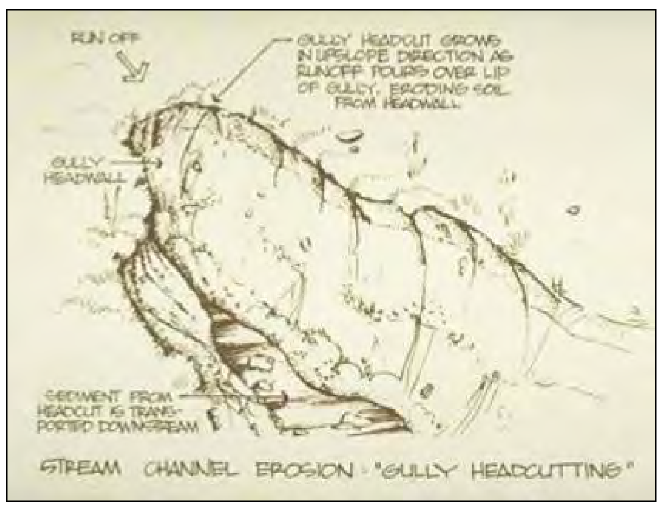


Figure 10-14. Gully erosion is complex; involving multiple failure processes.

Planning Considerations

Gully erosion is most commonly anthropogenic (human-caused) in origin. Alterations in watershed hydrology from various land uses, e.g., road and trail building, extended grazing, burgeoning impermeable surfaces, and agricultural practices, often result in unnatural and concentrated flows. The increased flows trigger the gully erosion process.

The primary failure mechanisms for gully formation and growth are:

- Downcutting
- Headcutting
- Widening

First, the channel incises (*downcuts*) in response to increases in flowing water (runoff). The *tractive forces* exerted by flowing water are the physical process that detaches the soil or rock. Besides *downcutting*, the gully will then grow longitudinally by the mechanism of *headcutting* at the "head" of the gully – where the runoff actually falls down into the newly-incised channel. The *potential energy* of falling water is the physical force that erodes a scour pool which continually undermines the headcut and allows the gully to "march upslope". As the gully continues to downcut it will also experience *widening* - the sides become over-steepened, are undermined by flowing water and eventually collapse due to *gravitational forces*. The widening of the gully banks can also be exacerbated by "*sapping*" (the release of subsurface flows out the face of the bank), by the headcutting of tributary gullies, or a combination of both.

Gully repair will often necessitate techniques designed to arrest downcutting and headcutting. Gully widening can usually be addressed by mechanically laying the banks back to a stable angle and revegetating the soil.

Continuity Equation, Q=AV

The overall size and dimensions of the gully is a relative indication of the amount of concentrated flows carried or drained by the gully. It is helpful to try and picture the gully flowing during an erosion-causing discharge – the depth of flow is probably ¼ to $^{1}/_{3}$ the depth of the gully. Anything that can be done to reduce the quantity of flow will decrease the gully erosion process.

Continuity Equation

Q = A x V

Q = discharge
A = channel cross-sectional area
V = velocity

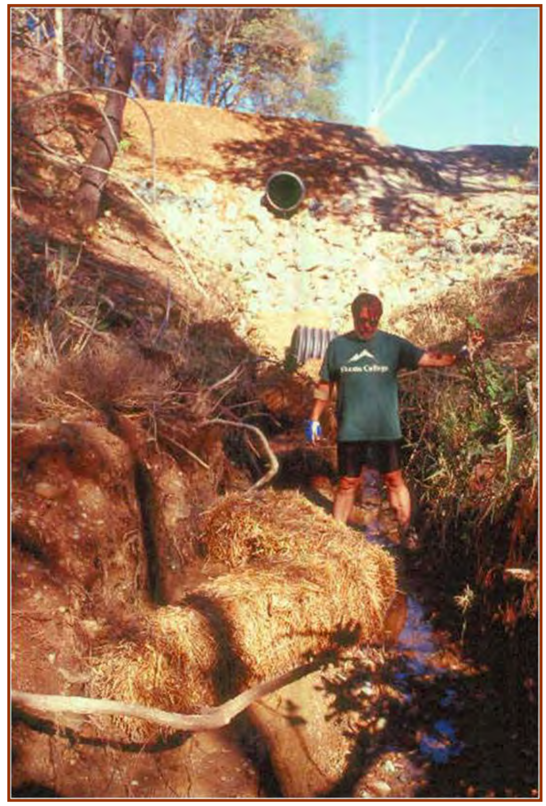
The **Continuity Equation** (Q = AV) predicts that as the runoff or discharge (Q) increases, so then must the channel area and/or flow velocity also increase. Usually what happens is the velocity increases. But as the velocity within the channel increases, so does the *erosive energy*. The **Energy Equation** (Erosive Energy ≈ $E=mV^2$) shows that erosive energy increases as the square of velocity, e.g., if velocity is doubled, then the erosive energy of the flowing water increases fourfold! This erosive energy will facilitate the channel to increase its' cross-sectional area – the gully will deepen and widen!

The Continuity Equation also predicts and describes the significant risks associated with placing check dams in a gully. For example, say you do nothing to reduce Q but you construct a check dam in the gully. A check dam will essentially reduce the channel cross-sectional area at that locale. If Q is constant and A (area) decreases, then V (velocity) has to increase proportionally. As velocity increases the erosive energy increases exponentially.

The risk associated with check dams is the tremendous erosive energy that can work on any opening that occurs at the side or bottom of the check dam.

Rigid and inflexible check dams that are difficult to anchor, such as those made with logs, gabions, straw bales, or geotextiles (silt fence) are extremely risky and quite often result in even more erosion! Check dams made from self-adjusting rock that are relatively low (small reduction in cross-sectional area) will not have the acute risks associated with their use.

Check dams made from logs or other rigid materials often result in failure and increased gully erosion.



The cross sectional area of this gully increased (eroded) due to the straw bale check dams.

Drainage

Gully repair is first and foremost a **drainage** issue. Successful treatment should include the **4 Ds;** 1. **D**e-water; 2. **D**ivert; 3. **D**isperse; 4. **D**issipate.

The first step to gully repair is to identify the source of concentrated flows and "*de-water*" the gully to the maximum extent possible. Sometimes the best you can do is to *divert* some of the runoff into another drainage area. However, care must be taken not to cause erosion in a new area.[**] It is often preferable to implement multiple diversions – dividing the concentrated flows until they are sufficiently reduced and thereby non-erosive.

When roads and trails are causing gullies, the best way to bring about multiple diversions, or *disperse* the runoff, is to outslope the road (think of it as "infinite diversions") and install multiple rolling dips.

De-water the Gully

Always attempt to divert, dissipate, or disperse the concentrated flows. De-watered gullies will no longer headcut or downcut. Conversely, gullies with reduced flows will have greatly reduced sediment delivery.

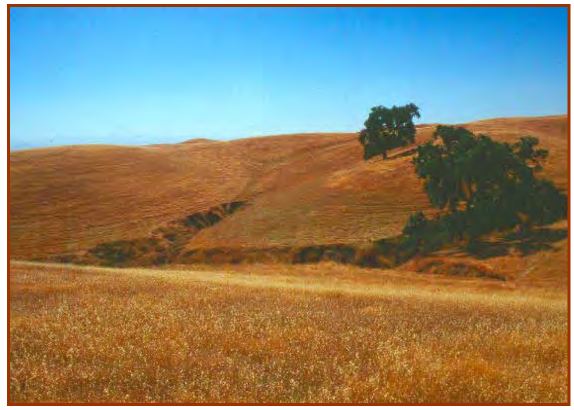
Gullies that cannot be dewatered will require additional measures such as grade control, drainage, and/or channel lining.

The gully causing runoff on this road/trail can be dispersed by outsloping the trail.

The same trail section after outsloping.

Another way to reduce the flows into a gully is to *dissipate* the runoff. The most common way to dissipate the runoff is by de-compacting the soil within the watershed area, as much as practicable. Increased infiltration rates will have a direct influence on reducing runoff. Less runoff results in less gully erosion. This is one reason why replanting disturbed areas with California perennial, native grasses is so important. These deeply rooted grasses greatly increase the soils' infiltration rates, permeability, and water holding capacity.

[**] The practice of "relieving" a roadside ditch or outletting concentrated flows onto a ridge line or onto a bunch of vegetation is not recommended. All too often this practice results in gullies also, just in areas which never had water flow in the past. Always try to release road drainage into natural drainages or swales.



The upper left gully was once a road! The gullies shown are all in heavily grazed environments. Decades of livestock grazing (sheep and cattle) have resulted in compaction (cow pans) and "vegetation-type conversion" - from deep-rooted native perennial grasses to shallow-rooted annual grasses. The hydrologic impacts from these intensive land-uses in the dryland areas of California are significant.

Repair

The repair and rehabilitation of the gully areas can take place after the causes of the gully (the drainage problems) have been addressed. The type of and level of repair effort is dependent on how successful the dewatering endeavor was.

If *dewatering efforts are successful* and will *substantially reduce future erosive flows*, then the prescribed repair treatments might include:

1. Do nothing as the downcutting and headcutting will be greatly reduced. Also the potential for sediment yield and downstream sedimentation is also greatly reduced. There is a high likelihood that over-steepened banks collapse until a relatively stable angle is achieved.
2. Mechanically lay the banks back to a stable angle of repose, usually 2:1, and plant the banks with native grasses, mulch and amendments. Refer to SS-1 Surface Roughening, SS-3 Mycorrhizae Inoculation, and SS-4 Seeding for more information.

3. Lay the banks back as in #2 previously, but also grade (widen and shape) the bottom of the channel to accommodate the expected flows. Line the channel bottom with appropriately-sized rock or vegetated TRMs selected for the design shear (velocity). Refer to RC-2 Rock-lined Channels and RC-4 Turf Reinforcement Mats / Grass-lined Channels for more information.
4. Fill the channel in and revegetate it. This work requires heavy equipment to re-grade and shape the features and then apply the Soil Stabilization (SS) BMPs.

If the dewatering efforts *did not completely reduce the erosive flows*, there are some techniques that can useful. These techniques generally fill the gully, at least partially, with soil, stone, and/or bioengineering materials that are intended to provide increased "hydraulic roughness" (decreased velocities) and reinforce the fill material. These techniques might include:

1. Fill gully with stone or graded (poorly sorted) rock. Filling the gully with rock will also counteract mass wasting of the side banks and the "sapping" at the headcut and at the banks. When using stone, or any other type of fill, make sure to leave adequate cross-sectional area to accommodate the flows.
2. Fill gully with *Straw and Ballast Rock*. This technique is experimental. Rock of sufficient quantity is sometimes in short supply. Smaller gullies, partially dewatered, can be filled (packed) with straw and rock. The straw will be essentially filler material and the rock will provide ballast. The materials will be mutually reinforcing while providing hydraulic roughness. The roughness will hopefully reduce erosion and encourage sedimentation and eventually some natural vegetation recruitment.
3. The Live Gully Fill Repair method (Gray and Sotir, 1996) is a biotechnical or bioengineering method similar to branch packing (a method for filling small holes and depressions in a slope) but is more suitable for filling and repairing elongated voids in a slope, such as gullies. As stated above, gully fill techniques will counteracts mass wasting of the gully sides and spring sapping at the gully head. Filling will only be successful, however, if the fill is suitably reinforced, seepage and overland flow into the gully diverted or intercepted, and the gully base level at its lower end stabilized.

If the gully *could not be dewatered sufficiently,* then treatments intended to specifically arrest the downcutting and headcutting are required. These techniques usually require rock.

1. *Rock check dams:* These structures are intended to be "grade control" structures, meaning they are intended to stop downcutting and incision. Rock check dams can be permeable, allowing low flows to slowly pass through. However in gullies with high erosion and sedimentation the rock will eventually infill with fines.
2. *Headcut structure:* A headcut structure is often referred to as a *drop structure*. This structure is intended primarily to carry the runoff from an area of high potential energy, above the head scarp, to the bottom of the gully while preventing further erosion and scour. This can be accomplished several ways:

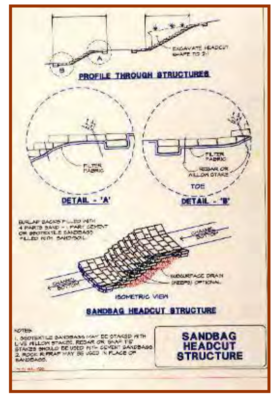
i. A pipe drop or over-side drain.

ii. Grading the head scarp back to a stable angle and lining the channel with TRM and possibly an energy dissipator at the bottom.

iii. Building a headcut structure out of rock or gravel bags.

iv. The headcut structure above can have biotechnical elements integrated so the structure grows and gets stronger with time. Refer to RR-2 Live Staking, RR-4 Live Fascines, and RR-5 Vegetated Rip Rap.

Gully headcut in heavily-logged Grass Valley Creek watershed.



Typical Drawing from Erosion Draw 5.0.

Headcut structure made from soil/cement sandbags structures.

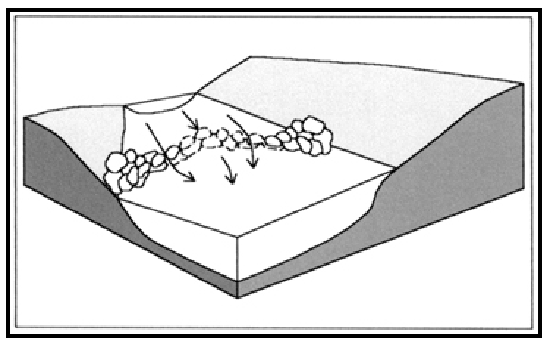
Headcut structures take runoff safely from high potential to low potential areas.

Construction Specifications

For gullies that cannot be substantially dewatered:

- Observe and make note of the gully's average cross-sectional area. The final treatment should maintain or provide for an enlarged cross-sectional area. Remember that increased (A) area will reduce (V) velocity and thence erosive energy; Q = AV.

- Proceed upstream to ascertain the source or cause of the concentrated runoff. Can discharges be reduced or are there watershed-scale impacts that defy simple 4-D treatments?
- Make a note of the gully headcut and/or other nick points. A gully can have multiple headcuts. A focused treatment plan will be required at these points. If you can stop the gully from lengthening you have won half the battle.
- If the gully is actively downcutting, (as indicated by over-steepened and bare banks, and the noticeable lack of deposition), then grade control is in order.
- Grade control structures, widening the bottom width and sloping back the banks, and developing a meandering flow pattern (planform) are all strategies that will reduce downcutting and provide grade control. Doug Shields, prominent hydrologist, always said, “The best grade control is a natural meander bend”.
- However, the most feasible grade control is usually a check dam. Rock is the preferable check dam material because it is self-adjusting.
- Construct the check dams from graded stone (poorly sorted) as the varied gradations will help the stone lock together while reducing scour and subsequent failure.
- The rock check dams should be constructed relatively low. As a general rule, rock check dams should not be more that 3-4 ft high for medium to medium large gullies (9-15 ft deep).
- Build the check dam across the gully perpendicular to the flow direction. The rock can be constructed straight across the gully or with a vortex pointing upstream and dipping. This configuration directs the flows to the center of the gully.
- Lay the rock with a triangular cross section at a 3:1 maximum angle. It is preferable to make the downstream side (spillway) with an even shallower angle, 4:1 to 10:1.



Vortex weir type check dam with the vortex dipping down and pointing upstream.

- No end runs. The weir crest or vortex of the check dam must be at a lower elevation than the side elevations to ensure that the flows do not go around the dam and erode the gully banks.
- Check dam repair starts at the lowest reach of the gully and proceeds up channel. Build the first check dam the lower end of the gully reach needing treatment. Make sure the weir crest is low enough to pass high discharges. Shoot a “line of sight”, angled up at 1%-5% (depending on the gradient (slope) of the gully), from the weir crest up the gully. Where the “line of sight” hits is the approximate location for the 2nd check dam. Proceed up the gully in a similar manner.

- Construct a headcut structure or some other type of "drop structure" at the gully head scarp.
- The Scour Stop® system can withstand high velocities, can be vegetated and is relatively easy to install once the head scarp is graded back to a stable angle (2:1). Refer to RC-1 Energy Dissipator for more information.
- Seed and mulch all disturbed soils.

For Gullies that can be filled and repaired:

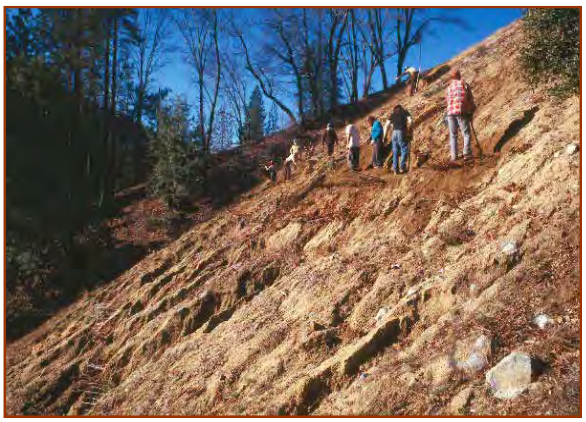
Live Gully Fill Repair (Gray and Sotir, 1996) consists of alternating layers of live branch cuttings and compacted soil. This technique should be used to fill small gullies in natural slopes and streambanks. Surface runoff entering the gully at its head should be intercepted and diverted away from the area. Refer to RC-4 Diversion Dikes and Diversion Swales.

- Use for gullies ranging in depth from about 1 to 6 ft deep to 30 ft long.
- This repair technique should only be used in channels or gullies with intermittent or ephemeral flows.
- The erosion processes at work in the incised channel, or "gully", must be correctly identified and understood to make a successful repair. For example, headcutting (erosion at a knickpoint or head scarp) from a culvert might be stabilized with a drop structure such as a slope drain or energy dissipator. Grade control and/or drop structures are necessary to stop the gully from growing in length (headcutting) or depth (downcutting).
- To prevent new headcuts from initiating, grade control, drop structures or energy dissipators (hard points) should be installed as needed. Refer to RC-1 Energy Dissipator.
- Fill placed in the channel should consist of graded and well drained soil.
- Use live branch cuttings ranging from 0.5 in to 2 inch in diameter. The branches should be long enough to touch the undisturbed soil at the bottom (back) of the gully and to protrude slightly beyond the rebuilt slope face.
- Imbedded branches and their secondary roots will reinforce the backfill used to repair the gully and protect it against future washout and scour.
- Side slopes might be graded back, stabilized with vegetation, and the surface runoff slowed with live fascines or fiber rolls.
- The use of additional reinforcement of soil lifts with geotextile or geogrid wraps may be considered in steep, critical gully channels.
- A subsurface drain may be required if significant amounts of seepage or groundwater still enters the gully at its head, or if substantial runoff cannot be diverted (see RR-4 Live Fascines, which can be used as subsurface drains).

Installation:

Live Gully Fill Repair begins at the lowest point in the gully and proceeds upward. The live branches are inserted between successive lifts of lightly compacted soil. The following guidelines and procedures (Gray and Sotir, 1996) are recommended when installing a live gully fill repair system:

- Starting at the lowest point of the slope, place a 3 to 4 inch thick layer of branches at the lowest end of the gully and approximately perpendicular to the gully bottom.
- Cover with a 6 to 8 inch thick layer of fill soil and compact.
- Place the live branches in a crisscross fashion. Orient the growing tips toward the slope face with the basal ends lower than the growing tips.
- Follow each layer of branches with a layer of soil; work and compact the soil to ensure intimate contact with the branches and to eliminate large voids in the fill.



Brush Packing or Live Gully Fill Repair uses soil and sometimes straw/soil mix to fill the gully. (J. McCullah photo, 1992)

Live Gully Fill Repair relies on the use of willow branches (and sometimes geotextiles) to provide soil reinforcement. (J. McCullah photo, 1994)

Limitations

- The limitation to rock check dams the ability to transport and deliver sufficient rock to remote area.
- Live fill can be subject to washout and scour if excessive groundwater or runoff saturates fill. Conversely, the plant material may not grow if there is insufficient moisture.

Inspection and Maintenance

- Periodically check on stability of gully fill, particularly during the initial vegetative establishment period. Make sure that runoff is diverted away from fill during initial stages.
- Inspect the gullies annually looking for check dam failures, continued incision, recent headcuts and bank failures, and sedimentation. The presence of vegetation and colonization are indicators that the gully system is improving.

This gully was filled, re-graded, and lined with soil-filled and vegetated TRM, designed for the 10-yr RI storm. (J. McCullah, 1992)

The soil-filled TRM (Enka Mat) protected the channel immediately. Reinforced with live staking. (J. McCullah, 1992)

The "Enka Mat Site" after 4 years. (J. McCullah, 1995)

The same site after 12 years. (J. McCullah, 2004)

This gully was dewatered and treated with a Live Pole Drain and Modified Brush Layers. (J. McCullah, 2003)

This landslide and gully repair, high above the Eel River, relied on modified Live Gully Fill Repair techniques. (J. McCullah, 2002)

The gullies were packed with *Live Pole Drains* (Live Fascines) to allow subsurface drainage.

Another technique used was *Modified Brush Layers*, a variation on Live Gully Fill.

After only two winters, the gullies and landslide scars are revegetating well. Native grasses were also used. (J. McCullah, 2004)

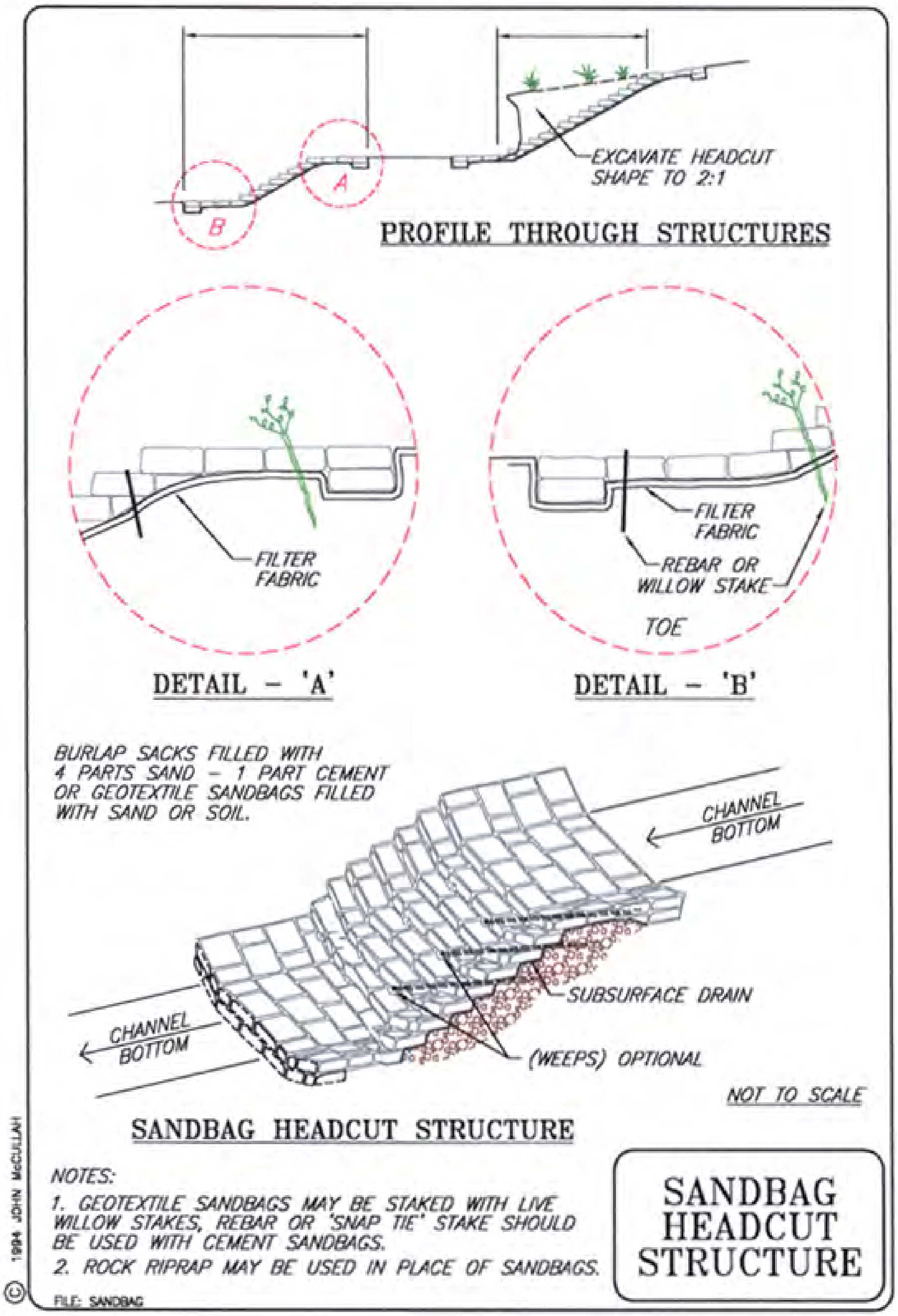


Figure 10-15. Sandbag Headcut Structure.

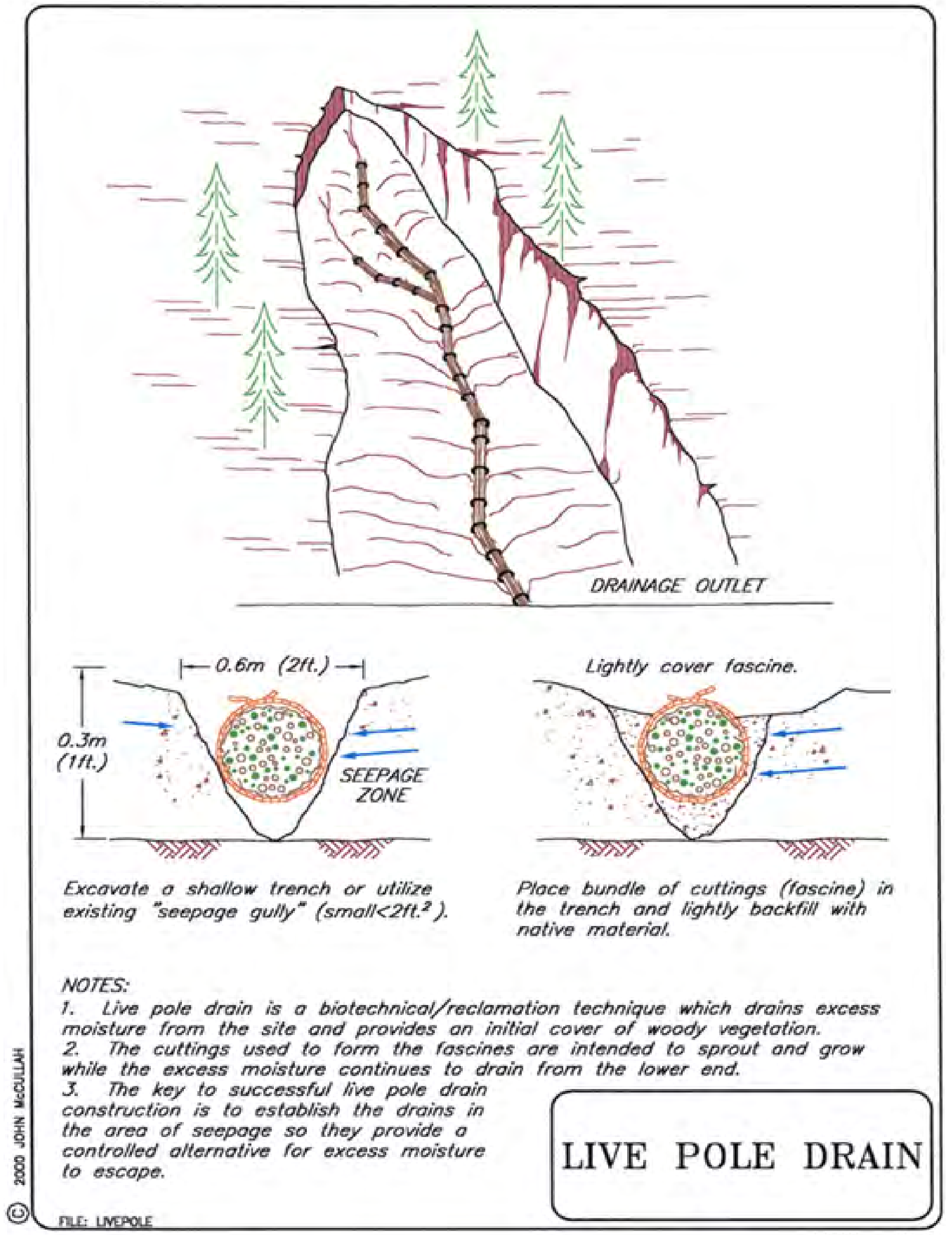


Figure 10-16. Live Pole Drain.

This gully could not be dewatered. It was re-graded and filled with rock, leaving sufficient cross sectional area for high discharges. (J. McCullah, 2003)

This rock check dam needs a lower weir crest to avoid "end runs".

Check dams installed at Carnegie SVRA have successfully arrested gully growth for nearly 20 years.

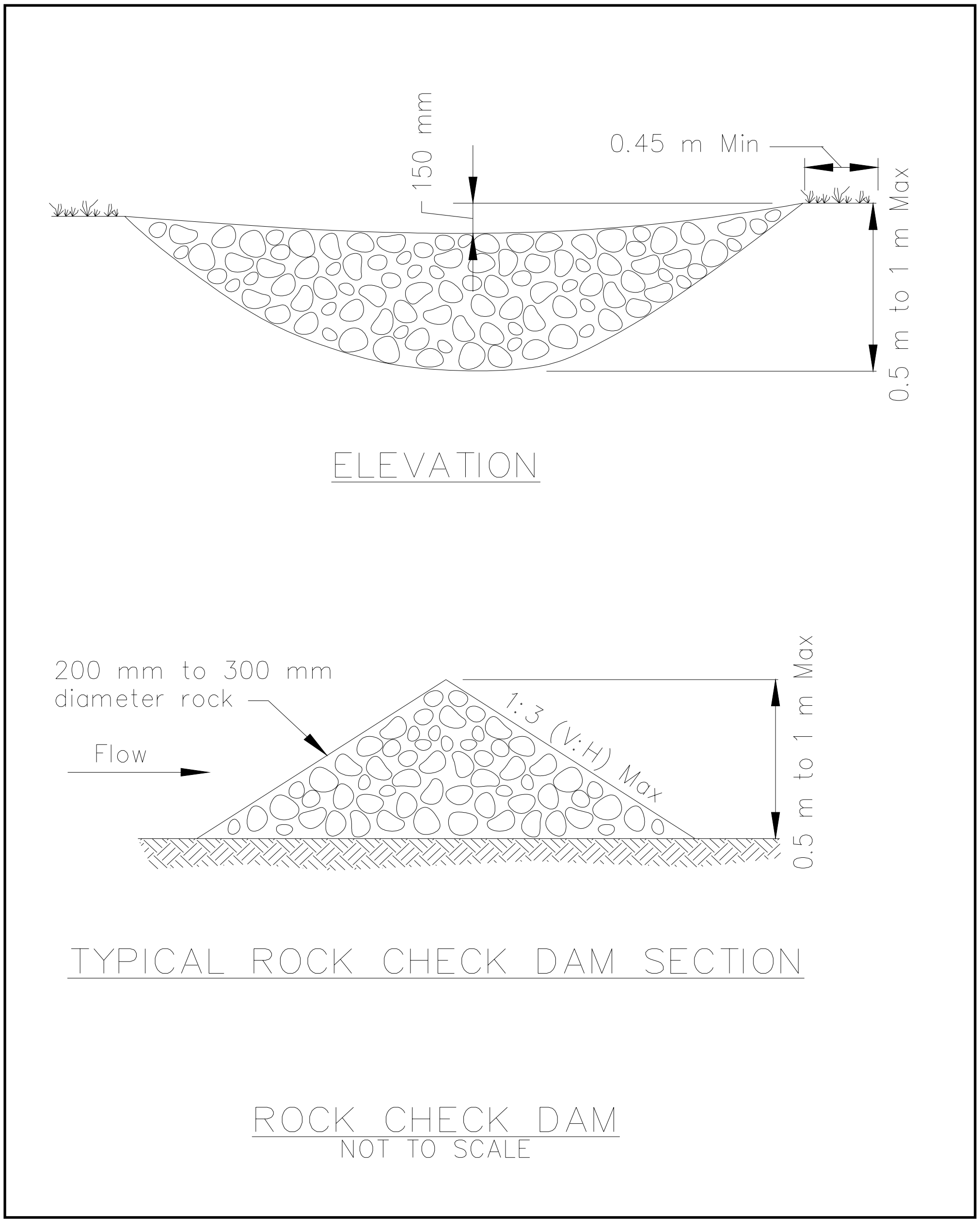
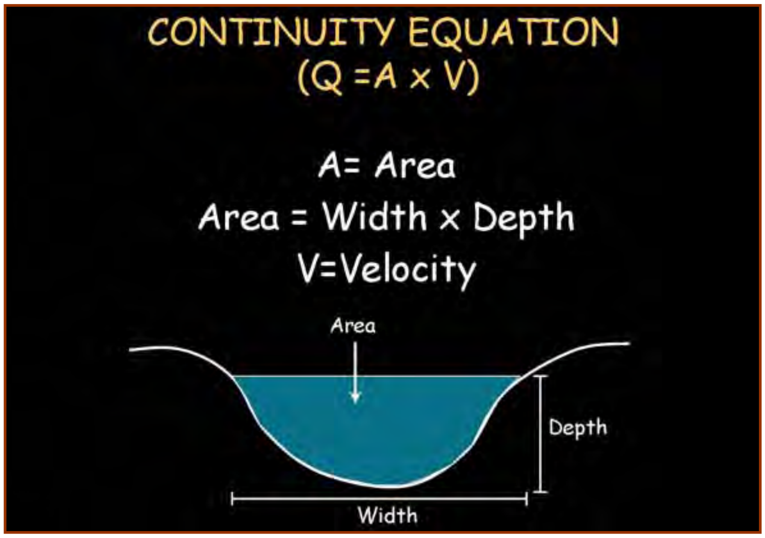
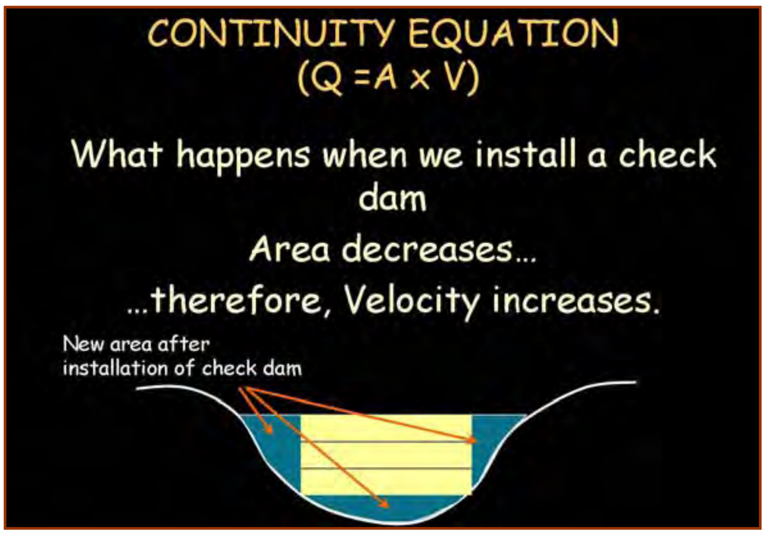
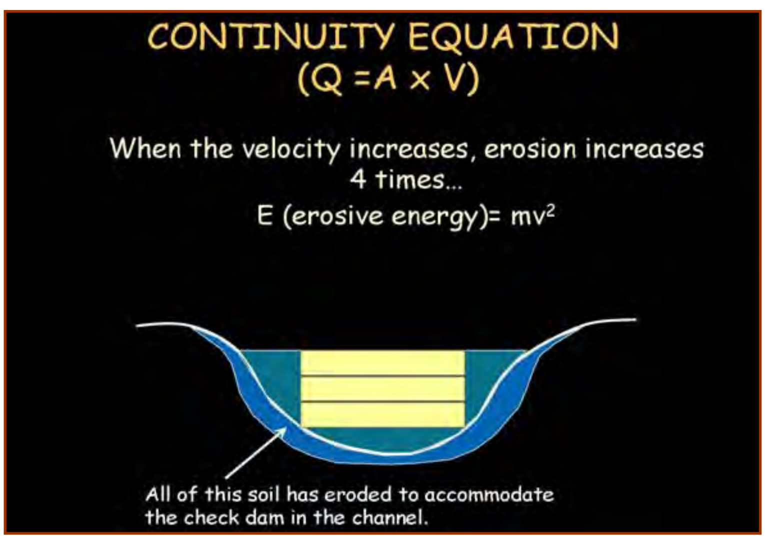


Figure 10-17. Rock Check Dam (from Caltrans, 2003).







The Continuity Equation predicts the risks associated with straw bale and log check dams. The treatment shown in the photo above is not recommended. Instead, de-water the gully (correct road drainage) as feasible, build headcut structure and then install graded control (rock check dams). Another alternative is re-grade, fill the gully (widen and lay-back banks) and line bottom with TRM.

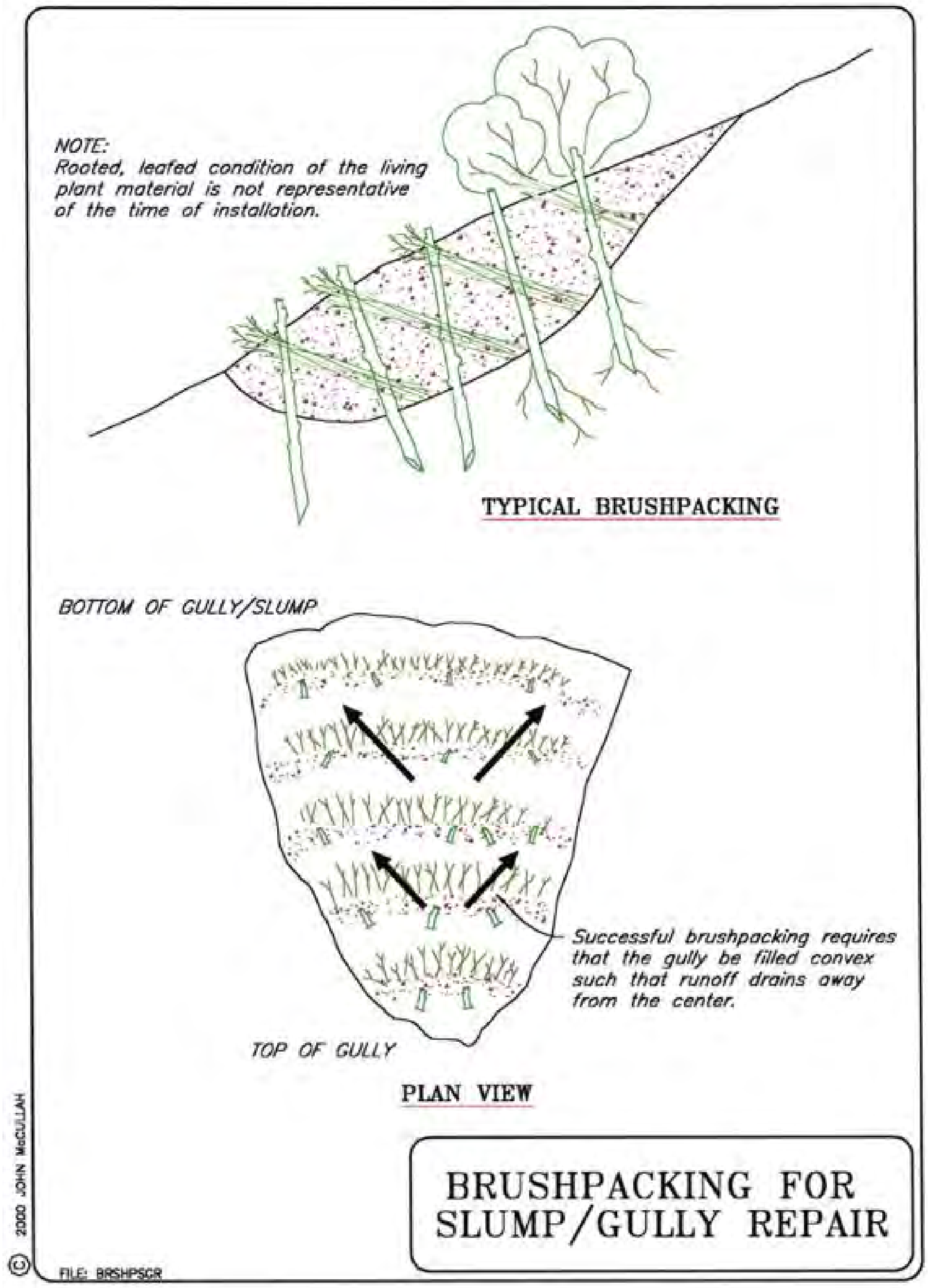


Figure 10-19. Brushpacking for Slump/Gully Repair.

11. PARK OPERATIONS AND MAINTENANCE (PO)

"Park Operations and Maintenance" BMPs include non-stormwater pollution control, waste management, inspection and maintenance of roads and trails, and visitor facility maintenance.

Many of these BMPs can also be referred to as "good housekeeping practices", which involve keeping clean, safe, well-maintained visitor facilities, while also preventing degradation of natural habitat.

Stormwater can become polluted by pesticides, paint, fertilizers, litter, oil, and other automotive fluids, and chemicals used to maintain Park facilities. Even small amounts of pollutants can be transported into nearby streams and cause harm to aquatic life. One of the most important best management practices regarding these pollutants is to educate Park staff in their identification, handling, storage, and disposal, particularly with hazardous materials and wastes.

By adhering to the BMP guidelines, water pollution should be significantly reduced from OHV Park management activities.

Avoid using roads during wet periods to reduce maintenance.

Problematic trails may need to be removed.

PO-1 Trail and Service Road Inspection and Maintenance

SWPPP Summary

Erosion control features on trails and service roads in the Park shall be maintained through periodic inspection and maintenance, including cleaning dips and crossdrains, repairing ditches, marking culvert inlets to aid in location, and clearing debris from culverts. Roads and trails will be avoided during wet periods if such use would likely damage the road drainage features.

Maintenance Specifications

Refer to the Road and Trail Drainage (RT) BMPs for specific inspection and maintenance techniques on various road and trail designs. Additional maintenance and monitoring guidance for trails can be found in the Soil Standards (CARC, 2005).

Maintenance of active and inactive roads shall be sufficient to maintain a stable surface, keep the drainage system operating, and protect the quality of streams. The following are general recommendations:

Road surfaces usually have a crown or slope (inslope or outslope). Vehicle traffic can damage road surfaces and reduce drainage effectiveness. Grading repairs the drainage; by smoothing surface ruts and potholes. However, avoid grading sections of road that don't need it. It creates a source of sediment from the newly disturbed surface. Raise the blade where grading is not needed!

- Keep culverts, flumes, and ditches functional before and during the rainy season to diminish danger of clogging and the possibility of washouts. This can be done by clearing away any sediment or vegetation that could cause a problem. Provide for practical and scheduled preventative maintenance programs for high risk sites that will address the problems associated with high intensity rainfall events.
- Conduct road surface maintenance as necessary to minimize erosion of the surface and subgrade.
- Keep the road surface crowned or outsloped, and keep the downhill side of the road free from berms except those intentionally constructed for protection of fill.
- Avoid using roads during wet periods if such use would likely damage the road drainage features.
- Damage should be promptly corrected.
- Grade road surfaces only as often as necessary to maintain a stable running surface and to retain the original surface drainage.
- Avoid cutting the toe of cut slopes when grading roads or pulling ditches.
- Spoils management; place all excess material removed by maintenance operations in safe disposal sites and stabilize these sites to prevent erosion. Avoid locations where erosion will carry materials into a stream.

PO-2 Campground Maintenance

SWPPP Summary

The implementation of best management practices for campground, trail, and parking lot activities is designed to prevent pollutants from these areas from entering nearby stream systems or stormwater conveyance systems.

Maintenance Specifications

- Park staff shall inspect campgrounds and other visitor use areas daily.
- In campsite areas, ground disturbed by road maintenance or road construction, campsite construction, or toilet site installation shall be seeded and mulched.
- Litter and debris shall be collected and disposed of properly, on a regular basis. All trash receptacles shall be wildlife-proof, if necessary.
- Leach fields associated with flushing toilet facilities shall be constructed away from drainages and deep enough to resist storm events.
- All storm drain inlets, culverts, and dry creeks or swales will be kept clean and free from debris.

All trash receptacles shall be wildlife-proof, if necessary (Carnegie SVRA).

Park staff shall inspect campgrounds and other visitor use areas daily (Carnegie SVRA).

PO-3 Portable Septic Waste Management

SWPPP Summary

Portable septic systems will be necessary in order to perform projects throughout isolated areas of the park. Portable septic waste management controls shall be practiced to minimize or eliminate the discharge of septic waste materials to watercourses. Park staff and other contractors shall be educated on portable septic practices.

Definition / Purpose

Septic waste management practices prevent the discharge of septic waste into watercourses.

Planning Considerations and Specifications

Temporary portable septic systems shall be located away from drainage facilities and watercourses. Also locate portable septic systems away from traffic circulation or other areas where there is risk of the facility being knocked over.

Portable septic waste systems shall be inspected daily and serviced at least weekly, sooner if needed (Carnegie SVRA).

- Park staff and other contractors shall be educated on portable septic waste storage and disposal procedures, as well as the danger to humans and the environment from septic wastes.
- Wastewater shall not be discharged or buried within the Park.
- If using an onsite disposal system, such as a septic system, comply with local health agency requirements, and make sure all connections to the septic system are properly connected in order to avoid illicit discharges.
- Ensure that portable septic facilities are maintained in good working order by a licensed service.
- Use only reputable, licensed septic waste haulers.

Inspection and Maintenance

The portable septic waste system shall be inspected daily and serviced at least weekly, sooner if needed.

PO-4 Vehicle Maintenance and Fueling

SWPPP Summary

Vehicle and equipment fueling procedures and practices are designed to minimize or eliminate the discharge of fuel spills and leaks into storm drain systems or to watercourses.

Definition / Purpose

These procedures are applied on all Park sites where vehicle and equipment fueling takes place, and this best management practice shall apply to both Park staff and OHV users.

Keep spill clean-up materials on hand. Immediately clean up spills and properly dispose of contaminated soil and cleanup materials.

Fueling and maintenance areas should be inspected on a regular basis. During construction activities, vehicles and equipment should be inspected for leaks each day.

Construction Specifications

The following procedures apply to Park staff, subcontractors, and OHV users, where applicable:

- When fueling must occur onsite for facility construction or Park maintenance, the subcontractor/Park staff shall have a designated area for this purpose, subject to approval of the project supervisor.
- Absorbent spill clean-up materials and spill kits shall be available in fueling areas and on fueling trucks and shall be disposed of properly after use.
- Drip pans or absorbent pads shall be used during vehicle and equipment fueling.
- Dedicated fueling areas shall be protected from storm water run-on and runoff, and shall be located at least 15 m (50 ft) from downstream drainage facilities and watercourses. Fueling must be performed on level-grade areas.
- Protect fueling areas with berms and/or dikes to prevent run-on, runoff, and to contain spills.
- Fuel tanks shall not be "topped-off".

- During construction or maintenance activities, vehicles and equipment shall be inspected on each day of use for leaks. Leaks shall be repaired immediately or problem vehicles or equipment shall be removed from the project site.
- Absorbent spill clean-up materials shall be available in fueling and maintenance areas and used on small spills instead of hosing down or burying techniques. The spent absorbent material shall be removed promptly and disposed of properly.
- Federal, state, and local requirements shall be observed for any stationary above ground storage tanks.
- Mobile fueling of construction equipment throughout construction sites at the Park shall be minimized. Whenever practical, equipment shall be transported to the designated fueling area.

Limitations

Onsite vehicle and equipment fueling shall only be used where it is impractical to send vehicles and equipment off-site for fueling.

Inspection and Maintenance

Fueling areas and storage tanks shall be inspected regularly. Keep an ample supply of spill cleanup material on site. Immediately clean up spills and properly dispose of contaminated soil and cleanup materials.

PO-5 Stockpile Management

SWPPP Summary

Stockpile management procedures and practices shall be implemented to reduce or eliminate air and stormwater pollution from stockpiles of soil, compost, sand, and paving materials such as Portland cement and asphalt-based materials, aggregates, and pressure-treated wood.

Soil and compost stockpiles shall be covered or protected with soil stabilization measures and a temporary perimeter sediment barrier at all times during the rainy season, or prior to the onset of precipitation during the non-rainy season.

Definition / Purpose

This BMP reduces or prevents storm water pollution that can be generated when storm water comes in contact with stockpiles of soil, paving materials, aggregates, pressure-treated wood, and similar construction materials during facility development projects, road/trail construction, road/trail maintenance activities, and rehabilitation projects. Fine materials such as sand can also contribute to wind erosion, so wind/dust erosion controls shall also be implemented as needed.

Construction Specifications

- Protection of stockpiles is a year-round requirement.
- Locate stockpiles a minimum of 50 feet away from concentrated flows of storm water, drainage courses, and inlets.
- Implement wind erosion control (SS-11 Dust Control and Tackifiers) as appropriate on all stockpiled material.
- Temporary stockpiling of contaminated soil shall be avoided if possible, however, if temporary stockpiling is necessary, contaminated soil stockpiles shall be managed by:
    1. Covering the stockpile with plastic sheeting or tarps.
    2. Installing a berm around the stockpile to prevent runoff from leaving the area.
    3. Do not stockpile in or near storm drains, drainage swales, areas where water can pond, or watercourses.

4. Stockpiles of contaminated soil shall be transported off site in accordance with rules and regulations of the EPA, CAL-OSHO, and local regulatory agencies.

- Bagged materials should be placed on pallets and under cover.
- Soil and compost stockpiles shall be covered or protected with soil stabilization measures and a temporary perimeter sediment barrier at all times during the rainy season, or prior to the onset of precipitation during the non-rainy season.
- Concrete rubble or asphalt material stockpiles shall be covered and protected with a temporary perimeter sediment barrier during the rainy season, or prior to the onset of precipitation during the non-rainy season.
- Pressure-treated wood should be stockpiled on pallets and covered with plastic during the rainy season, or prior to the onset of precipitation during the non-rainy season.

Erosion-safe stockpile areas should be planned ahead of time. Level to gently sloping, grassed areas usually provide good stockpile sites. Soil should *not* be stockpiled in or along wetlands, drainage ditches, swales, streambanks, areas within 50 feet of a waterway, or against slopes that are more than 2:1.

Inspection and Maintenance

Repair and/or replace perimeter control and covers as needed, or as directed by the project supervisor, to keep them functioning properly. Sediment shall be removed when sediment accumulation reaches one-third (1/3) of the barrier height.

PO-6 Solid and Liquid Waste Management

<u>SWPPP Summary</u>

Solid and liquid waste management procedures and guidelines shall be practiced in order to minimize or eliminate the discharge of pollutants to the watercourses at the Park. The specifications for PO-6 Solid and Liquid Waste Management shall be followed for the creation, collection, and disposal of these wastes. Recycling stations shall be made available in order to reduce solid waste.

<u>Definition / Purpose</u>

A solid waste creation, collection, and disposal BMP minimizes or eliminates the chances of solid waste coming into contact with storm water and entering watercourses. A liquid waste BMP may be needed for construction projects that generate non-hazardous by products such as wash water (see TC-4 Wash Racks).

<u>Planning Considerations</u>

Solid waste includes but is not limited to:

- Construction wastes including brick, mortar, timber, steel and metal scraps, sawdust, pipe and electrical cuttings, non-hazardous equipment parts, styrofoam and other materials used to transport and package construction materials.
- Litter generated by Park staff, construction contractors, and park visitors, including food containers, beverage cans, coffee cups, paper bags, plastic wrappers, other non-hazardous campground refuse, and smoking materials.

Liquid waste includes the following non-hazardous byproducts, residuals, and wastes:

- Drilling slurries or drilling fluids.
- Grease-free and oil-free wastewater and rinse water.
- Dredgings.
- Other non-storm water liquid discharges not permitted by separate permits.

<u>Construction (Management) Specifications</u>

Education:

- Instruct Park staff and subcontractors on identification of solid waste, liquid waste, and hazardous waste, including the activities that generate these wastes.
- Instruct Park staff, subcontractors, and suppliers that it is unacceptable for any liquid waste to enter any storm drainage structure, waterway, or receiving water.
- Educate Park staff and subcontractors on solid and liquid waste storage and disposal procedures.

- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).
- Require that Park staff and subcontractors follow solid and liquid waste handling and storage procedures.
- Prohibit littering by Park staff, visitors, and subcontractors.
- Whenever possible, minimize production of solid waste materials.

Collection, Storage, and Disposal of Solid and Liquid Wastes:

- Dumpsters of sufficient size and number shall be provided to contain the solid waste generated by normal use, Park construction projects, or special events, and they shall be properly serviced.
- For Park construction projects, road/trail building projects, and maintenance projects, trash receptacles shall be provided in the project area and at locations where workers congregate for lunch and break periods.
- Collected litter and debris shall not be placed in or next to drain inlets, storm water drainage systems, or watercourses.
- Storm water run-on shall be prevented from contacting stored solid and liquid waste through the use of berms, dikes, or other temporary diversion structures or through the use of measures to elevate waste from site surfaces.
- Solid and liquid waste storage areas shall be located at least 15 m (50 ft) from drainage facilities and watercourses and shall not be located in areas prone to flooding or ponding.
- Capture all liquid wastes running off a surface, which has the potential to affect storm drainage systems, such as wash water.
- Do not allow liquid wastes to flow or discharge uncontrolled. Use temporary dikes or berms to intercept flows and direct them to a containment area or device for capture.
- If the liquid waste is sediment-laden, use a sediment trap (see SC-2 Sediment Traps).
- Contain liquid wastes in a controlled area, such as a holding pit, sediment trap, or portable tank. Containment devices must be structurally sound, leak free, and must be of sufficient quantity or volume to completely contain the liquid wastes generated.
- Segregate potentially hazardous waste from non-hazardous solid and liquid waste.
- Make sure that hazardous liquid waste (e.g. used oils, solvents, and paints) and chemicals (e.g. acids, pesticides, additives, curing compounds) are not disposed of in dumpsters designated for construction debris or any other park dumpster (see PO-7 Hazardous Materials and Waste Management).
- Liquid wastes, such as from dredged material, may require testing and certification whether it is hazardous or not before a disposal method can be determined.
- Salvage or recycle useful vegetation debris, packaging and/or surplus building materials when practical. For example, trees and shrubs from land clearing or

road/trail building can be converted into wood chips, then used as mulch for soil stabilization. Wood pallets, cardboard boxes, and construction scraps can also be recycled.

Solid Wastes:

- Temporary stockpiling of certain construction wastes may not necessitate stringent drainage-related controls during the non-rainy season (see PO-5 Stockpile Management).

Liquid Wastes:

- Disposal of some liquid wastes may be subject to specific laws and regulations, or to requirement of other permits secured for specific construction projects. (e.g., National Pollutant Discharge Elimination System [NPDES] permits, Army Corps permits, etc.).
- Does not apply to concrete slurry residue.
- Does not apply to non-storm water discharges permitted by an NPDES permit. Typical permitted non-storm water discharges can include: water line flushing; landscape irrigation and irrigation water; diverted stream flows; discharges from potable water sources; springs; flows from riparian habitats or wetlands; and, discharges or flows from emergency fire fighting activities.

Inspection and Maintenance

For liquid wastes, remove deposited solids from sediment traps as needed, and at the completion of the project. Inspect containment areas routinely for damage, and repair as needed.

For solid wastes, Park staff should police construction sites and visitor areas for litter and debris, and ensure that subcontractors and park visitors are using trash receptacles.

PO-7 Hazardous Materials and Waste Management

SWPPP Summary

Hazardous materials and waste management controls shall be practiced in order to minimize or eliminate the discharge of pollutants from hazardous waste to a storm drain or to watercourses.

Definition / Purpose

Hazardous materials and wastes in construction, demolition, remediation, and maintenance projects must be properly managed to avoid fines or environmental liability. Proper management includes delivery and storage, application, identification, accumulation, and disposal. Identification and accumulation prior to disposal is the responsibility of the Park staff or subcontractor performing the work.

Problems associated with hazardous wastes include:

- They can pollute the land, air, or water, or endanger human health and animal safety.
- Septic systems can be ruined from contamination by hazardous waste.
- Disposing of hazardous waste with nonhazardous waste (trash) is detrimental to solid waste collection systems, causes problems at landfills, poses a potential health threat to workers, and is illegal in many areas.
- Improper disposal of hazardous waste can lead to costly cleanups. Under federal and state law, businesses are liable for improper hazardous waste disposal and hazardous waste spills or releases.

Planning Considerations

Hazardous waste management practices are implemented on construction projects, maintenance projects, or rehabilitation projects that generate waste from the use of:

- Petroleum products
- Asphalt products
- Concrete curing compounds
- Pesticides
- Acids
- Paints
- Stains
- Solvents
- Wood preservatives
- Roofing tar
- Any materials deemed a hazardous waste in California Code of Regulations, Title 22 Division 4.5, or listed in EPA Code of Federal Regulations Title 40, Parts 110, 117, 261, or 302.

Construction Specifications

Refer to the Material Safety Data Sheet (MSDS), published by the manufacturer for each product, to help determine whether the waste produced could be hazardous.

Hazardous Materials:

- Storage of hazardous materials on site shall be minimized. Any hazardous materials used during construction shall be containerized and kept closed during work activities.
- Hazardous materials shall conform to all applicable local, state, and federal requirements.
- Hazardous materials shall be stored in sealed containers within an enclosed container or a bermed and permanently covered storage area. Lids alone shall not be considered adequate cover.
- Specific areas shall be designated on construction sites for hazardous material delivery and storage. Designated storage areas will be placed near construction site entrances, to the extent practical, and away from drain inlets, culverts, and surface water bodies.
- Designated storage areas shall be kept clean and well organized.
- The following types of materials shall be stored in accordance with these provisions: fertilizers, herbicides, pesticides, detergents, oil, grease, glues, paints, solvents, curing compounds materials, and other similar materials that could be considered potential pollutants in storm water discharge.
- Fuel shall be stored and managed in accordance with PO-4 Vehicle Maintenance and Fueling.
- Regular inspections of storage areas shall be conducted to monitor inventory and check for leaking containers.

Hazardous Wastes:

- Hazardous wastes and containers shall be placed in a designated hazardous waste storage area that is permanently covered and has an impermeable bottom surface surrounded by secondary containment to minimize the mixing of wastes with storm water and to prevent the direct release of liquid hazardous waste with storm water. Temporary storage and removal of hazardous wastes from the site shall be in accordance with all applicable state and federal laws.
- Wastes shall be segregated and recycled where feasible (e.g. paints, solvents, used oil, batteries, anti-freeze). Wastes shall not be mixed since this can cause potentially dangerous chemical reactions, make recycling impossible and complicate disposal.
- Covered waste bins shall be designated for the disposal of all empty hazardous waste product (e.g., paints, solvents, glues, petroleum products, exterior finishes, pesticides, fertilizers, etc.) containers. The original product label shall not be removed as it contains important safety and disposal information.

- Toxic wastes and chemicals shall not be disposed of in dumpsters designated for non-hazardous solid wastes or construction debris.
- If any asbestos is discovered in demolished materials, asbestos removal and disposal shall be performed by a licensed contractor or licensed subcontractor trained in asbestos removal, and all guidelines and regulations for asbestos disposal shall be followed.
- Park staff and subcontractors shall be trained on proper storage practices.

Limitations

Space limitations may preclude indoor storage. Storage sheds must meet building and fire code requirements.

Inspection and Maintenance

Storage areas shall be kept clean, well organized, and equipped with ample clean-up supplies as appropriate for the materials being stored. Perimeter controls, containment structures, covers, and liners shall be repaired or replaced as needed to maintain proper function. Inspect storage areas before and after rainfall events, and at least weekly during other times. Hazardous spills shall be cleaned up and reported in conformance with the applicable Material Safety Data Sheet (MSDS) and the instructions posted at the project site. Spills should be reported to Park supervisors who have been informed on how to manage hazardous spills and all reporting requirements.

PO-8 Hazardous Spill Response

SWPPP Summary

Hazardous spill control procedures shall be implemented anytime chemicals and/or other hazardous substances are actively used or stored. This BMP shall apply to all construction, maintenance and road/trail building projects.

PO-8 Hazardous Spill Response BMP should apply to all construction, maintenance, and road/trail building, restoration, and rehabilitation projects.

Definition / Purpose

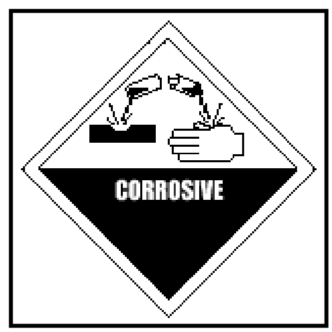
The PO-8 Hazardous Spill Response BMP ensures that the proper procedures and practices for hazardous spills are implemented in a manner in order to minimize or eliminate the risk of the spilt material contaminating a storm drain system or watercourse.

Planning Considerations

Sites located near natural watercourses, canals, and reservoirs are at highest risk of an uncontained spill contaminating surface waters.

Spill prevention and control applies to chemicals and hazardous substances including, but not limited to:

- Soil stabilizers
- Palliatives
- Herbicides
- Growth inhibitors
- Fertilizers
- Deicing/anti-icing chemicals
- Fuels
- Lubricants, and
- Other petroleum distillates.



Construction Specifications

Education:

- Educate Park staff and subcontractors on what a “significant spill’ is for each material they use, and what is the appropriate response for “significant” and “insignificant” spills.
- Educate Park staff and subcontractors on potential dangers to humans and the environment from spills and leaks.
- Hold regular meetings to discuss and reinforce appropriate disposal procedures (incorporate into regular safety meetings).

- Establish a continuing education program to indoctrinate new employees.
- Designate a construction supervisor to oversee and enforce proper spill prevention and control measures.

Clean up and Storage Procedures for Minor Spills:

- Minor spills typically involve small quantities of oil, gasoline, paint, etc. which can be controlled by the first responder at the discovery of the spill.
- Use absorbent materials on small spills rather than hosing down or burying the spill.
- Remove the absorbent materials promptly and dispose of properly.
- The practice commonly followed for minor spills is:
    1. Contain the spill.
    2. Recover spilled materials.
    3. Clean the contaminated area and/or properly dispose of contaminated materials.

Minor spills typically involve small quantities of oil, gasoline, paint, etc.

Clean up and Storage Procedures for Semi-significant Spills:

- Semi-significant spills can be controlled by the first responder along with the aid of other personnel such as Park management and a construction supervisor, etc. This response may require the cessation of all other activities.
- Clean up spills immediately, and follow these guidelines:
    1. Notify the project supervisor immediately.
    2. Contain the spread of spills.
    3. If the spills occur on paved or impermeable surfaces, clean up using "dry" methods (absorbent materials, cat litter and/or rags). Contain the spills by encircling with absorbent materials and do not let the spill spread widely.
    4. If the spills occur in dirt areas, immediately contain the spill by constructing an earthen dike. Dig up and properly dispose of contaminated material.
    5. If the spills occur during rain, cover up if possible.

Clean up and Storage Procedures for Significan/Hazardous Spills:

- For significant or hazardous spills that cannot be controlled by personnel in the immediate vicinity, the following steps shall be taken:
    1. Notify the construction supervisor and Park manager immediately and follow up with a written report.
    2. Notify the local emergency response by dialing 911. In addition to 911, the supervisor will notify the proper county officials. It is the supervisor's responsibility to have all emergency phone numbers at the construction site.
    3. For spills of federal reportable quantities, the supervisor will notify the National Response Center (800) 424-8802 (United States).
    4. Notification should first be made by telephone and followed up with a written report.
    5. The services of a spills contractor, Haz-Mat team, or other designated professional agency shall be obtained immediately. Construction personnel should not attempt to clean-up until the appropriate and qualified staff has arrived at the job site.

Other agencies which may need to be consulted include, but are not limited to, the Fire Department, Department of Toxic Substances, State OSHA, etc.

Limitations

Use only a reputable, licensed spill clean up company to clean up large spills. Procedures and practices presented in this BMP are general. Park management shall identify appropriate practices for the specific materials used or stored on site.

Inspection and Maintenance

Verify weekly that spill control clean-up materials are located near material storage, unloading, and use areas. Update spill prevention and control plans and stock appropriate clean-up materials whenever changes occur in the types of chemicals on-site.

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