NORTHWEST FLORIDA UNPAVED ROAD-STREAM CROSSING MANUAL

CHAPTER IV
STREAM CROSSING FIELD SURVEY PROCEDURES

Stream Crossing Culverts
(Photo by Teresa Thom)

STREAM CROSSING TECHNICAL CENTER

Facilitating informed decision-making and measurable improvements in watershed management, aquatic resource recovery and conservation, and water quality

NORTHWEST FLORIDA UNPAVED ROAD-STREAM CROSSING MANUAL

SECTION IV
STREAM CROSSING FIELD SURVEY PROCEDURES

(Florida State Archives)

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APRIL 2005

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1. INTRODUCTION

This chapter describes the purpose and scope of the *Northwest Florida Unpaved Road-Stream Crossing Assessment: Field Survey Procedures*, outlines the components, problems, and environmental effects of unpaved road-stream crossings, and provides a user guide.

1.1 PURPOSE AND SCOPE

The procedures provided by this section are intended to assist end users in exercising technical knowledge and best professional judgments in conducting on-site unpaved road-stream crossing (SC) investigations. The purpose is to provide field personnel with guidelines and instructions to collect, interpret, and record northwest Florida SC field data. Specific objectives are to:

- Optimize data accuracy, confidence, and applications by standardizing SC data identification, collection, and management methods.
- Maximize data technical utilities and SC ground application opportunities by collecting diverse types of SC data at appropriate intensities that fulfill environmental and socioeconomic analysis and assessment requirements.
- Facilitate the population of the Northwest Florida Road-Stream Crossing database with data that promotes SC condition and aquatic resource impact assessments and identification of priority SC recovery and conservation sites.
- Facilitate the development of customized SC site prescriptions that provide long-term reductions in unpaved road sediment production and delivery and measurable improvements in aquatic habitats and water quality.

Development precepts of this document include:

- Standardizing field data collection and recording techniques in a manner that minimizes errors and maximizes data confidence and applicability.
- Providing an application framework for identifying and characterizing relevant SC ecological and maintenance issues.
- Producing interpretative field tools that facilitate a clear understanding of SC problems, options, and opportunities.
- Demonstrating a basis for decision making and creating a transparent project development trail.

Ultimately it is intended that the SC data generated by applying these procedures will result in the development of SC projects that meet ecological and road maintenance objectives. This procedures document does not preclude the use of other techniques in collecting data; flexibility is required to accommodate the diversity of adverse conditions encountered in the field. However, strict adherence is required in the types of field data collected, establishment of field markers, performance of site measurements, and recording of field data. Since this document is designed for use by individuals experienced in conducting field surveys, details are not provided relating to the performance of surveying techniques or survey book record keeping.

1.2 USER GUIDE

The reconstruction of SCs to reduce sediment delivery potentials and foster the recovery of affected wetlands and aquatic systems encompasses complex, interrelated ecological features and processes. It is imperative to SC evaluation, assessment, planning, and decision-making processes to acquire and process site-specific data in a manner that produces interpretative datasets that convey end user knowledge regarding SC features, conditions, and processes. The anticipated results are viable solutions to the diversity of water quality and aquatic habitat issues associated with Northwest Florida SCs.

Accurate data collection and analysis is pivotal to characterizing, prioritizing, maintaining, restoring, and monitoring SCs and crossing conditions. The diversity of data acquisition required to fulfill these requirements stipulates that particular types of SC data be collected at appropriate detail, scale, and intensity to build a complete picture of existing features, conditions, and aquatic resource impact potentials. The extensive range and potential combinations of variables represented by the different types of SCs encountered in Northwest Florida mandates that field survey methods and field datasheets be developed to accommodate the potential variability of SCs. In some cases, the SC data collection requirements will be minimal, whereas in cases that exhibit numerous features and/or extensive disturbance stresses the data collection requirements may be extensive.

This procedures manual provides users with technical instruction and guidance in collecting and recording SC field data. As applicable, photographs and illustrations are provided in this document to convey SC and related natural resource feature identification, attribute, and condition information for interpretative purposes.

1.2.1 Field Datasheets

Comprehensive datasheets have been developed to accommodate the collection of diverse types of field data. A copy of the SC datasheets is presented in Appendix A. For each SC waterway, crossing structure, and road approach component, site data is collected regarding SC features and interpretative conditions, and in some cases field measurements are required. The datasheet modules and associated data block nomenclature corresponds to the SC database where the information is stored and managed. The data collection process is divided into Level 1 and Level 2 survey modules that are specific to particular SC components and survey intensity requirements.

1.2.2 Unpaved Road-Stream Crossing Field Survey Methods

To accommodate the variability of SC data collection requirements, field surveys are divided into Level 1 and Level 2 surveys. A list of survey equipment requirements is presented in Appendix B.

1.2.2.1 Level 1 Survey

The Level 1 survey is purposive in that only a specific set of SC features and conditions are surveyed. This survey is limited to the collection of data generated by SC survey crew observations; no feature measurements are conducted during a Level 1 survey. The survey provides SC waterway, crossing structure, and road approaches feature and condition data. Determinations of SC feature (waterway, crossing structure, and road approaches) attributes and conditions are based on manual instruction

and best professional judgments of field personnel. Data is entered onto the features and conditions modules of the field datasheet (Section 1.3.2).

1.2.2.2 Level 2 Survey

The Level 2 survey differs from the Level 1 survey in that specific types of physical feature measurements are taken and calculations are performed to satisfy data requirements. Data is entered onto the Level 2 survey modules of the field datasheet (Section 1.3.2). The Level 2 survey also requires the use and maintenance of a field survey book. The subsections that follow generally describe the baseline survey method, stream cross-section monuments, measuring distance, survey field book, and global positioning systems.

Baseline Method Survey

The simplest method for locating features and establishing permanent survey points is establishing a survey baseline. The baseline is a straight, one axis line from which the distances of features are measured at a right angel to the baseline. One of the primary purposes of the baseline is to establish the stream cross-section monuments; however, it is also used to tie-in other important features identified during the survey such as USGS benchmarks and other control points with known coordinates, gully erosion sites, and other features. Selectively tying in features other than the stream cross-section monuments is at the discretion of the survey crew. An example of a stream survey baseline is presented in Figure 1-1.

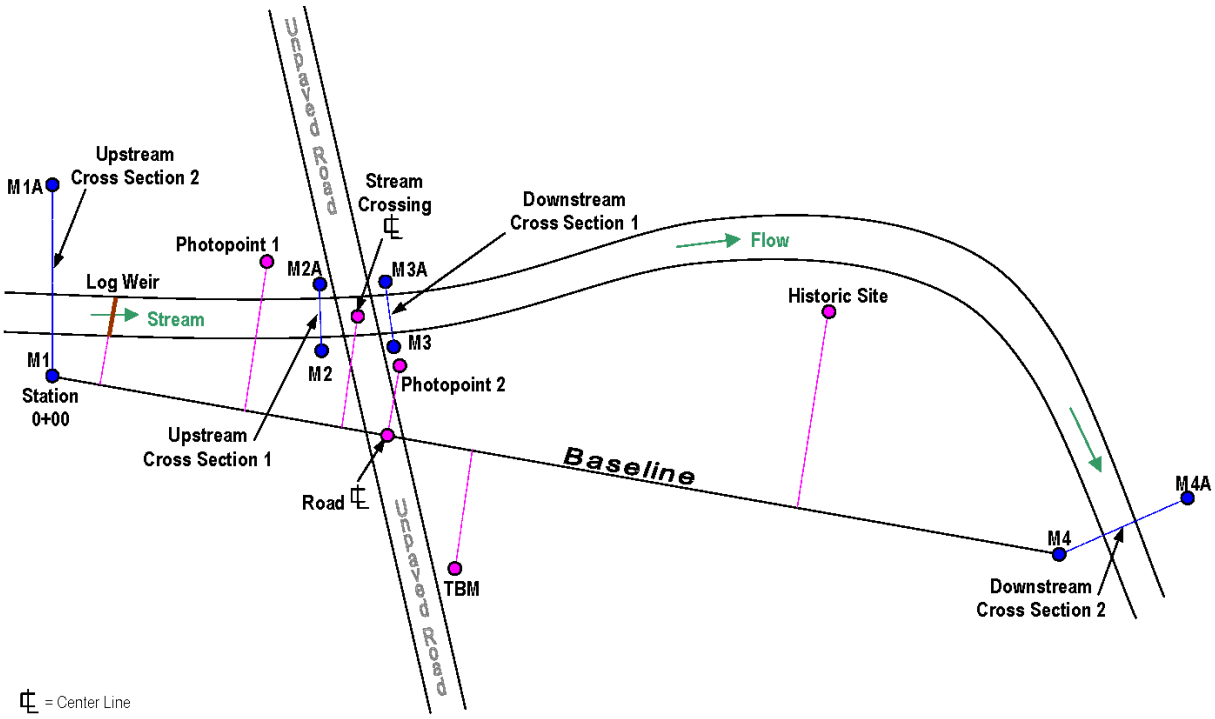

Figure 1-1. Stream Survey Baseline (not to scale)

Establishing the Baseline

Although it is preferred that baselines be set parallel to the waterbody to be surveyed, they can be set arbitrarily. The survey crew establishes the baseline between two set endpoints that are oriented to suit the conditions and survey requirements of the site. Baseline endpoints are set with four foot long rebar irons whereas interior baseline points may be set with wooden stakes or wire flags. It is important to tie the baseline endpoints to permanent markers or GPS coordinates so it can be reestablished at a later time.

The baseline can be established with range poles or the survey instrument. For the range pole method, at least three poles are required to establish and maintain line. The azimuth or direction of the baseline is measured with a compass and recorded. Azimuth is the angle to a line of sight, measured clockwise from a north meridian. Bearings are used to indicate angular orientation with respect to the earth and consist of three components:

- The cardinal direction of the nearest end of the meridian (North or South)
- The angle measured from the nearest end of the meridian
- The cardinal point indicating the direction of deflection from the meridian (East or West)
- The angular measure is always within the range of 0 to 90 degrees.

Tying Features to the Baseline

All features are tied to the baseline by measuring the distance from the baseline to the feature at a right angel to the baseline. Distances between points along the baseline are recorded as stations. For long baselines (greater than 300 feet), preset baseline station points with stakes of chaining pins every 100 feet before conducting tie-in surveys. The baseline startpoint from which all offset baseline distances are measured is designated as Station 0+00. The first 100-foot station from 0+00 is Station 1+00, the second Station 2+00, and so on. The total distance from the start to stop baseline endpoint is recorded. For a baseline 565.5 feet long, the baseline stop endpoint would be designated as Station 5+65.5.

To tie in a feature, set a point on the baseline that is perpendicular to the feature. This feature point can be determined using a right-angle prism (Figure 1-2) or by using less accurate “manual right methods.” Measure and record the distance along the baseline with a tape (Figure 1-3) from Station 0+00 or interior station to the baseline feature point and record the station distance (a baseline feature point 54.7 feet from station 2+00 would be Station 2+54.7).

Next measure and record the offset distance from the baseline point to the feature. Repeat the process for each feature tied to the baseline. Maintain baseline drawings and measured distances in the field survey book. The procedure for establishing the upstream and downstream cross-sections is discussed in the following subsection and in Section 3.3.

Figure 1-2. Right Angle Prism

Figure 1-3. Survey Tape

Stream Cross Section Monuments

Monumented stream cross-sections are established perpendicular to the direction of flow to serve points of reference for replicating stream surveys. Since the stream cross-section is the basis for delineating current and future channel morphology and flow regimes, it is important to tie elevations and location data to permanent points or monuments.

For the purpose of SC stream cross-sections, establish a permanent cross-section monument on each side of the stream using four-foot rebar. Establish an elevation at each monument and, if GPS equipment is available, identify and record the coordinates for each point. If possible, make one upstream and one downstream cross-section monument on the same side of the stream the endpoints for the survey baseline.

Measuring Distance

During plane surveying, the distance measured between two points is known as the horizontal distance. Horizontal and vertical distance measurements are discussed in the following subsections.

Horizontal Distance

Distance is measured by pacing, tachometry (stadia), taping, and electronic distance measurement (EDM). If EDM equipment is not available, taping is the preferred distance measuring method. During taping, the head chainman leads with the zero end of the tape. Use chaining pins when the end of the tape is reached or when breaking tape. The taped distance is read to the nearest tenth of a foot. The rear chainman is responsible for keeping the head chainman on line when taking measurements and retrieving chaining pins. Record distances on the datasheet or field survey book as applicable.

During taping on gentle slopes, hold the tape horizontal and use a plumb bob at one end. On steep slopes, breaking tape techniques are used to measure horizontal distance. During this procedure shorter distances are measured to allow the tape to be held at or below chest height. The procedure is as follows:

- The head chainman places a pin at the tape mark.
- The rear chainman moves ahead holding the tape mark at the pin as the head chainman proceeds.

The procedure continues until the full distance is measured. If possible tape downhill since this is normally easier than taping uphill. At all times remain on line. In some instances, it may be easier to tape along the slope and determine the angle of inclination or the difference in elevation to determine the horizontal distance (Figure 1-4).

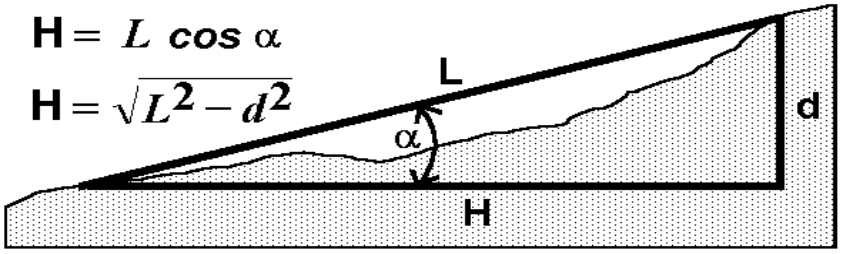

Figure 1-4. Angle of Inclination Formula

Leveling

Leveling is the process of measuring the differences in vertical distance (elevation) between two or more points. The principle is based on the intersection of an accurately leveled line-of-sight with a graduated rod to gain information about the relative height of a given location. Survey equipment requirements include an automatic level, tripod, and level rod. General leveling procedures are discussed below.

Choose or establish a control point with a known or assumed elevation. A temporary benchmark (TBM) is a point of assumed elevation to which all elevations taken on that sight are relative. A benchmark (BM) is a permanent marker (usually a bronze disk) at a point of determined location (elevation and possibly coordinates). For most leveling activities, 100 feet is an adequate assumed TBM elevation.

The TBM serves as the leveling backsight (BS). The BS is the first reading taken from the level rod after setting the level. Since a leveling survey progresses from a point of known elevation to a point of unknown elevation, a backsight is the reading looking backward along the line of progression. The BS is only taken from a BM or TBM. The foresight (FS) is the point to which an elevation is to be established; it is the elevation reading looking forward along the line of progression. The BS and FS elevations are determined by reading a level rod through the level instrument (Figure 1-5). For the purposes of SC profile leveling, read the level rod to the nearest hundredth.

Figure 1-5. 25 Foot Telescoping Level Rod
(Yoas Services, Inc.)

Turning points are set as TBMs when moving the instrument and are backsighted after instrument setup. Since the turning point is used to extend the leveling survey, its

elevation must be precisely recoverable. To maintain accurate TBM foresight and backsight readings, the TBM should be set on solid surface points such as a concrete portion of a bridge or a stake driven into the ground. A spot on rough ground is unacceptable. When leveling over long distances several turning points will be required. Use pacing to keep the distances between the instrument and the BS and FS as near the same as possible.

Survey Field Book

Survey field books are standard forms for recording survey data as it is collected (Figure 1-6). Survey field notes are a permanent record of the work performed in the field. Notes consist of lengths, azimuths, bearings, elevations, sketches, descriptions, and other data. If an error is made do not erase. Make the correction by marking through the entry, enter the new data, and initial the change. Maintain a log of field activities in a survey field book as directed by the data module discussions beginning with Section 2. The intent is not to duplicate the information provided by the field datasheets but to be inclusive where possible of all observations and measurements conducted during SC surveys; paper is cheap – information is not.

Figure 1-6. Survey Field Books (Photo by Mike Rainer)

Global Positioning Systems (GPS)

The baseline survey methods described above rely on establishing lines of sight, sighting from fixed points, and tying in features. In contrast, GPSs are used to provide relatively accurate position information for any point on the surface of the Earth by simply using a GPS receiver. The system is based on a constellation of 24 satellites that orbit the earth at high altitudes and constantly transmit information regarding their exact location and a time code. Portable GPS receivers receiving signals from any four of these satellites can calculate its location to a relative degree of accuracy. Until 2000, signals available to civilian users from the satellites operated by the U.S. Department of Defense were subjected to deliberately induced error to reduce the accuracy of GPS receivers. However, even though this source of error has been removed, other natural sources of error can limit GPS receiver

accuracy to about 30 meters. An accuracy of + or – 30 meters is not generally acceptable for surveying purposes.

Overcoming accuracy errors typically involves the use of differential correction to GPS (DGPS) techniques when operating GPS receivers. Using the College Trimble ProXR DGPS system can fix locations with an accuracy of better than 50 centimeters. The information is stored in a data logger that allows the user to enter feature data and download data to a computer for plotting and/or analysis.

There are various instruments and techniques available for surveying and the choice of the appropriate equipment and techniques depends on a number of factors including level of accuracy, equipment availability, site accessibility, time constraints, and other circumstances. For the purposes of SC surveys, it is recommended that features be located using 50-centimeter accuracy GPS receivers, particularly stream cross-section monuments.

1.2.3 Who Should Perform the Surveys?

Because of the technical nature of the procedures used in collecting and recording field data, Level 1 and Level 2 road-stream crossing surveys should only be performed by individuals with land surveying and field data collection experience; training in aquatic resource feature recognition and condition assessments; and experience in unpaved roads and road crossing structure design and evaluation.

2. MODULE 1: CROSSING SURVEY BASELINE

The purpose of this module is to record crossing information from office sources before the field survey and record initial field data (weather, crew, and photographs) once the crossing survey begins.

2.1 DATE

The crossing survey date is written on the worksheet as year, month, and day in block 1-1. As an example, 23 January 2003 would be entered as 20030123.

2.2 COUNTY

Record the name of the county in which the road-stream crossing occurs in block 1-2.

2.3 USGS QUAD SHEET

Record the name of the USGS quad sheet in which the road-stream crossing occurs in block 1-3.

2.4 SUBBASIN

Record the name of the fourth level hydrologic unit code (HUC), subbasin (8 digit code) in which the road-stream crossing occurs in block 1-4. As an example, the Yellow River subbasin HUC code is 03140103.

2.5 WATERSHED

Record the name of the fifth level HUC watershed (10 digit code) in which the road-stream crossing occurs in block 1-5.

2.6 RIVER BASIN

Record the name of the river basin in which the road-stream crossing occurs in block 1-6.

2.7 OWNER

Identify the entity responsible for maintaining the crossing in block 1-7. If there is shared responsibility for the maintenance of the unpaved road, then include both entities.

2.8 ROAD NAME

Write in the road name on which the crossing occurs in block 1-8.

2.9 ROAD NUMBER

Write in the road number on which the crossing occurs in block 1-9.

2.10 LONGITUDE

Write in the longitude of the crossing in block 1-10. If this information is not available, write in NA. Provide longitude data in high precision geodetic network (HPGN) datum and degrees, minutes, and seconds format. If otherwise, identify the datum and format of the geographic coordinates.

2.11 LATITUDE

Write in the latitude of the crossing in block 1-10. If this information is not available, write in NA. Provide datum and longitude data in degrees, minutes, and seconds. Provide latitude data in HPGN datum and degrees, minutes, and seconds format. If otherwise, identify the datum and format of the geographic coordinates.

2.12 ROAD TRAFFIC SERVICE LEVEL

The traffic service or maintenance level identifies the level of trafficking the road is designed to support. As an example, some federal reservations identify road maintenance levels as primary, secondary, and tertiary. Write in the service level in block 1-12; if no descriptor is available, write in NA.

2.13 ROAD CLOSURE STRUCTURES

In block 1-13, identify if road closure structures are or are not (yes or no) within one mile of the crossing. Closure structures may include functional gates or permanent closure barriers typically associated with abandoned or decommissioned roads.

2.14 PROXIMITY OF OTHER ROAD CROSSINGS

Measure or estimate the upstream and downstream channel miles to the next crossing as indicated on the Road-Stream Crossing Inventory Map provided by SAIC or the U.S. Fish and Wildlife Service within blocks 1-14 and 1-15. Enclose estimated miles in parentheses.

2.15 CROSSING PHOTOGRAPHS

Identify if photopoints were established and crossing feature photographs taken in block 1-16.

2.16 SURVEY CREW

Write in the name of each individual that participated in the survey in block 1-17. Provide the initial of the first name and spell out the last name. Identify which crewmember filled out the datasheets and survey task assignments of other crewmembers using land survey symbols.

2.17 PERIOD SINCE LAST MAJOR RAIN EVENT

Identify the period since the last major rain event. For the purposes of this assessment, a major rain event is a storm during which greater than one inch of precipitation occurred within a 12-hour period. Identify rain interval in block 1-18.

2.18 RECORDERS NAME

Write in the name of the individual(s) who completed the survey datasheets and the name of their affiliated organization and a phone number in block 1-19. Provide the initial of the first name and spell out the last name. This information makes it easier to clarify any points or recording issues.

2.19 SURVEY WEATHER

Identify the overall weather condition at the time of the survey in block 1-20. Select a condition that best represents the dominant weather experienced during the survey.

2.20 SITE DRAWING

In block 1-21, identify (yes or no) if a site drawing was created during the survey.

2.21 BASELINE COMMENTS

Write in additional information regarding owner(s), closure structure(s), weather, baseline data gaps, or pre-entered data inaccuracies in block 1-22. Verify that comment block entries are clear and legible.

2.22 WHAT IS NEXT?

Following the completion of the Module 1, Baseline datasheet blocks, move on to Module 2A, Waterway Level 1 Features Survey datasheet.

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3. MODULE 2: WATERWAY

The following procedures identify waterway data important to characterizing the nature of the upstream and downstream reaches of the waterway affected by the crossing.

3.1 MODULE 2A: WATERWAY LEVEL 1 FEATURES SURVEY

3.1.1 Feature Name

Write in the name of the waterbody; for clarification avoid abbreviations in block 2A-1.

3.1.2 Waterbody Type

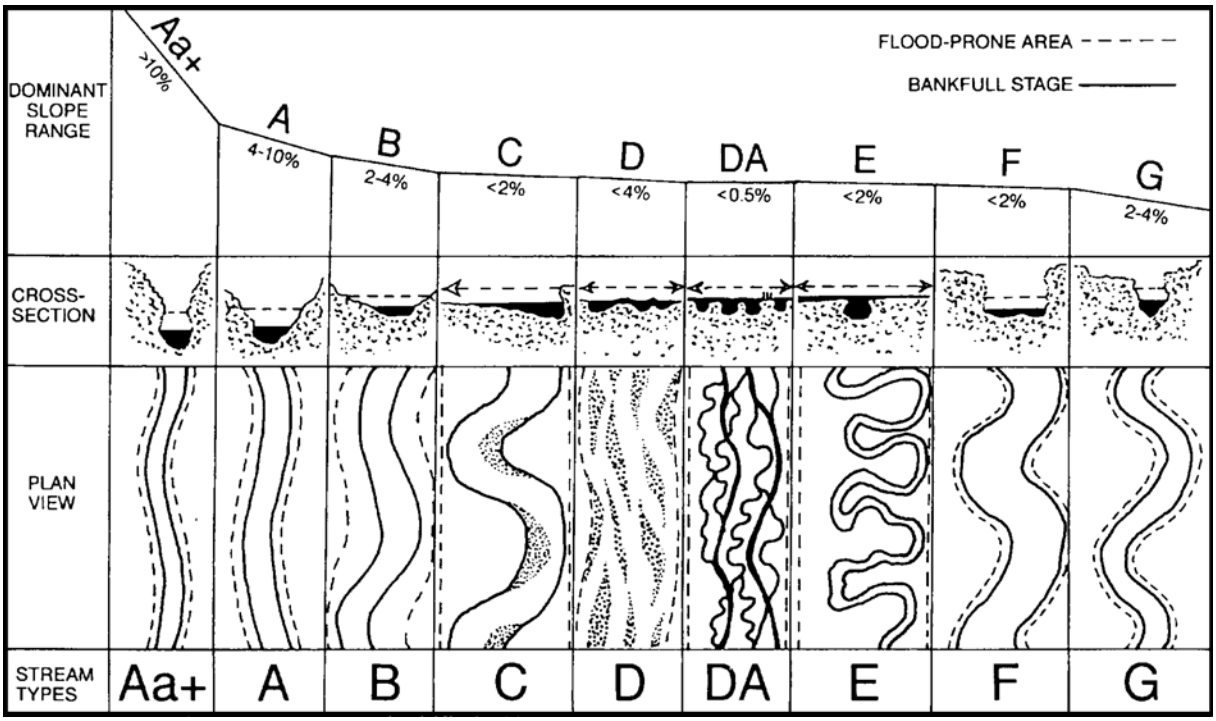
Identify the waterbody type in block 2A-2. A description of the datasheet selections are described as follows:

Stream	S1.	A natural surface-water feature with flow in a defined channel.
	S2.	A body of water, generally flowing in a natural surface channel.
	S3.	A channelized natural stream.
Drain		A small stream, generally unnamed, with a defined channel, that typically accepts overflow from a swamp or other depression.
Canal	C1.	A large manmade drainage feature, usually completely artificial but may be a channelized stream.
	C2.	An artificial open channel.
Slough		A natural surface-water feature with flow but no defined channel.
Outlet		Outflow stream from a reservoir or lake or an opening through which water flows out of a reservoir or stream.
Bayou		A stream without gradient but with flow generated by tide or stream discharge.
Lagoon	L1.	An elongated shallow water body with poorly defined tidal flux, protected by a barrier island.
	L2.	A shallow sound, channel, or pond communicating with a larger body of water, or a shallow artificial pool or pond.
Reach	R1.	A section of a stream (the section will often be separated by a lake or marsh from other sections and may have a different name).
	R2.	A straight, continuous, or extended part of a stream viewed without interruption (as between two bends) or chosen between two specified points.

Select one or more variables to identify waterbody type. An example of an applicable multiply identifier would be a beaver pond drain above the crossing and a stream below the crossing. Where multiply identifiers are used, provide a description in the comments block (2A-8) and illustration on the site drawing.

3.1.3 Stream Type

Identify the upstream (U/S) and downstream (D/S) stream types in blocks 2A-3 and 2A-5. A diagram of stream types is presented in Figures 3-1 and 3-2.



Dominant Bed Material	A	B	C	D	DA	E	F	G
1 BEDROCK								
2 BOULDER								
3 COBBLE								
4 GRAVEL								
5 SAND								
6 SILT/CLAY								
ENTRH.	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	<12	<12
SLOPE	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

Figure 3-1. Stream Types
(Harrelson et al., 1994)

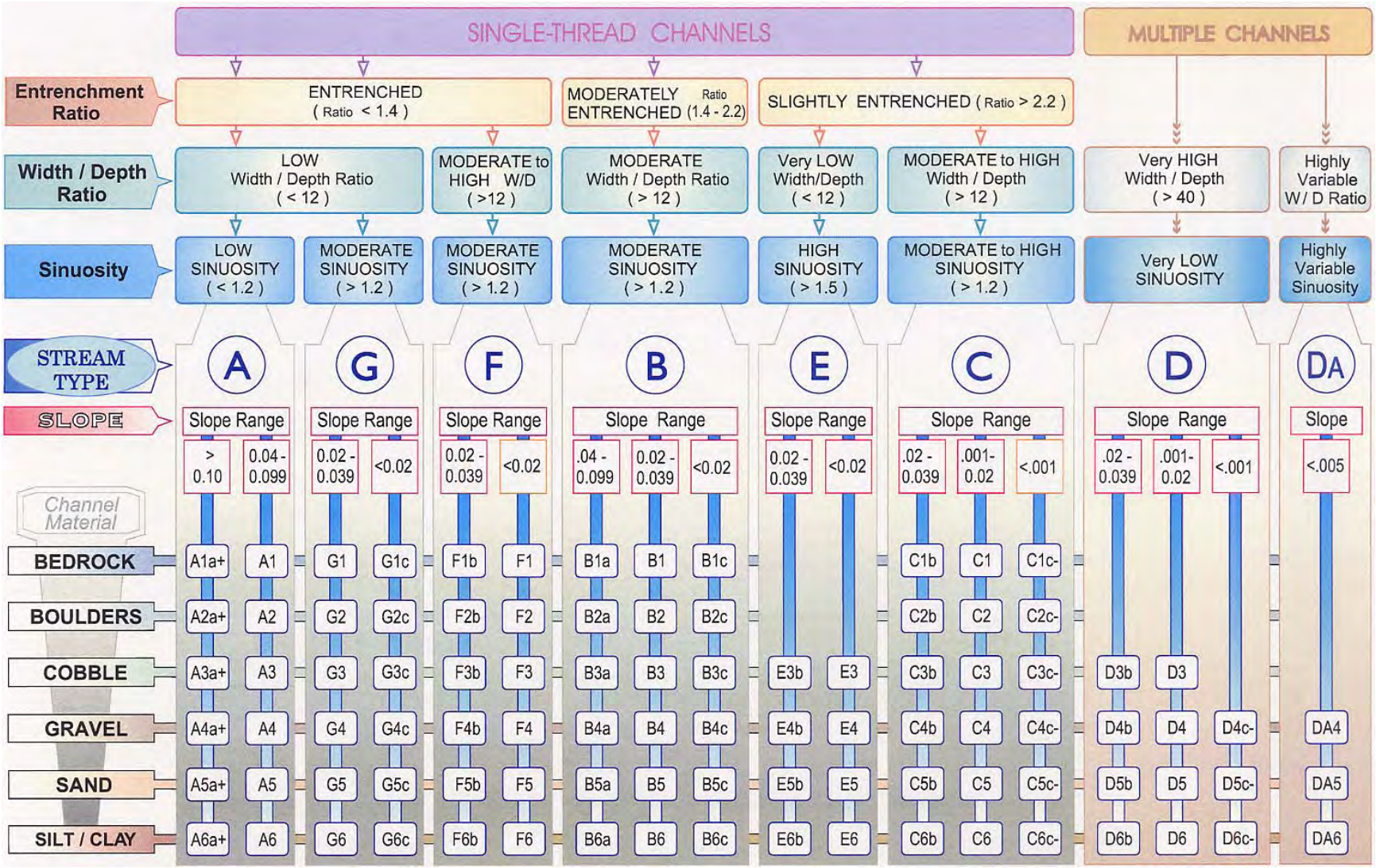


Figure 3-2. Key to the Rosgen Classification of Natural Rivers
(Wildland Hydrology)

3.1.4 Stream Features

Identify the U/S and D/S waterbody features within 500 feet of the crossing in blocks 2A-4 and 2A-6. Selections include: Single Channel, Braided Channel, Wetland, Lake, Pond, Beaver Dam, and Other. Multiple features may be selected to identify the upstream reach. Provide site-specific comments in block 2A-8 as required.

3.1.5 Flow Regime

Identify the waterbody flow regime in block 2A-7. The datasheet selections are as follows:

- *Perennial* — Flow is continuous during both wet and dry periods. Baseflow is primarily generated by groundwater discharge.
- *Intermittent* — Flows only occur during certain times of the year. Seasonal flows typically last longer than 30 days per year.
- *Ephemera*l — Flows only during or immediately after periods of precipitation.
- *Ponded* — Water is retained or confined by natural or anthropogenic features.
- *Other* — Other flow regimes are described.

Select only one flow regime variable.

3.1.6 Waterway Feature Comments

Expound on observations and present additional comments concerning waterway features in block 2A-8. Examples of additional comments could include relatively broad or narrow floodplain, recent floodplain sediment deposition, channel rootwads, channel blockage, floodplain vegetation, etc.

3.1.7 What is Next?

Once this module is complete, move on to Module 2B, Waterway Level 1 Conditions Survey.

3.2 MODULE 2B: WATERWAY LEVEL 1 CONDITIONS SURVEY

3.2.1 Waterway Alteration

Identify the level of U/S and D/S alteration that is present in the channel in blocks 2B-1 and 2B-2. Streambed, channel, streambank, and large woody debris (LWD) indicators of recent channel alteration include:

- Streambed Characteristics: Extensive areas of scour, extensive areas of bar (unvegetated), large extensive sediment wedges, elevated mid-channel bars, extensive riffle zones, limited pool frequency and extent.
- Channel Pattern: Multiple channels (braiding).
- Streambanks: Eroding banks and isolated sidechannels or backchannels.
- LWD: Most LWD is parallel to banks and recently formed log jams.

Waterway condition selections include the following:

- *Natural* — Stream follows a normal and natural meandering pattern; evidence of alteration is not present.
- *Minor* — Some minor alterations, dredging, artificial embankments, or dams present; no evidence of recent alteration activities.
- *Partial* — Somewhat channelized; 40 to 80 percent of the channel has been straightened, dredged, or otherwise altered.
- *High* — Greater than 80 percent of the stream area and habitat has been highly altered (banks box cut, rip rapped, dam structure, and/or absent native vegetation).

Select only one waterway alteration variable.

3.2.2 Instream Woody Vegetation

Identify (yes or no) if live woody plants are present within the U/S and D/S channel in blocks 2B-3 and 2B-4. If sediment islands are present, note the number and morphology (Figure 3-3) in the comments block (2B-11) and the general location on the site map.

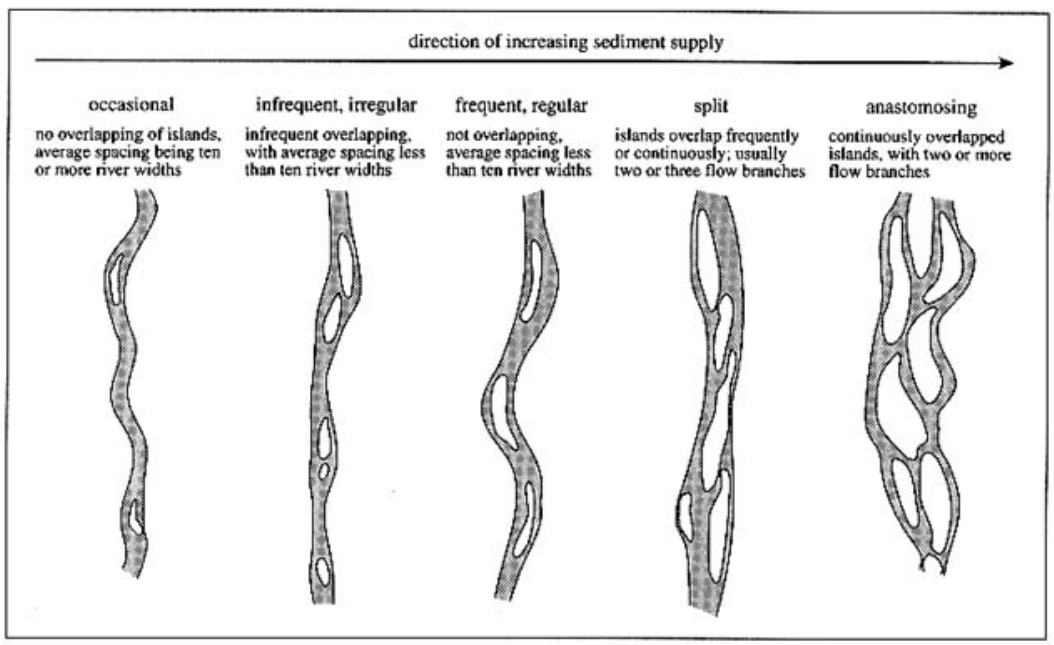


Figure 3-3. Stream Island Morphology
(http://www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/CHANNEL/chan3.htm)

3.2.3 Stream Stability

Identify the overall U/S and D/S stability of the channel and streambank in blocks 2B-5 and 2B-6. Selections include the following:

- *High* — Well defined streambed, well-vegetated banks, moderate slope, little or no streambank modification, and no erosion.

- *Moderate* — Some modification of the streambanks and signs of erosion or undercuts; however, the overall stream morphology is intact.
- *Low* — Stream morphology has been significantly degraded by steep or exposed banks, washouts, severe undercuts, poorly defined multiple channels, and/or no obvious banks.

Select only one stream stability variable.

3.2.4 Channel Entrenchment

Identify (yes or no) if the U/S and D/S channel is entrenched in blocks 2B-7 and 2B-8.

3.2.5 Fish

Identify (yes or no) if fish were observed in the channel in block 2B-9.

3.2.6 Aquatic Insects

Identify (yes or no) if aquatic insects were observed in the channel in block 2B-10.

3.2.7 Sedimentation

Identify the current extent of stream reach sedimentation generated by the crossing in block 2B-11. In many cases, in-channel road fill sediment will have an orange to red color. Datasheet selections include:

- *Extensive* — Significant amounts of road approach or crossing structure fill materials are present in the waterway. Sediment delivery and deposition in the channel has altered the form and function of the stream reach.
- *Moderate* — Moderate amounts of road or crossing fill material has been eroded into the waterway. Sediment delivery has not adversely altered the form and function of the stream reach; however, if current conditions persist channel alteration is likely to occur.
- *Minor* — The crossing has contributed relatively small volumes of sediment that have not altered the stream reach; the crossing fill and road approaches were not observed to be a sediment generation or delivery source.

Select only one sedimentation condition variable.

3.2.8 Spoil Banks

Identify the location of spoil on the U/S and D/S banks created during channel dredging operations in blocks 2B-12 and 2B-13.

3.2.9 Waterway Conditions Comments

- Expound on observations and present additional comments regarding waterway conditions in block 2B-11. Examples of additional comments could include good flow, stable stream conditions, etc.

3.2.10 What is Next?

If U/S and/or D/S adverse conditions were identified during this portion of the survey move on to Module 2C and conduct a Waterway Level 2 Survey. Adverse condition indicators would include:

- Highly altered channel (2B-1 and 2B-2)
- Instream woody vegetation (2B-3 and 2B-4)
- Low stream stability (2B-5 and 2B-6)
- Channel entrenchment (2B-7 and 2B-8)
- Extensive or moderate stream reach sedimentation (2B-11)

Survey equipment (Appendix B) and techniques (Section 1.3.2) are required to complete Module 2C. If adverse conditions were not recorded during the Module 2B, Waterway Level 1 Conditions survey, move on to Module 3, Crossing Structure.

3.3 MODULE 2C: WATERWAY LEVEL 2 SURVEY

During the Level 2 waterway survey, channel cross sections locations are established with permanent markers for collecting stream channel data (Section 1.3.2.). All waterway survey measurements are taken at two channel distance intervals from the upstream (U/S) and downstream (D/S) side of the crossing. The exact location of each distance interval is based on proximity to the crossings and stream morphology.

For U/S and D/S surveys, the first distance interval channel cross section is to be taken within 10 feet of the crossing structure. The second distance interval is to be located within a portion of the stream with consistent channel width over a distance sufficient to characterize the reach as stable and relatively uninfluenced by crossing variables. Typically the second distance interval will occur within 500 feet for the downstream side of the crossing structure and within 1,000 feet for the upstream side of the crossing structure. The exact location of the distance intervals will vary based on the levels of stream disturbance and channel pool and riffle conditions encountered. The exact location of the channel cross sections is based on the on-site best professional judgments of the crossing survey crew. Other important considerations in conducting Level 2 waterway surveys include the following:

- For perennial stream channels, all measurements are taken at the stream riffle.
- For channels with intermittent, ephemeral, or ponded flow regimes, locate the first U/S and D/S distance interval in the same manner as used for perennial streams. For the second distance interval, locate the cross section in a stable portion of the channel not influenced by the crossing structure.
- It is also important to establish the correct orientation for determining left and right side channel attributes. For the purpose of all U/S and D/S waterway surveys, left and right sides are assigned by facing D/S. This orientation also holds true for left and right crossing and road approach attributes.
- All channel cross section values are to be calculated by averaging at least three separate measurements.

Most streams share a similar characteristic of alternating, regularly spaced, shallow, and deep areas known as riffles and pools. Normally, riffles normally form in a straight portion of the channel and pools form along the outside bank of bends (Figures 3-4 and 3-5). Riffles are areas of naturally occurring, short, relatively shallow, zones of fast moving water followed by a pool. Riffles occur where the stream bottom is higher relative to streambed elevation upstream or downstream. Water depth sufficient to classify an area as a pool may vary from eight inches in small streams, several feet for wadeable streams, and tens of feet in large rivers.

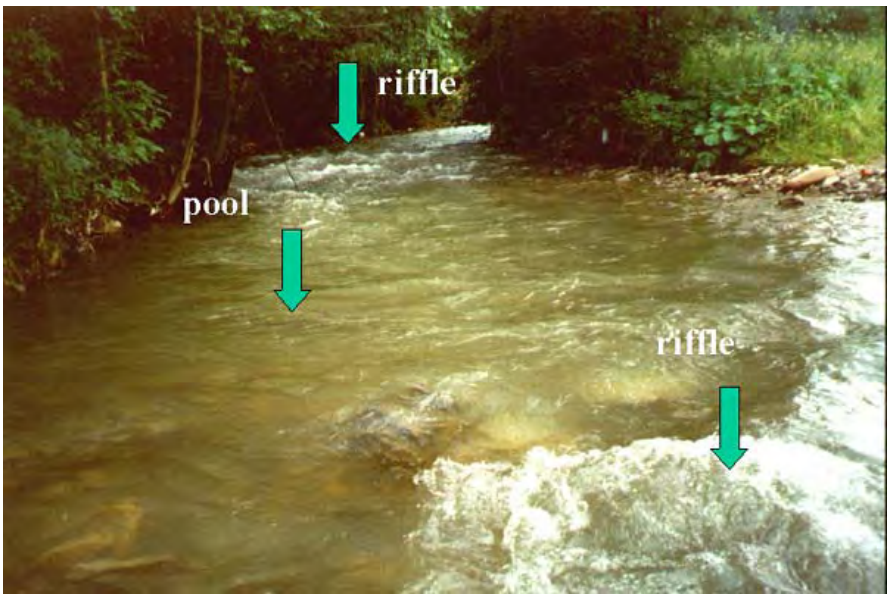


Figure 3-4. Pool-Riffle Sequence
(www.ejpau.media.pl/series/volume5/issue2/environment/art-01.html)

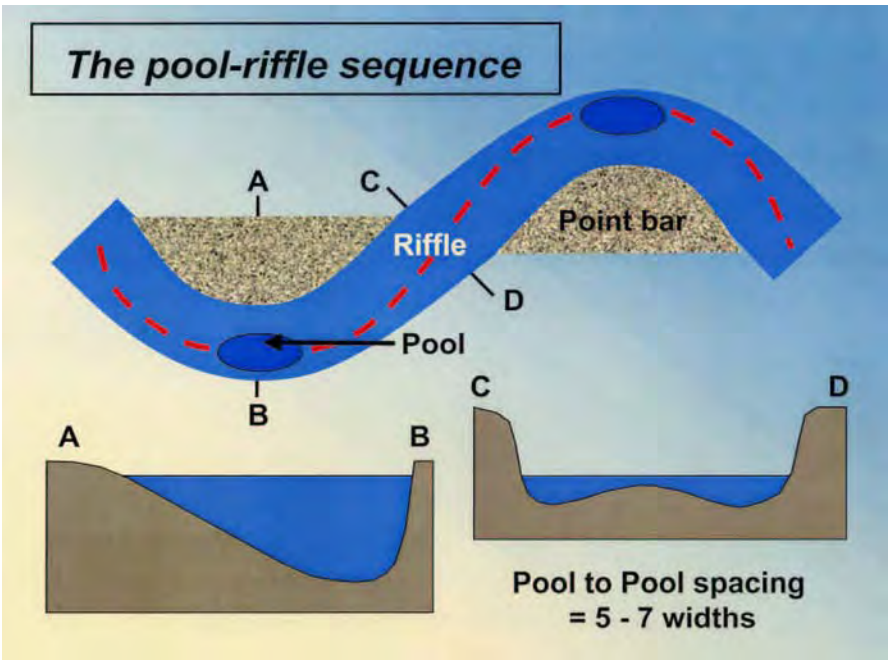


Figure 3-5. Stream Pool-Riffle Sequence in Sinuous Streams
(www.ex.ac.uk/geography/modules/GEO1202/)

Sand-bed and high gradient streams typically do not form true riffles. In sand-bed streams, the grain size distribution in the riffle area is similar to that within pools, and in high gradient streams, water flows from pool to pool in a step fashion. Although these streams do not form true pools, they normally form evenly spaced pools.

3.3.1 Survey Baseline

Following the layout of the U/S and D/S survey baseline and establishment of channel cross-section markers as described in Section 1.3.2, complete the following Module 2C datasheet blocks.

- Total length of the baseline (blocks 2C-1 and 2C-24)
- Location of the baseline (blocks 2C-2 and 2C-25)
- Distance between U/S distance intervals cross-section markers M1 and M2 and D/S distance intervals cross-section markers M3 and M4 (blocks 2C-3 and 2C-26)
- Total channel reach distance from the stream crossing structure to the second distance interval cross section (blocks 2C-4 and 2C-27)

Include additional comments in blocks 2C-5 and 2C-28. Additional measurements are recorded in the survey field book.

3.3.2 Channel Gradient

The channel gradient or slope is calculated from water's edge elevations taken at the two channel distance intervals. Using the distance interval cross-section elevations and distance measurements, multiply the rise/run ratio by 100 to calculate the percent slope. Record the estimated U/S and D/S percent channel gradient in blocks 2C-6 and 2C-29. Include known BM or assumed TBM location data and elevation, BS and FS shots, height of instrument, and feature elevation calculations in the survey field book.

3.3.3 Wetted Width

The wetted width is the horizontal distance between the water's edges on opposite sides of the stream measured at right angles to the general orientation of the streambanks or shoreline (Figure 3-6). Water surface under banks, protruding logs, stumps, and bars surrounded by water are included in the total distance. The wetted width of a multiple channel waterway is determined by measuring the total distance and subtracting the widths of sandbars and sediment islands. Record the U/S and D/S wetted width for the two distance intervals in blocks 2C-7 and 2C-8 and 2C-30 and 2C-31.

3.3.4 Bankfull Width

Bankfull width is the horizontal distance between streambanks at normal high water (bankfull stage) marks as determined by site indicators and at right angles to the direction of flow (Figures 3-7 and 3-8). The bankfull stage occurs just prior to flooding when the channel overflows with no banks exposed. In many instances, multiple indicators are used jointly to define bankfull stages. Bankfull indicators including top of pointbars, bank undercuts, stain lines, change in vegetation, and change in slope are described and illustrated in the following discussion.

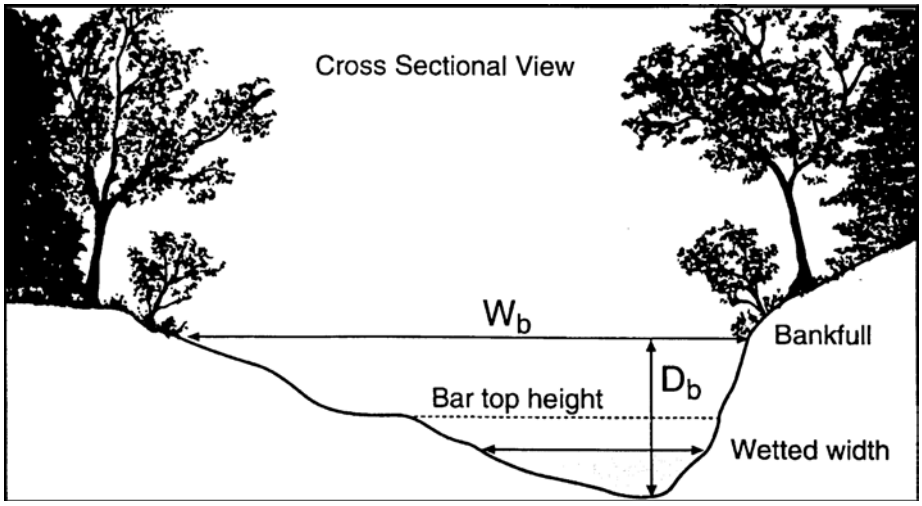


Figure 3-6. Stream Wetted Width and Bankfull Width (Wb) and Depth (Db)
(Johnston and Slaney, 1996)

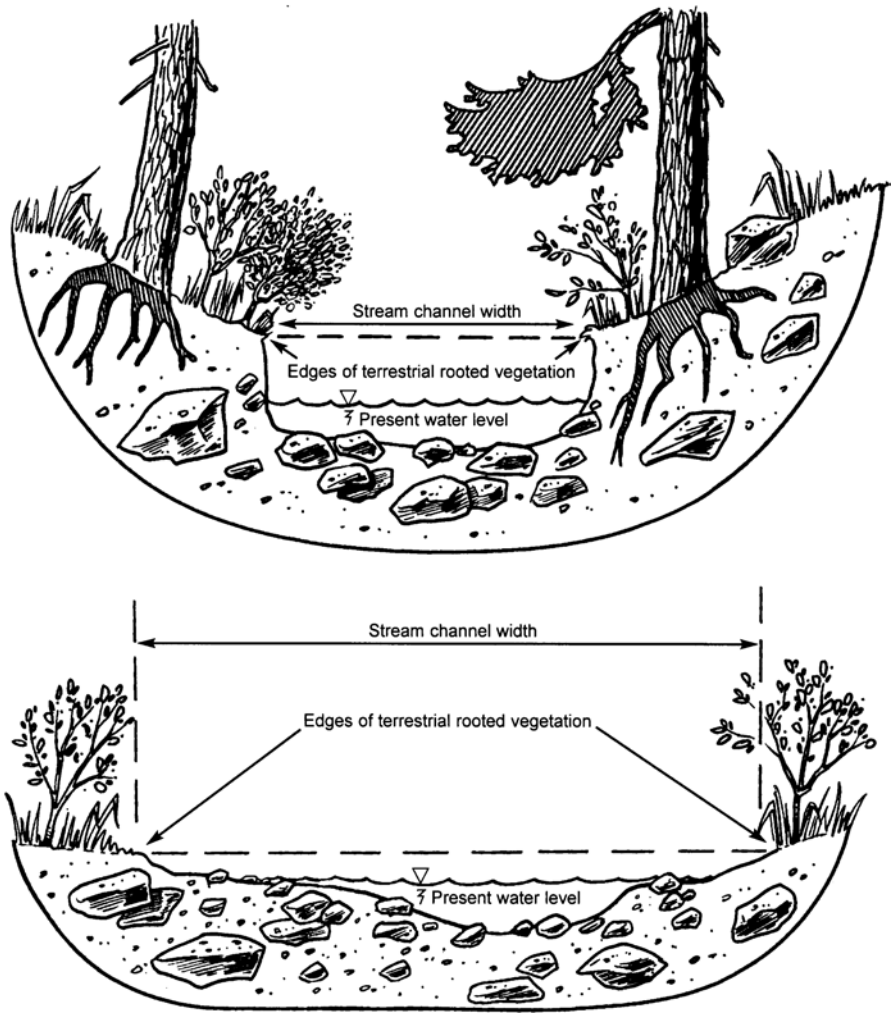


Figure 3-7. Determining Stream Channel Bankfull Width
(B.C. Ministry of Forests, 2002)

- *Top of Point bars* — Point bars are the result of stream material deposition on the inside of meander bends and represent the beginning location where the floodplain is being constructed by sediment deposition. Thus, the top of the point bar equates to the lowest possible bankfull stage (Figure 3-8).

Figure 3-8. River Point Bar Feature
(Photo by Chris Metcalf)

- *Stain Lines* — Look for water lines on streamside trees. Stain lines are typically created by frequent, low stage bankfull flows. The bankfull point will be at or above the highest stain line (Figure 3-9).

Figure 3-9. Streamside Tree Exhibiting Stain Lines (Photo by Chris Metcalf)

- *Change in Vegetation* — Identify the lower limit of perennial vegetation on the bank or a sharp break in vegetation types and/or density (Figure 3-10 and 3-11). On land below the floodplain, vegetation is absent, annual, or limited to tolerant wetland species. The lower limit of mosses or lichens may also indicate the bankfull.

Figure 3-10. Streamside Floodplain Vegetation (Photo by Chris Metcalf)

Figure 3-11. Streambanks Lined with Overhanging Vegetation
(Photo by Chris Metcalf)

- *Change in Slope* — The change from a vertical streambank to a flat or more horizontal floodplain slope is a good indicator of the transition to a bankfull stage. This is especially true for low-gradient meandering streams (Figure 3-12).

Figure 3-12. Streamside Riparian Area with Abrupt Changes in Slope
(Photo by Chris Metcalf)

- *Bank Undercuts* — In steep, entrenched channels lacking floodplains, bank undercuts may be used as an indicator of the bankfull stage (Figure 3-13).

Figure 3-13. Streambank Undercuts (Photo by Chris Metcalf)

At each distance interval cross-section, mark probable bankfull indicators using wire flags or flagging. Measure the width in feet. At any cross section with two or more channels, the sum of the channel widths determines the total bankfull width. Establish a datum at the highest bankfull stage for determining bankfull channel depths in Section 3.3.4. Record the U/S and D/S bankfull channel width measurements for the two distance intervals in blocks 2C-9 and 2C-10 and 2C-32 and 2C-33.

3.3.5 Bankfull Channel Depth

Measure the vertical distance from a horizontal line at the height of the bankfull width to the streambed at the distance interval cross sections. For smaller channels, run a level string or surveyors tape at the height of the bankfull width. Measure the vertical distance from the tape to the streambed at three points taken one-fourth, one-half, and three-quarters of the distance across the distance interval cross section with the surveyor's rod. Record the mean U/S and D/S bankfull depths for the two distance intervals in blocks 2C-11 and 2C-12 and 2C-34 and 2C-35.

3.3.6 Listed Flora

Identify (yes or no) if federal and/or state listed aquatic flora were observed in the U/S and D/S sections of the waterway during the survey (blocks 2C-13 and 2C-36). Use the listed aquatic plants photo log (Appendix C) to assist in making determinations. Note listed plants in the comments block (2C-23 and/or 2C-46).

3.3.7 Nonnative Flora

Identify (yes or no) if nonnative, invasive flora were observed in the U/S and D/S channel during the survey (blocks 2C-14 and 2C-37). Use the nonnative, invasive plants photo log (Appendix C) to assist in making determinations. Note identified species in the comments block (2C-23 and/or 2C-46).

3.3.8 Streambank Cover

Estimate the average percent cover of the waterway U/S and D/S streambanks between the first and second distance interval markers and select the range closest to actual conditions from blocks 2C-15 and 2C-18 and 2C-38 and 2C-41. Selections include 0 to 20 percent, 20 to 60 percent, and greater than 60 percent.

3.3.9 Streambank Slope Gradient

Estimate the average U/S and D/S slope gradients in degrees for the streambanks between the first and second distance interval cross-section markers. Record estimated slopes in blocks 2C-16 and 2C-19 and 2C-39 and 2C-42.

3.3.10 Streambank Height

Determine the average U/S and D/S streambank heights using a telescoping survey rod. Take a minimum of three measurements between the first and second distance interval markers. Record the averaged streambank heights in blocks 2C-17 and 2C-20 and 2C-40 and 2C-43.

3.3.11 Instream Cover

Instream cover refers to habitat available for aquatic species. Types of cover include:

- *Undercut (UC) Banks* — Streambanks that overhang the stream caused by water erosion.
- *Overhanging (OH) Vegetation* — Vegetation including trees, shrubs, and grasses that extends out from the water's edge over the surface of the stream within one to two feet of the water surface.
- *Deep Pools* — A depression or hole in the stream bottom where water is substantially deeper than the average depth of the stream.
- *Aquatic Plants* — Aquatic macrophytes.
- *Debris* — Logs, branches, and roots.

Select one or more of these cover type variables that are in areas of sufficient water depth (≥ 1 inch) from blocks 2C-21 and 2C-44.

3.3.12 Flow Velocity

The channel velocity is measured by calculating the average speed (feet/second) of an orange floated over a measured channel distance at the center of an area with even flow, uniform stream depth, and wetted width. A slow riffle is typically the best location. Observe the orange for 10 seconds and divide the distance it travels by 10. Record the estimated upstream flow velocity in blocks 2C-22 and 2C-45.

3.3.13 Waterway Survey Comments

Expound on observations and present additional comments concerning the waterway survey in the comments block (2C-23 and 2C-46). Examples of additional comments include listed plants, nonnative invasive plants, riparian vegetation, wildlife observed and water quality, etc.

3.3.14 What is Next?

Following completion of this Module 2C move on to Module 3: Crossing Structure.

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4. MODULE 3: CROSSING STRUCTURE

The purpose of this module is to collect and record data concerning the stream-road crossing structure features and conditions. For this portion of the field survey, the crossing structure procedures are divided into three modules that identify the type of crossing and the features and conditions of the crossing type. Based on field observations and condition assessments, field measurements may be required to complete this module.

4.1 MODULE 3

To complete this portion of the module, identify whether the crossing structure is a culvert, bridge, or low water crossing (block 3-1). If it is a culvert crossing, write in the number of separate culvert conduits that comprise the crossing in block 3-2. A box culvert with multiple sections is evaluated as a single culvert. Create a separate record for each culvert structure. Facing downstream, number the culverts sequentially from left to right starting with the number 1. Record the location of each culvert on the site drawing.

How data is recorded depends on the number of crossing culverts. Use the existing 3A-1 through 3A-3 modules for a crossing with one culvert (culvert number 1). For crossing with multiple culverts, use the extra module 3A datasheets for creating separate records for each culvert (culvert number 2, 3, 4, etc.). Make sure the culvert number and crossing ID is written in at the top of each datasheet.

Based on the type of crossing identified, the recorder proceeds to Module 3A-1 (Culvert Features), Module 3B-1 (Bridge Features), or Module 3C-1 (Low Water Crossing Features). In the following sections, the data fields are identified and procedures for completing the datasheet modules are described.

4.2 MODULE 3A-1: CULVERT LEVEL 1 FEATURES SURVEY

4.2.1 Culvert Identification

Record the culvert identification number in block 3A-1 based on the procedure previously discussed.

4.2.2 Culvert Type

Identify the type of culvert in block 3A-2. Selections include round, pipe elliptical, open arch, box, trough box, open box, and other. Write in other types of culverts observed and describe in the comments block. The general shape of typical types of culverts is shown in Figure 4-1.

4.2.3 Culvert Material

Identify the type of material from which the culvert is constructed in block 3A-3. Selections include corrugated metal, polyvinyl chloride, high-density polyethylene, reinforced concrete, iron, clay, and other. Write in the other types of culvert materials in the comments block.

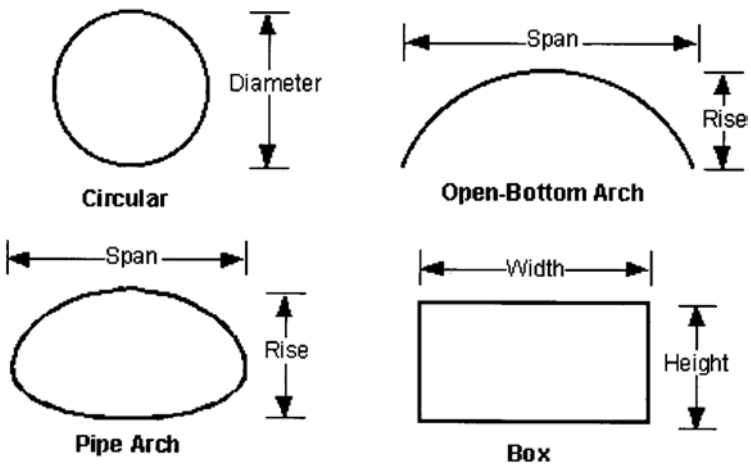

Figure 4-1. Culvert Types (Clarkin et. al., 2003)

4.2.4 Culvert Embeddedness

Identify (yes or no) if the culvert is embedded below the channel bottom in block 3A-4.

4.2.5 Inlet and Outlet Type

Identify the type of culvert inlet and outlet in blocks 3A-5 and 3A-6. Selections include projecting, headwall, wingwall, mitered, and other. Write in the other types of culvert inlet configurations observed in the comments block. Examples of the types of culvert configurations are shown in Figures 4-2 through 4-4.

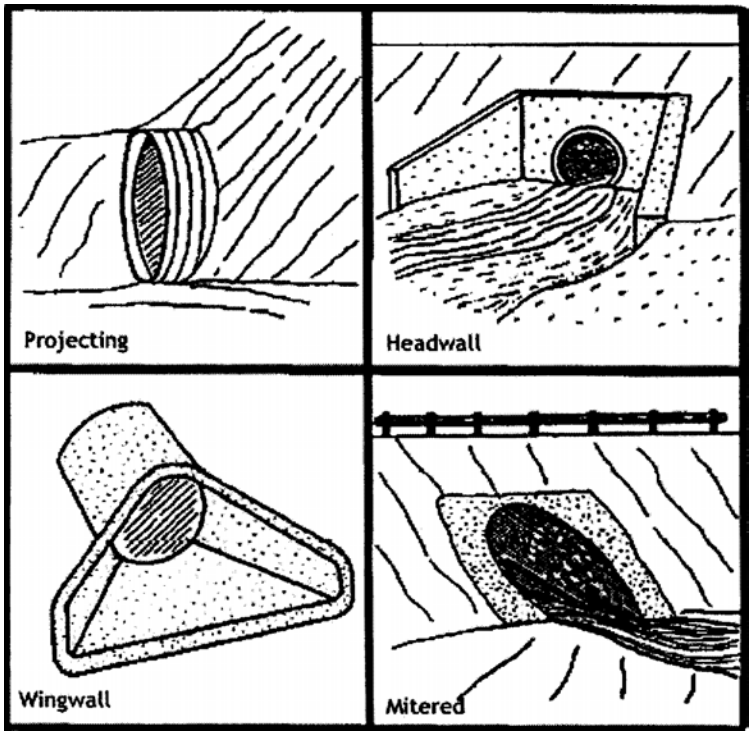

Figure 4-2. Culvert Inlet and Outlet Types (Normann et. al., 2001)

Figure 4-3. Single Culvert Crossing Concrete Headwall (Photo by Mike Rainer)

Figure 4-4. Double Culvert Concrete Headwall (Photo by Mike Rainer)

4.2.6 Culvert Inlet Basin Configuration

The configuration of the culvert inlet basin can directly influence plugging by debris transported by the stream (Figure 4-5). Inlet basins that maintain the natural channel configuration promote debris movement through the culvert, whereas channel widening upstream of the crossing culvert(s) increases plugging potentials. As water moves laterally during high water conditions, debris tends to accumulate in eddies and become perpendicularly oriented to the culvert opening. In cases where the culvert is submerged, debris frequently accumulates into woody rafts. Once the water recedes the raft

of materials tends to plug the culvert rather than pass through. Identify the culvert inlet basin configuration in block 3A-7.

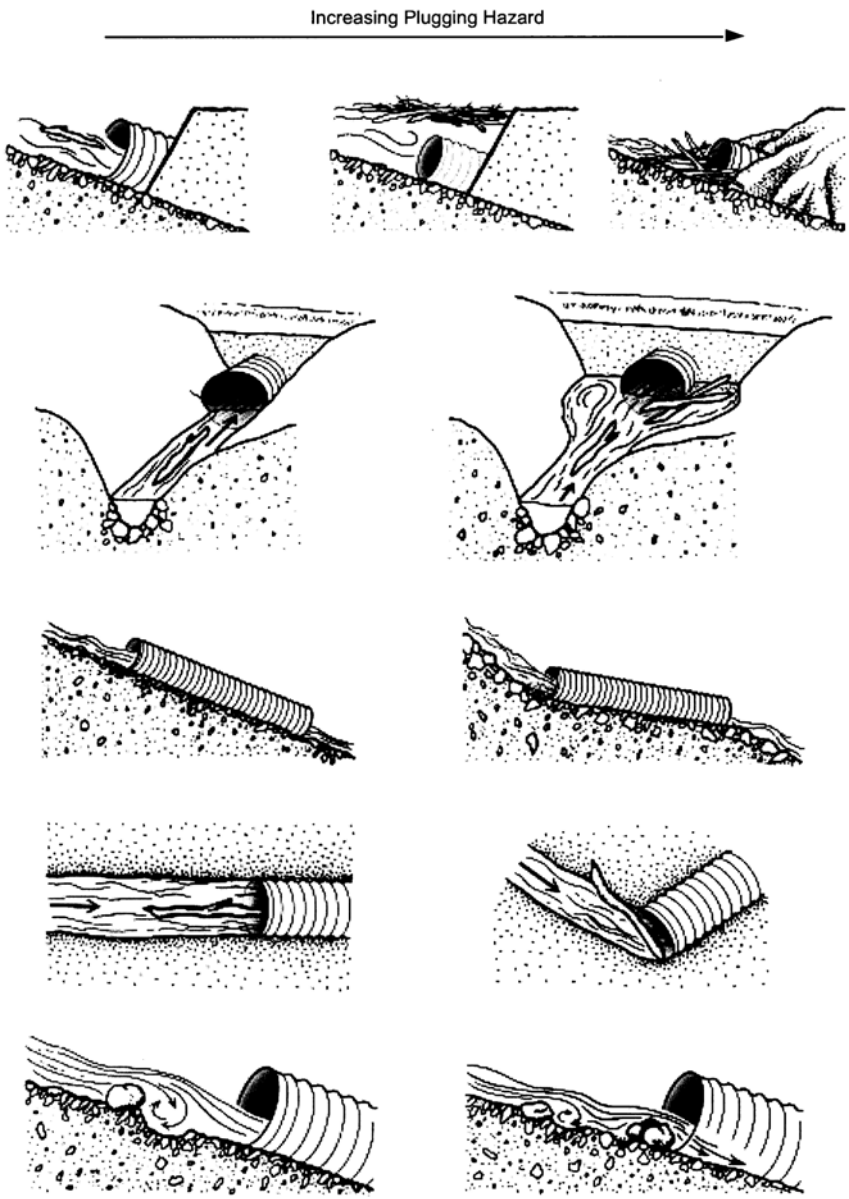

Figure 4-5. Culvert Configuration and Debris Plugging Potentials (Furniss et al., 1997)

4.2.7 Upstream Culvert Skew Angle

Culvert skew (alignment) with the existing channel strongly influences sediment transport and deposition and debris plugging potentials (Figure 4-5). Abrupt changes in channel direction promote plugging by increasing woody debris lodging. Identify the upstream angle of the culvert to the stream channel in block 3A-8. Selections include straight, 0 to 10 degrees, 10 to 20 degrees, 20 to 30 degrees, and greater than 30 degrees.

4.2.8 Culvert Crossing Fill Height

Measure the height of the fill from the top of the culvert to the top of the fill in block 3A-9 and the average height of fill above the top of the headwall (Figure 4-3) in block 3A-10 if applicable.

4.2.9 Culvert Crossing Fill Cover

Identify the predominate type(s) of fill cover present in block 3A-11. Selections include herbaceous, woody, and/or nonnative plants, bare ground, rock, and concrete. More than one cover type may be selected.

4.2.10 Culvert Crossing Features Comments

Expound on observations and present additional comments concerning culvert-crossing features in block 3A-12. Examples of additional comments include recent crossing repairs, heavily used crossing, beaver activity, nonnative invasive plants growing on crossing fill, etc.

4.2.11 What is Next?

Once Module 3A-1 is completed move to Module 3A-2, Culvert Level 1 Conditions Survey.

4.3 MODULE 3A-2: CULVERT LEVEL 1 CONDITIONS SURVEY

4.3.1 Culvert Crossing Fill Condition

Identify the overall condition of the crossing fill in block 3A-13. Selections include:

- *Good* — Fill is structurally protected or well vegetated and shows no signs of erosion.
- *Fair* — Fill surface has 50 percent or less vegetation coverage and shows evidence of isolated sheet and rill erosion.
- *Poor* — Fill surface is void or nearly void of vegetation and exhibits extensive rill erosion and/or gully formation.

Select only one condition variable.

4.3.2 Culvert Structural Condition

Identify the overall structural condition of the culvert in block 3A-14. Selection includes:

- *Good* — Culvert is structurally sound. Slightly rusted.
- *Fair* — Culvert is beginning to show signs of deterioration or stress such as advanced rusting, cracking, or partial collapse. Current condition is not compromising the capability of the culvert to function.
- *Poor* — Culvert is not structurally sound and has extensive cracking, rusting, collapse, and/or other defects that have deteriorated the structural integrity and capability of the culvert to function properly; structure failure is imminent and is failing.

Select only one condition variable.

4.3.3 Culvert Inlet and Outlet Condition

Identify the structural condition of the culvert inlet and outlet in blocks 3A-15 and 3A-16. Selections include:

- *Not Impaired* — No obstruction is present and the culvert inlet is structurally sound and undamaged.
- *Scouring* — Stream bottom materials have been scoured by water flows.
- *Inlet Islands* — Sediment islands have formed near the culvert.
- *Blocked* — Greater than 30 percent of the culvert is blocked by debris.

More than one inlet condition variable may be selected.

4.3.4 Culvert Crossing Conditions Comments

Expound on observations and present additional comments concerning culvert-crossing conditions in block 3A-17. Examples of additional comments include recent culvert repair or replacement, culvert installation damage, woody debris blockage, fish blockage, etc.

4.3.5 What is Next?

If selected culvert condition variables are **not** *good* or *fair* for blocks 4.3.1 and 4.3.2 and *not impaired* for block 4.3.3, move to Module 3A-3 and conduct a Culvert Level 2 Survey. Survey equipment and techniques as presented in Section 1.3.2 are required to complete the Level 2 survey. If the culvert conditions were other than those previously mentioned, the Level 1 culvert conditions module is complete; move on to Module 4, Road Approaches.

4.4 MODULE 3A-3: CULVERT LEVEL 2 SURVEY

4.4.1 Culvert Length

Measure the full length of the culvert and record the measurement in feet (Figure 4-6) in block 3A-18.

4.4.2 Culvert Diameter

Measure the diameter of round culverts and record the measurement in feet (Figure 4-6) in block 3A-19.

4.4.3 Culvert Rise and Span

Measure the rise and span of pipe elliptical and open arch culverts and record the measurement in feet in blocks 3A-20 and 3A-21.

4.4.4 Box Culvert Height and Width

Measure the height and width of box culverts and record the measurement in feet in blocks 3A-22 and 3A-23.

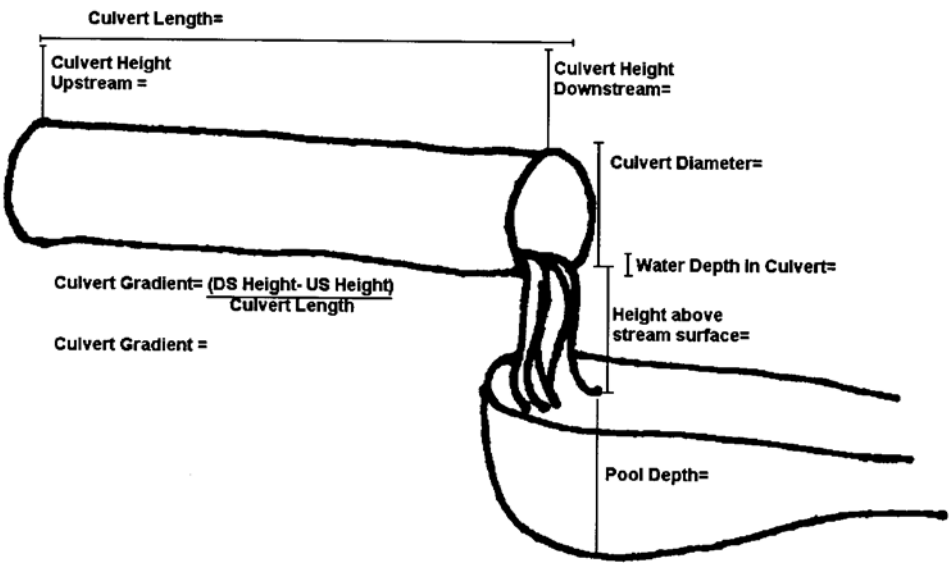

Figure 4-6. Culvert Features (Oregon Watershed Enhancement Board, 2001)

4.4.5 Culvert Gradient

The culvert slope is determined using the inlet and outlet invert elevations (Section 4.4.6). Record the calculated slope in percent in block 3A-24. Include known BM or assumed TBM location and elevation data, inlet and outlet shots, and calculations in the survey field book.

4.4.6 Inlet and Outlet Elevation

Take the inlet and outlet elevation shots from the top of the culvert and record the elevations (Figure 4-6) in blocks 3A-25 and 3A-29. Record the known BM or assumed TBM location and elevation data in the survey field book.

4.4.7 Culvert Embeddedness

Measure the distance the culvert inlet and outlet is above or below the channel bottom and record in blocks 3A-26 and 3A-30 and 3A-27 and 3A-31. For the blocks not filled, write in an NA for not applicable; if the culvert is at the channel bottom, place an NA in both blocks.

4.4.8 Bankfull Pool Depth

Use the survey rod to measure the bankfull depth of the pool immediately downstream of where the culvert water plunges into the stream at the outlet (Figure 4-6). If there is not a discernible drop between the culvert and the stream, measure the depth of the pool/stream at the point where the velocity of the water leaving the culvert visibly dissipates. Record the pool depth in blocks 3A-28 and 3A-32.

4.4.9 Culvert Outfall Drop

Measure the vertical drop between the bottom of the culvert and the surface of the pool at the culvert outfall (Figures 4-6 and 4-7). Record the distance in block 3A-33.

Figure 4-7. Dual Stream Crossing Culverts Outfall Drop (Photo by Mike Rainer)

4.4.10 Culvert Water Depth

Use the survey rod to determine the depth of water flowing through the culvert at the U/S culvert inlet deepest point in block 3A-34.

4.4.11 Culvert Fill Eroded Volume

Estimate the volume of sediment that has been eroded from the crossing fill. Record the volume in cubic yards in block 3A-35.

4.4.12 Potential Culvert Fill Eroded Volume

Estimate the potential volume of sediment that could be generated by the crossing fill. Record the volume in cubic yards in block 3A-36.

4.4.13 Sediment Delivery

Estimate the percent of potentially eroded crossing fill material sediments that enter the waterway in block 3A-37. The sediment delivery estimates are based on the assumption that the overall integrity of the crossing fill will not be compromised and complete failure of the structure is not imminent. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

4.4.14 Culvert Crossing Survey Comments

Expound on culvert crossing observations and measurements in block 3A-38.

4.4.15 What is Next?

After the completion of Module 3A-3, move on to Module 4, Road Approaches.

4.5 MODULE 3B-1: BRIDGE LEVEL 1 FEATURES SURVEY

4.5.1 Bridge Type

Identify if the bridge structure is permanent (Figures 4-8, 4-9, and 4-10) or temporary (Figures 4-11 and 4-12) in block 3B-1.

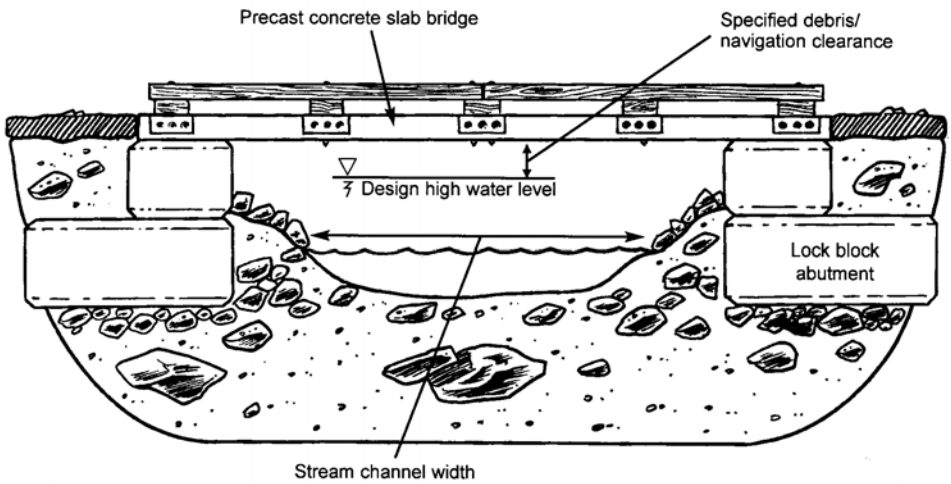

Figure 4-8. Concrete Slab Bridge (B.C. Ministry of Forests, 2002)

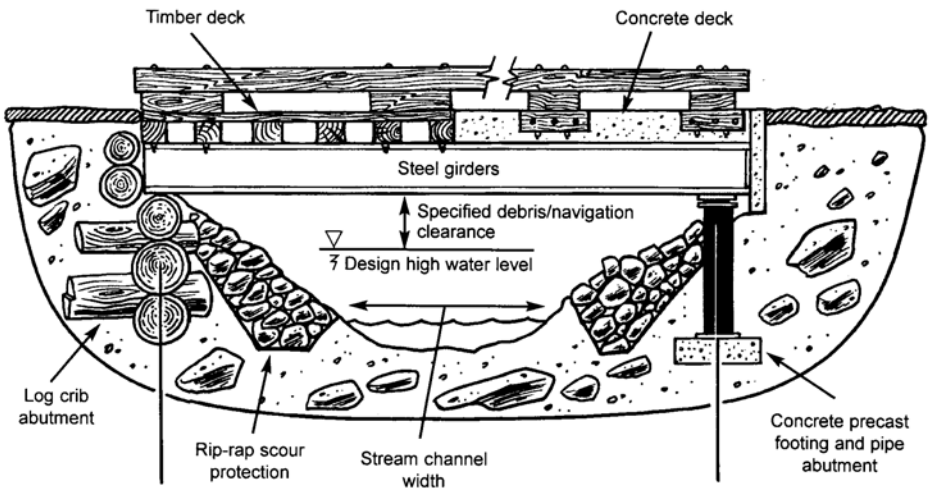

Figure 4-9. Steel Girder Bridge (B.C. Ministry of Forests, 2002)

4.5.2 Deck Materials

Identify the type of bridge deck materials in block 3B-2. Selections include concrete, metal, wood, or other. Types and features of permanent road-stream crossing bridge structures are shown in Figures 4-10, 4-11, and 4-12.

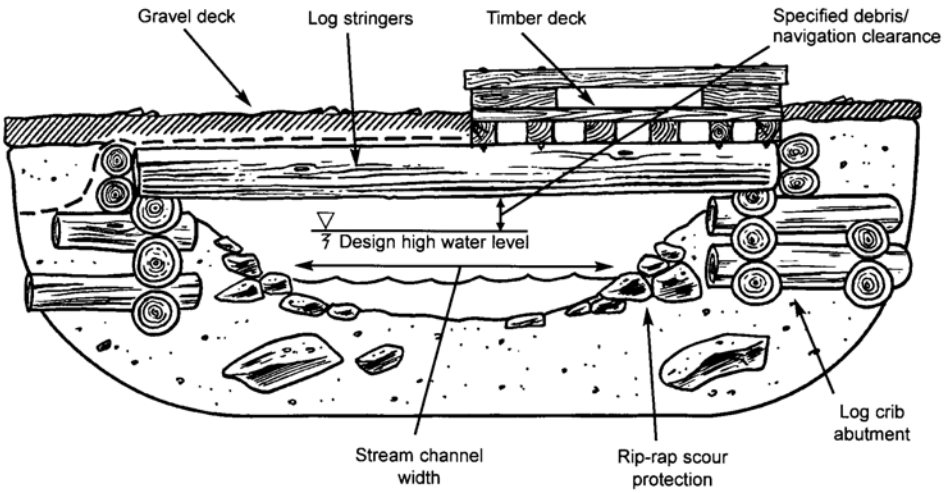

Figure 4-10. Log Stinger Bridge (B.C. Ministry of Forests, 2002)

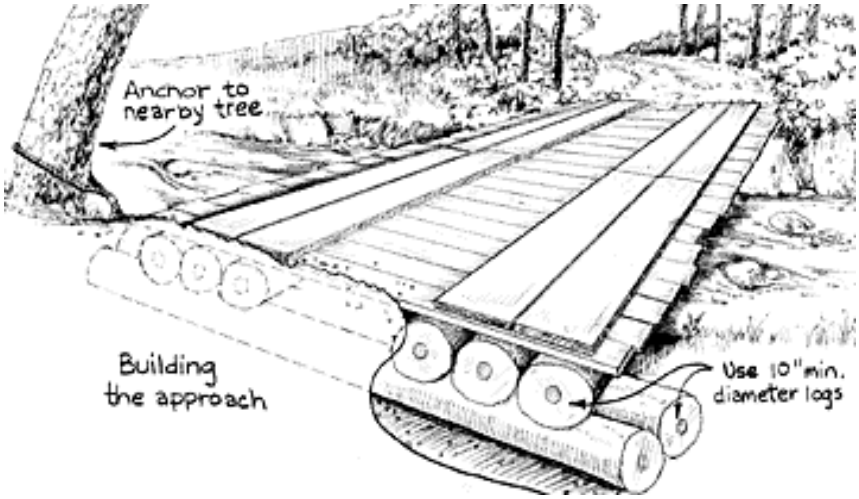

Figure 4-11. Temporary Log Stinger Bridge
(University of Minnesota Extension Service, 2002)

Figure 4-12. Temporary Steel Bridge (University of Minnesota Extension Service, 2002)

4.5.3 Bridge Features Comments

Expound on observations and present additional comments concerning bridge-crossing features in block 3B-3. Examples of additional comments include recent bridge repairs, heavily used crossing, etc.

4.5.4 What is Next?

After the completion of Module 3B-1, move on to Module 3B-2, Bridge Level 1 Conditions Survey.

4.6 MODULE 3B-2: BRIDGE LEVEL 1 CONDITIONS SURVEY

4.6.1 Deck Cover

Identify the degree to which the bridge deck is covered by road approach fill materials in block 3B-4. Selection includes the following:

- *Clear* — No or minimal (less than 25 percent cover) road prism fill material is present on the bridge deck.
- *Semi-Covered* — Eroded road prism materials cover an estimated 25 to 50 percent of the bridge deck.
- *Covered* — Eroded road prism materials cover greater than 50 percent of the bridge deck.

Deck cover by road fill indicates that materials are being moved and deposited on the deck by road maintenance activities and/or water erosion (Figure 4-13).

Figure 4-13. Road-Stream Crossing Bridge Covered with Road Fill Materials
(Photo by Mike Rainer)

4.6.2 Deck Cover Thickness

For bridge decks covered by road fill, write in the average depth in block 3B-5. Take measurements at three different locations on the deck to calculate the average.

4.6.3 Bridge Sediment Delivery Features

Identify features of the bridge that could promote stream sedimentation in block 3B-6. Selections include none, lip damage, deck holes, or other features. Bridge design or damage to the deck could create conditions that promote delivery of road fill materials directly into streams (Figure 4-14).

Figure 4-14. Bridge Abatement Structure that Allows Direct Deposition of Road Fill Materials into the Stream Channel (Photo by Mike Rainer)

4.6.4 Bridge Conditions Comments

Expound on observations and present additional comments concerning bridge-crossing conditions in block 3B-7. Examples of additional comments include effects of road grading on deck cover conditions, overall texture of deck cover fill, etc.

4.6.5 What is Next?

If the bridge deck is covered by road fill materials or has features that promote sediment delivery into the stream channel, move to the Module 3B-3 and conduct a Bridge Level 2 Survey. If the bridge conditions were other than those previously mentioned, the Level 1 bridge survey is complete; move on to Module 4, Road Approaches.

4.7 MODULE 3B-3: BRIDGE LEVEL 2 SURVEY

4.7.1 Bridge Deck Span

Measure the total length of the deck span (Figure 4-15) and record the distance in block 3B-8.

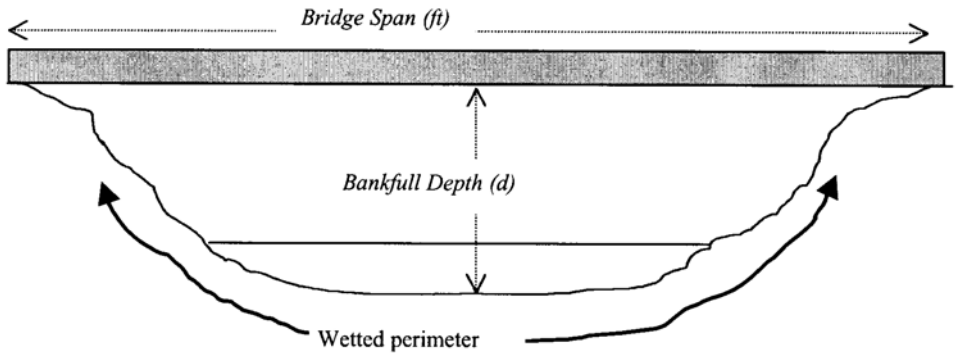

Figure 4-15. Bridge Span (Oregon Department of Forestry, 2002)

4.7.2 Bridge Deck Width

Measure the total bridge deck width and record the distance in block 3B-9.

4.7.3 Span to Streambed Depth

Measure the vertical distance from the bottom of the bridge span to the streambed at points taken one-fourth, one-half, and three-quarters of the distance across the wetted perimeter of the channel below the bridge (Figure 4-15). Record the mean depth in block 3B-10.

4.7.4 Potential Eroded Volume

Estimate the cubic yards of road approach fill deposited on the road deck that could be delivered to the stream in the future in block 3B-11. Base the calculation on the average depth of the fill material on the deck and the span and width of the bridge deck.

4.7.5 Sediment Delivery

Estimate the percent of road deck sediments that could enter the waterway in block 3B-12. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

4.7.6 Bridge Survey Comments

Expound on observations and measurements in block 3B-13.

4.7.7 What is Next?

Following completion of Module 3B-3, move on to Module 4, Road Approaches.

4.8 MODULE 3C-1: LOW WATER CROSSING LEVEL 1 FEATURES SURVEY

4.8.1 Low Water Crossing Type

Identify if the low water crossing (also known as a ford) is unimproved or improved (Figures 4-16 and 4-17) in block 3C-1.

Figure 4-16. Unimproved Low Water Crossing (Photo by Mike Rainer)

Figure 4-17. Improved Low Water Crossing (Photo by Mike Rainer)

4.8.2 Low Water Crossing Materials

Identify the dominant type of material that comprises the low water crossing in block 3C-2. Selections include native, rock, concrete, synthetic, and other.

4.8.3 Low Water Crossing Features Comments

Expound on observations and present additional comments concerning low water crossing features in block 3C-3. Examples of additional comments include recent low water crossing repairs, size of low water crossing materials, heavily used crossing, etc.

4.8.4 What is Next?

After the completion of Module 3C-1, move on to Module 3C-2, Low Water Crossing Level 1 Conditions Survey.

4.9 MODULE 3C-2: LOW WATER CROSSING LEVEL 1 CONDITIONS SURVEY

4.9.1 Low Water Crossing Condition

Identify the overall condition of the low water crossing in block 3C-4. Selections include the following:

- *Good* — Crossing and adjacent areas are relatively stable and there is no evidence of accelerated channel or streambank erosion.
- *Fair* — Improper crossing structure, maintenance, and/or heavy use have created unstable conditions. Continued use of the low water crossing, in the present condition, will reduce the integrity of the site and increase site sediment contributions.
- *Poor* — The crossing is experiencing extensive erosion of the waterway channel and/or streambank and is contributing substantial amounts of sediment to the waterway.

Select one condition variable.

4.9.2 Low Water Crossing Condition Comments

Expound on observations and present additional comments concerning low water crossing conditions in block 3C-5. Examples of additional comments include recent low water crossing repairs, heavily used crossing, low water crossing damage, blocked fish passage, nonnative plants, backed up flows resulting from improper low water crossing depth, etc.

4.9.3 What is Next?

If the low water crossing condition is identified as good, move on the Module 4, Road Approaches. If the condition is other than good, move on to Module 3C-3, Low Water Crossing Level 2 Survey.

4.10 MODULE 3C-3: LOW WATER CROSSING LEVEL 2 SURVEY

4.10.1 Low Water Crossing Length

Identify the length of the low water crossing between the stream channel centerline and each streambank wetted perimeter for road approaches AP-1 and AP-2 in blocks 3C-6 and 3C-12.

4.10.2 Low Water Crossing Width

Identify the average width of the low water crossing between the stream channel centerline and each streambank wetted perimeter for road approaches AP-1 and AP-2 in blocks 3C-7 and 3C-13.

4.10.3 Approach Gradient

Use the structure length and corresponding elevation shots or a clinometer to determine the gradient for AP-1 and AP-2 low water crossing streambank approaches. Record slopes in percent in blocks 3C-8 and 3C-14. Include known BM or assumed TBM location and elevation data, BS and FS elevation shots, height of instrument, and calculations in the survey field book.

4.10.4 Low Water Crossing Flow Depth

Measure the stream flow depth in the deepest point in the low water crossing and record the measurement in block 3C-9.

4.10.5 Potential Eroded Volume

Estimate the cubic yards of streambank sediments that could be generated by the low water crossing for road approaches AP-1 and AP-2 in blocks 3C-10 and 3C-15.

4.10.6 Sediment Delivery

Estimate the percent of low water crossing sediments that could enter the waterway for road approach AP-1 and AP-2 in blocks 3C-11 and 3C-16. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

4.10.7 Low Water Crossing Survey Comments

Expound on low water crossing survey observations and measurements in block 3C-17.

4.10.8 What is Next?

Following completion of Module 3C-3, move on to Module 4, Road Approaches.

5. MODULE 4: ROAD APPROACHES

This module defines the data fields for describing the convergence of the two unpaved road approaches at a waterway crossing. The identification of the road approaches is determined by standing on the crossing facing downstream; the road to the right is identified as road approach AP-1 and the road to the left is identified as road approach AP-2. The left and right side of each road approach is determined by standing on the road facing the stream crossing and designating the left and right roadsides for the survey.

5.1 MODULE 4A-1: ROAD APPROACH LEVEL 1 FEATURES SURVEY

5.1.1 Traffic Lanes

Identify the number of traffic lanes in blocks 4A-1 and 4B-1.

5.1.2 Configuration

Identify the overall configuration of the road approach (Figure 5-1) in blocks 4A-2 and 4B-2. Selections include:

- *Crowned* — High point in the center of the road.
- *Outslope* — High point on the inside of the road.
- *Inslope* — High point on outside of the road.
- *Flat* — Road prism with no high point configuration (Figure 5-2)

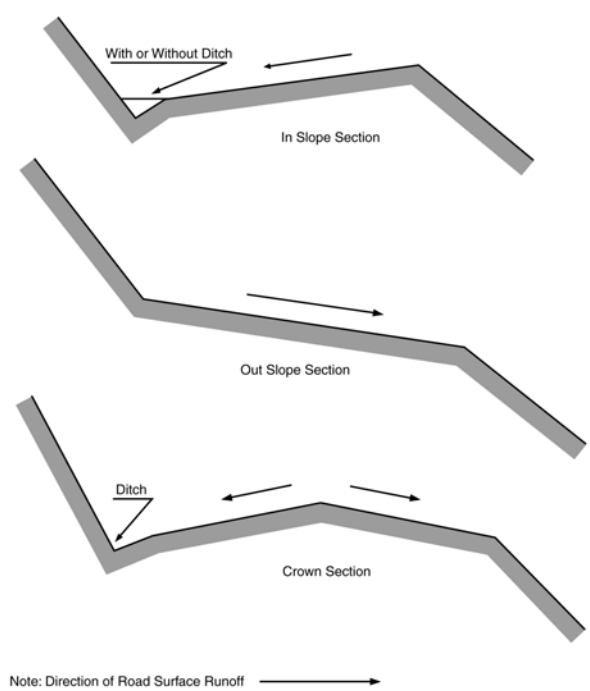

Figure 5-1. Unpaved Road Configurations (Moll et. al., 1997)

Figure 5-2. Unpaved Road with a Flat Road Prism (Photo by Mike Rainer)

5.1.3 Surface Material

Identify the overall type of road prism road surface material in blocks 4A-3 and 4B-3. Selections include native soil, sand-clay, gravel aggregate, crushed rock aggregate, chemical soil amendment, and other. Native soil surface materials refer to a road solely constructed with on-site soil materials with no additional surfacing added. Provide details of other types of material in the comments block.

5.1.4 Road Prism Elevation

Identify the overall grade of the road prism in relation to the grade of natural ground in blocks 4A-4 and 4B-4. Selections include:

- *Above Grade* — The road prism has been constructed at a grade above the surrounding natural ground (Figure 5-3).
- *At Grade* — The road prism is maintained at a relatively flush elevation with surrounding natural ground (Figure 5-4).
- *Below Grade* — Extensive road grading and/or erosion has removed surface materials resulting in a road prism that is below the grade of natural ground (Figure 5-5).

Measure or estimate the average distance of the road prism above or below the road prism and record the measurements in blocks 4A-4 and 4B-4.

Figure 5-3. Above Grade Unpaved Road (Photo by Chris Metcalf)

Figure 5-4. At Grade Unpaved Road (Photo by Mike Rainer)

Figure 5-5. Below Grade Unpaved Road (Photo by Mike Rainer)

5.1.5 Road Maintenance Berms

Identify the general location (left side, right side, both sides, or none) of historic and/or recent road grading maintenance berms in blocks 4A-5 and 4B-5. Examples of roadside maintenance berms are shown in Figures 5-6 and 5-7.

Figure 5-6. Roadside Maintenance Berm (Photo by Mike Rainer)

Figure 5-7. Roadside Maintenance Berm and False Ditch (Photo by Mike Rainer)

5.1.6 Level of Road Maintenance

Identify the level of road maintenance observed at the time of the survey in blocks 4A-6 and 4B-6. Selections include:

- *Extensive* — Evidence of extensive road segment grading and ditching activity.
- *Minor* — Evidence of spot road repairs and minimal road segment grading and ditching.
- *Other* — Identify other road maintenance level in comments field.

5.1.7 Broad-Based Dips

Identify (yes or no) if rolling dips are present on the road prism in blocks 4A-7 and 4B-7. Rolling dips are gently sloping excavations running diagonally across the road surface that are similar to waterbars in function but are different with regard to design and use. A cross-section and profile view of a rolling dip is presented in Figure 5-8.

5.1.8 Waterbars

Identify (yes or no) if waterbars are present on the road prism in blocks 4A-8 and 4B-8. A water bar is a narrow berm and excavation constructed diagonally across the road surface. The height of the structure may vary from 1 to 3 feet. The purpose of the waterbar is to reduce the accumulation of water and divert runoff to a controlled discharge point at predetermined intervals. Waterbars are typically installed at a 30 to 45-degree downslope angle from the road prism centerline. A cross-section and profile view of a water bar is presented in Figure 5-8.

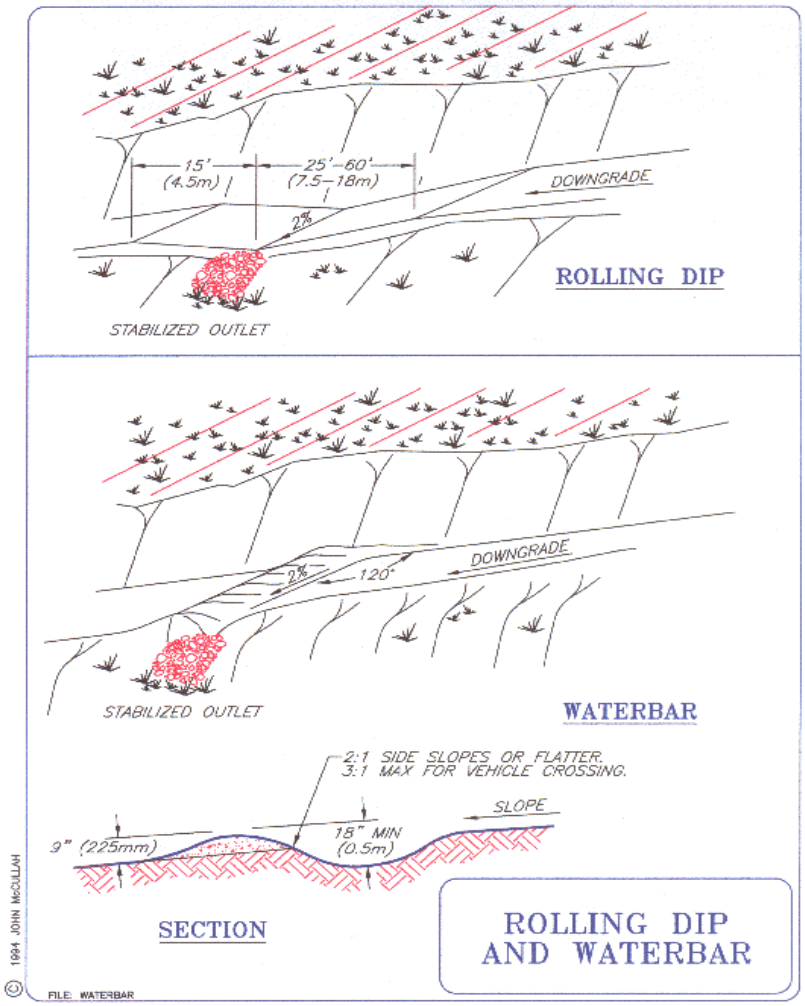

Figure 5-8. Rolling Dip and Water Bar Specifications
(Salix Applied Earthcare)

5.1.9 Improved Drain

Identify the general location (left side, right side, or both sides) of an improved roadside drainage system in blocks 4A-9 and 4B-9. The indicators of an improved drainage conditions include:

- Road prism configuration (crown or outslope) has been used to facilitate runoff sheet flow directly into receiving natural drainways.
- Drainage ditches have been constructed to collect and deliver runoff to a discharge point.

5.1.10 Unimproved Drain

Identify the general location (left side, right side, or both sides) of unimproved roadside drainage system in blocks 4A-10 and 4B-10. The indicators of unimproved drainage conditions include:

- Insloping has concentrated runoff along the road inside road cut.

- The road has false ditches (Figures 5-9 and 5-10) that have formed within or along the road prism. False ditches are not a drainage design feature.
- No practices or road configuration is in place to control and manage road runoff in a nonerosive manner.

Figure 5-9. Inslope False Ditch Created After a Rainstorm (Photo by Mike Rainer)

Figure 5-10. Road Prism False Ditch and Rill Erosion (Photo by Mike Rainer)

5.1.11 Ditch Berm

Identify the general location (left side, right side, or both sides) of barriers or check dams within roadside drainage ditches in blocks 4A-11 and 4B-11. Ditch berms are typically concrete barriers constructed across the ditch to reduce water velocities (Figures 5-11 and 5-12).

Figure 5-11. Roadside Ditch Concrete Berm (Photo by Mike Rainer)

Figure 5-12. Roadside Ditch Rock Check Dams (Photo by Mike Rainer)

5.1.12 Ditch Turnout

Identify the general location (left side, right side, or both sides) of roadside turnouts in blocks 4A-12 and 4B-12. A turnout is a transitional excavated depression that intercepts and conveys roadside

runoff to a stable discharge outlet. Turnouts serve to convert a concentrated flow of runoff to nonerosive sheet flow. An example of a turnout is presented in Figure 5-13.

Figure 5-13. Roadside Turnout (Photo by Mike Rainer)

5.1.13 Armored Drain

Identify the general location (left side, right side, or both sides) of synthetic materials that have been used to line constructed ditches in blocks 4A-13 and 4B-13.

5.1.14 Holding Pond

Identify the general location (left side, right side, or both sides) of roadside holding ponds in blocks 4A-14 and 4B-14. An example of a holding pond is presented in Figure 5-14.

5.1.15 Hay Bales/Silt Fences

Identify the general location (left side, right side, or both sides) of roadside hay bales and/or silt fences in blocks 4A-15 and 4B-15. Examples of hay bales and silt fences are presented in Figure 5-15.

5.1.16 Improved Drain Outlet

Identify the general location (left side, right side, or both sides) of practices installed to move water collected in the roadside drainage system into receiving waterways in a nonerosive manner in blocks 4A-16 and 4B-16. Examples include drop pipes and outlets protected by riprap.

Figure 5-14. Degraded Roadside Holding Pond (Photo by Mike Rainer)

Figure 5-15. Ineffective Silt Fence/Hay Bale Treatment (Photo by Mike Rainer)

5.1.17 Unimproved Drain Outlet

Identify the general location (left side, right side, or both sides) of unprotected points at which the road drainage system discharges directly into receiving waterways in blocks 4A-17 and 4B-17. These outlets have no runoff, erosion, or sediment control practices at discharge points.

5.1.18 No Drain Outlet

Identify the general locations (left side, right side, or both sides) where there is no evidence of a direct discharge point into receiving waterways in blocks 4A-18 and 4B-18.

5.1.19 Other Practices

Identify the general location (left side, right side, or both sides) and briefly describe other roadway erosion, runoff, and sediment control practices observed during the survey in blocks 4A-19 and 4B-19.

5.1.20 Ditch Ground Cover

Identify the dominant type of ground cover for the left and/or right road approach ditch system in block 4A-20 and 4B-20. Selections include bare soil, vegetation, synthetic material, concrete, or other. Describe other types of ground cover in comments blocks 4A-25 and 4B-25.

5.1.21 Dominant Roadside Vegetation

Identify the dominant types of roadside vegetation in blocks 4A-21 and 4B-21. Selections include woodland, wetland, grassland, shrubland, and bare soil.

5.1.22 Roadside Nonnative Plants

Identify (yes or no) if roadside nonnative, invasive plant species are present in blocks 4A-22 and 4B-22. Species that occur in northwest Florida are presented in Appendix C. Note identified species in comments blocks 4A-25 and 4B-25.

5.1.23 Roadside Landuse

Identify the dominant landuses in blocks 4A-23 and 4B-23. Selections include commercial, residential, row crops, pasture, barren land, borrow pit, silviculture, forested, and/or other. More than one landuse may be selected for left and right roadside areas. Note any additional landuse features or linkages between landuses in the comments blocks in 4A-25 and 4B-25.

5.1.24 Roadside Cultural Features

Identify if roadside historic or prehistoric features were observed during the course of the survey. Note the characteristics, conditions, and/or features of the site in the comments in block 4A-24 and 4B-24.

5.1.25 Road Approach Features Comments

Write in additional road approach features comments in blocks 4A-25 and 4B-25.

5.1.26 What is Next?

Following completion of Module 4A-1 and 4B-1, move on to Module 4A-2 and 4B-2, Road Approach Level 1 Conditions Survey.

5.2 MODULE 4A-2: ROAD APPROACH LEVEL 1 CONDITIONS SURVEY

5.2.1 Cohesive Condition of the Road Prism

Identify the overall cohesive condition of the road prism surface materials at the time of the survey in blocks 4A-26 and 4B-26. Selections include:

- *Compact* — Road surface exhibits minimal loose material and is relatively stable (Figure 5-16).

Figure 5-16. Compact Unpaved Road Surface (Photo by Mike Rainer)

- *Loose* — Road surface exhibits extensive loose surface materials from uncompacted grading operations and/or erosion and sediment deposition within the road (Figure 5-17).

Figure 5-17. Loose Fill Unpaved Road Surface (Photo by Mike Rainer)

- *Rills* — Road surface is rilled by concentrated runoff (Figure 5-18).

Figure 5-18. Road Rill Erosion (Photo by Mike Rainer)

- *Gullied* — Highly concentrated runoff has created a gully or gullies within the road prism (Figure 5-19).

Figure 5-19. Road Prism Gully (Photo by Mike Rainer)

Select one of more conditions that represent the overall condition of road surface materials stability.

5.2.2 Road Drainage System Condition

Identify the overall condition of the road drainage system in blocks 4A-27 and 4B-27. Selections include:

- *Good* — Road prism configuration has been utilized to create nonerosive natural drainways that sheet flow discharge into adjacent lands. Drainage system drainage features are in place and well maintained.
- *Fair* — Natural drainway and/or constructed drainage systems are in place and functioning. Minor erosion is occurring within the drainage system because of the lack of maintenance.
- *Poor* — The road prism and/or adjacent lands are suffering from extensive rill and/or gully erosion associated with existing natural drainway or constructed drainage systems. False ditches are eroding road prism materials.

5.2.3 Drainage System Outlet Condition

Identify the overall condition of the road drainage outlets in blocks 4A-28 and 4B-28. Selections include:

- *Good* — Water outlet control practices are in place and functioning at drainage discharge points. Runoff enters the waterway in a nonerosive manner and causes minimal waterway disturbance.
- *Fair* — Water outlet control practices are in place and functioning. Minor erosion and/or channel disturbance has occurred because of a lack of maintenance.
- *Poor* — No water control practices are present at drainage discharge points. Direct delivery of runoff into the waterway has resulted in extensive erosion of the streambank and/or disturbance of the waterway. Drainage runoff is diverted into the road prism and is discharged directly into the waterway at the crossing structure.

5.2.4 Road Approach Conditions Comments

Write in additional road condition comments in blocks 4A-29 and 4B-29.

5.2.5 What is Next?

If selected road approach condition variables were **not** *compact* and drainage system variables were not *good* or *fair* move to Module 4A-3 and 4B-3 and conduct a Road Approach Level 2 Survey. Survey equipment and techniques as presented in Section 1.3.2 are required to complete the Level 2 Survey.

5.3 MODULE 4A-3: ROAD APPROACH LEVEL 2 SURVEY

5.3.1 Road Length

Measure the distance from the road approach hydrologic break to the center of the crossing structure. The hydrologic break is the road location furthest from the crossing where runoff flows away from

rather than towards the crossing. This break in stormwater flows generally occurs on the hillcrest. Record road length distances in blocks 4A-30 and 4B-30.

5.3.2 Road Width

Determine the average road width from three different cross sections along the road approach. Base width measurements on the estimated road grading width. Record average width in blocks 4A-31 and 4B-31.

5.3.3 Road Slope

Use the road approach distance and corresponding elevation shots or a clinometer to determine the gradient of the road approach. Record slope in percent in blocks 4A-32 and 4B-32. Include known BM or assumed TBM location and elevation data, BS and FS elevation shots, height of instrument, and calculations in the survey field book.

5.3.4 Potential Road Prism Eroded Volume

Estimate the potential volume of sediment that could be generated by the road prisms and record the volume in cubic yards in blocks 4A-33 and 4B-33. An equation for estimating potential road prism erosion in cubic yards is as follows:

$$\frac{T \times L \times W}{27}$$

Where:

T = Average thickness of loose road fill (in feet) over the measured length and width of the road prism
L = Measured length of the road approach in feet
W = Average width of the road approach road prism measured in feet
27 = Cubic feet per cubic yard

5.3.5 Sediment Delivery

Estimate the percent of potentially eroded road prism fill material sediments that enter the waterway in blocks 4A-34 and 4B-34. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

5.3.6 Road Approach Survey Comments

Record additional Level 2 survey comments in blocks 4A-35 and 4B-35.

5.3.7 What is Next?

Following the completion of Module 4, move on to Module 5, Roadside Soil Erosion Features.

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6. MODULE 5: ROADSIDE SOIL EROSION FEATURES

The purpose of this module is to identify and collect site-specific field data for roadside soil erosion features associated with the stream crossing. Soil erosion features include sheet, rill, and gully erosion. Background information concerning the soil erosion process and features are discussed in Appendix D.

6.1 MODULE 5

In addition to the unpaved road prism, erosion features created by road runoff can have a profound effect on sediment generation and delivery and waterway environmental impact potentials. Of particular importance is to identify those features that are hydrologically connected to the waterway. Soil erosion features not connected with the waterway are not under consideration by this survey. Mention can be made of unconnected soil erosion features in the comments section of block 5A-3; however, no field data is to be collected.

A separate record is created for each roadside soil erosion feature. Creating soil erosion feature records depends on the number of features identified. If only one sheet/rill feature and/or one gully is identified, use the existing Module 5 datasheet. However, if two or more crossing erosion features are surveyed use the extra Module 5 datasheets to create a separate record and unique identifier for each feature.

6.2 MODULE 5A: SOIL EROSION LEVEL 1 FEATURES SURVEY

6.2.1 Number of Soil Erosion Features

Record the total number of crossing erosion features surveyed in block 5A-1.

6.2.2 Types of Soil Erosion Features

Identify the types of soil erosion features that occur within the roadside areas in blocks 5A-2. Selections include sheet, rill, and/or gully, or none. Refer to Appendix D for a description of each feature type.

6.2.3 Feature Comments

Record additional feature comments in block 5A-3. Examples could include information regarding non-road disturbances that may be influencing the development of soil erosion features and general information regarding the location and type of erosion features in the area that are not connected to the waterway.

6.2.4 What is Next?

Following the completion of Module 5A, move to Module 5B Sheet/Rill Erosion Feature Level 2 Survey or Module 5C, Gully Erosion Feature Level 2 Survey, as applicable.

6.3 MODULE 5B: SHEET/RILL EROSION LEVEL 2 SURVEY

This module is used to collect roadside sheet and rill feature data. Sheet and rill features are surveyed together because they are area-type features that normally occur together. In contrast, gullies are surveyed as individual channel line features.

6.3.1 Sheet/Rill Feature Identification Number

The erosion features are identified based on the road approach and side of the road on which they occur. Beginning with road approach AP-1, number each feature sequentially beginning with the number 1 from the right to the left roadside, regardless of feature type. Create identifications for all the features on the right roadside before moving to the left roadside. Transfer the number sequence from road approach AP-1 to AP-2. As an example, if the last number for the features on AP-1 is 3, then the first number for the feature associated with AP-2 is 4. The feature identification number shall also include an “R” or “L” to signify on which side of the road the feature occurs.

An example of a feature identification number is AP-1-R-1. The “R” signifies that the feature occurs on the right side of road approach AP-1 and the last number identifies this feature as the first in the numbering sequence. An identification number of AP-2-L-9 would signify that feature number 9 occurs on the left side of road approach AP-2. Enter the soil erosion feature identification in block 5B-1. Mark the location of the feature on the site drawing.

6.3.2 Sheet/Rill Feature Orientation

Identify the relative orientation of the erosion feature to the road approach in block 5B-2. Selections include AP-1 left, AP-1 right, AP-2 left, or AP-2 right.

6.3.3 Sheet/Rill Feature Boundary Points

Identify (yes or no) if boundary points were established using GPS (refer to Section 1.2.2.2) in block 5B-3. Establish geographic reference points (up to six points) along the boundary of the eroded area to generally define the configuration and area of the site.

6.3.4 Sheet/Rill Feature Activity Class

Identify the current erosion and sediment transport potential of the sheet/rill site in block 5B-4. Selection include:

- *Active* — Soil erosion feature exhibits evidence of recent soil detachment and/or gully bank sloughing, fresh sediment and little or no vegetation (<25 percent). The majority of exposed surface materials are unprotected, unstable, and prone to further erosion.
- *Semi-Active* — The surface slopes of erosion features have achieved a relatively stable grade and are being colonized by vegetation. Generally vegetative cover is between 25 and 50 percent. Limited areas susceptible to erosion and/or sloughing persist.
- *Stable* — The surfaces slopes of the erosion feature have attained a relatively stable grade and have vegetative cover greater than 50 percent. There are minimal areas susceptible to erosion and sediment generation.

6.3.5 Sheet/Rill Feature Disturbance Area

Designate the sheet/rill site total disturbance area in block 5B-5. This includes all denuded surface areas that have experienced soil removal by stormwater. Record the area in acres.

6.3.6 Sheet/Rill Feature Hydrologic Connectivity

Identify how the sheet/rill site is hydrologically connected to a waterway in block 5B-6. Selections include:

- *Direct* — A sheet/rill feature discharges stormwater runoff directly into a waterway.
- *Indirect* — A sheet/rill feature discharges runoff into an intermittent drain that feeds into a perennial waterway. Runoff flows within the intermittent drain greater than 200 feet before entering the waterway. The feature may also feed sediment-laden runoff into another feature that is directly connected to a waterway. An example would be a sheet/rill feature that feeds runoff into a stream discharge gully.

6.3.7 Sheet/Rill Site Drawing

Identify (yes or no) if a drawing of the sheet/rill site is included in block 5B-7.

6.3.8 Sheet/Rill Site Photopoints

Identify (yes or no) if photopoints were established at the sheet/rill site in block 5B-8.

6.3.9 Sheet/Rill Feature Eroded Volume

Estimate the volume of sediment that has been eroded from the site. Record the volume in cubic yards in block 5B-9.

6.3.10 Sheet/Rill Feature Potential Eroded Volume

Estimate the potential volume of sediment that could be generated by the sheet/rill site. Estimate the sediment generation based on the formula presented in Section 3.2.7. Record the volume in cubic yards in block 5B-10.

6.3.11 Sheet/Rill Soil Series

Identify the dominant soil associated with the sheet/rill site by soil series name in block 5B-11. A dominant soil is one that occupies greater than 50 percent of the site and/or was determined to be the primary contributor of sediment for the site. Use USDA Natural Resources Conservation Service county soil survey to identify the soil.

6.3.12 Sheet/Rill Feature Sediment Delivery

Estimate the percent of potentially eroded soil that could enter the waterway in block 5B-12. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

6.3.13 Sheet/Rill Feature Comments

Include additional observations in block 5B-13. Examples include exposed soil features and conditions, surface hardpans, drainage characteristics, and connection to other erosion features.

6.3.14 What is Next?

Following completion of Module 5B, move to Module 5C, Gully Erosion Feature Level 2 Survey, as applicable. If gully features are not present, the survey is complete.

6.4 MODULE 5C: GULLY LEVEL 2 SURVEY

6.4.1 Gully Identification

Identify gully features using the procedure described in Section 6.3.1. Enter the gully identification in block 5C-1.

6.4.2 Gully Orientation

Identify the relative orientation of the gully to the road approach in block 5C-2. Selections include AP-1 left, AP-1 right, AP-2 left, or AP-2 right.

6.4.3 Gully GPS Cross Sections

Identify (yes or no) gully feature cross sections were established using GPS (refer to Section 1.2.2.2) in block 5C-3.

6.4.4 Gully Activity Class

Identify the current erosion and sediment transport potential of the gully in block 5C-4. Selection include:

- *Active* — Soil erosion feature exhibits evidence of recent soil detachment and/or gully bank sloughing, fresh sediment and little or no vegetation (<25 percent). The majority of exposed surface materials are unprotected, unstable, and prone to further erosion.
- *Semi-Active* — The surface slopes of erosion features have achieved a relatively stable grade and are being colonized by vegetation. Generally vegetative cover is between 25 and 50 percent. Limited areas susceptible to erosion and/or sloughing persist.
- *Stable* — The surfaces slopes of the erosion feature have attained a relatively stable grade and have vegetative cover greater than 50 percent. There are minimal areas susceptible to erosion and sediment generation.

6.4.5 Gully Hydrologic Connectivity

Identify how the gully is hydrologically connected to a waterway in block 5C-5. Selections include:

- *Direct* — A gully discharges stormwater runoff directly into a waterway.

- *Indirect* — A gully discharges runoff into an intermittent drain that feeds into a perennial waterway. Runoff flows within the intermittent drain greater than 200 feet before entering the waterway. The feature may also feed sediment-laden runoff into another feature that is directly connected to a waterway.

6.4.6 Gully Cross Sections

Gully cross sections are established at the gully headwall, transport corridor, discharge point, and or fan using GPS (refer to Section 1.2.2.2). Utilize coordinate point data to calculate headwall and transport corridor top of bank and bottom widths and fan length and width. For each gully cross section, collect the natural ground top edge, bottom, and opposite natural ground top edge. If the gully has a V-bottom shape, collect a point at the deepest location on the cross section. If the gully has a flat bottom, collect a point at the toe of each valley wall. Determine headwall and corridor heights by using a survey rod or tape. Estimate the percent vegetative cover within the gully transport corridor and fan. Data is entered as appropriate in blocks 5C-6 through 5C-26.

6.4.7 Gully Catchment Terrain

The catchment is the primary area of influence adjacent to the gully feature. Estimate the average catchment area slope and identify the primary ground cover type in blocks 5C-27 and 5C-28.

6.4.8 Gully Eroded Volume

Estimate the volume of sediment that has been eroded from the gully site. Record the volume in cubic yards in block 5C-29.

6.4.9 Gully Potential Eroded Volume

Estimate the potential volume of sediment that could be generated in the future by the gully. Record the volume in cubic yards in block 5C-30.

6.4.10 Gully Site Drawing

Identify (yes or no) if a drawing of the gully is included in block 5C-31.

6.4.11 Gully Sediment Delivery

Estimate the percent of potentially eroded soil that could enter the waterway in block 5C-32. Selections include 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent. Select one range value.

6.4.12 Gully Site Photopoints

Identify (yes or no) if photopoints were established at the gully site in block 5C-33.

6.4.13 Gully Soil Series

Identify the dominant soil associated with the gully by soil series name in block 5B-34. A dominant soil is one that occupies greater than 50 percent of the site and/or was determined to be the primary

contributor of sediment for the site. Use USDA Natural Resources Conservation Service county soil survey to identify the soil.

6.4.14 Gully Comments

Include additional observations in block 5B-35. Examples include exposed soil features and conditions, surface hardpans, drainage characteristics, sediment texture, types of transport corridor vegetation, and connection to other erosion features.

6.4.15 What is Next?

Following the completion of Module 5C move to Module 6, Crossing Photographs, and Module 7, Crossing Photopoints, to establish photographic records of the crossing.

7. CROSSING PHOTOGRAPHS

The photographic record of the crossing survey is a critical visual record of the crossing and effective tool for monitoring conditions. The photographs taken during the site survey create visual images for additional interpretation and establish a reference for future evaluation (Figure 7-1). This section describes the procedures for conducting a photopoint survey.

7.1 INTRODUCTION

Road-stream crossing photographic documentation is created using baseline crossing photographs and photopoints. Baseline crossing photographs provide a record of the general orientation and relationship of crossing features and the conditions of the surrounding environment. For the purpose of the crossing survey, baseline photographic requirements include:

- Road approach AP-1 and AP-2 taken from the crest (hydrologic break) towards the crossing structure.
- Road approach AP-1 and AP-2 taken from the stream crossing towards the uphill crest.
- Road approach AP-1 and AP-2 roadside vegetation.
- Crossing inlet and outlet taken from a position in the channel or at the waters edge.
- Upstream and downstream segments floodplain and riparian areas.
- Non-crossing related sources of ground disturbance
- Features of interest and/or concern including nonnative plants, listed species, beaver dams, and culture resource sites.

Because of their general natural and absence of a monitoring requirement these types of photographs are not referenced to ground monuments.

In contrast, photopoints are monumented ground locations from which photographs are taken to record conditions of concern and monitor changes over time. To ensure future duplication of the photograph, a permanent ground marker that is tied to GPS coordinates or the survey baseline is required. For the purpose of road-stream crossing surveys, photopoints are used to document roadside sheet/rill areas and gullies, crossing structure fill erosion and degradation, road approach degradation, and near-crossing channel sedimentation and degradation (Figure 7-1). The steps in setting and using photopoints are as follows:

- Select the location(s) that provide unencumbered views of features or conditions of interest. Once locations have been identified, review and consolidate locations where applicable.
- Create photopoint ground monuments. The photopoint location can be marked in one of three ways: 1) drive a rebar or stake into the ground, 2) inscribe a mark on a permanent surface such as a bridge deck, or 3) establish two points (rebar or stakes) in line with the marker location and measure the distance from one or both points to the marker location.
- Position the camera at a measured vertical distance directly over the ground marker and take the photographs. Take a compass reading in the direction of the photograph.

January 2001

August 2003

Figure 7-1. Photographic Documentation of Crossing Induced Sedimentation
(Photos by Mike Rainer)

- Use a staff gage or survey rod to provide scale in the photographs. Make sure that the one-foot increments are clearly visible.
- Place a photograph identification card in the camera view for each picture taken. Blank photograph identification cards are provided in Appendix A. Preferred paper colors are Hammermill Brite Hue Blue or Georgia Pacific Papers Hots Blue. These colored papers are more resistant to bleaching compared to other more common light colored paper (Hall, 2001).
- Use the field survey photopoint datasheet to create separate records for crossing feature photographs.

Frame the photographs in a manner that provides the appropriate representation of site features and conditions at the time of the survey. Track the sequence of the pictures taken during the survey. Following download of the data from the camera, rename the photos to clarify the identity of what is represented in the picture; otherwise the position from which the picture was taken and/or its significance may be lost. Tie the feature in the photo to the waterway (upstream or downstream), crossing (fill and/or structure), or road approaches (approach AP-1 and AP-2, left or right).

Effective photopoint monitoring can be achieved by adhering to the following procedures:

- Utilize the photopoint datasheet to document each photograph taken during the survey.
- To the degree possible, take the photographs at the same season and/or time of day.
- Electronically file the photopoint photos separately from other crossing photographs.

Create a separate electronic folder for storing the crossing feature photopoint photographs. Rename each photograph using in sequential order the word “photopoint,” crossing ID number, and date (year, month, day) the photograph was taken. In the photograph name, separate these three identification components with an underbar line. Once the photograph record is complete, a copy is sent along with the road-stream crossing datasheets to SAIC for data warehousing.

7.2 MODULE 6: BASELINE CROSSING PHOTOGRAPHS

7.2.1 Date

The baseline crossing photograph survey date is written on the worksheet as year, month, and day in block B-1 of the Crossing Photographs Module datasheet. As an example, 23 January 2003 would be entered as 20030123.

7.2.2 Photographer

Enter the first initial and last name of the person who took the photographs in block B-2.

7.2.3 Time

Identify the time the baseline photograph survey started in block B-3. Enter time in military format. As an example, 9 A.M. is 0900 and 2 P.M. is 1400.

7.2.4 Survey Weather

Identify the overall weather condition at the time of the survey in block B-4. Select a condition that best represents the dominant weather experienced during the survey.

7.2.5 Camera

Identify the type of digital camera used during the survey in block B-5. Include the camera make and model. Only digital cameras are to be used for baseline surveys.

7.2.6 Camera Setting

Identify particular setting used to take the photographs (high quality, zoom, etc.) in block B-6.

7.2.7 Total Number of Baseline Photographs

Enter the total number of baseline photographs that were taken during the survey in block B-7.

7.2.8 Baseline Photograph Identification and Description

Identify each photograph using the prescribed naming convention and provide a description of the photographs as applicable in blocks B-8 through B-32. Use extra datasheets if greater than 25 baseline photographs were taken.

7.2.9 Baseline Photograph Comments

Record additional baseline photograph information in block B-33.

7.3 MODULE 7: CROSSING PHOTOPOINTS

7.3.1 Date

The crossing photopoint survey date is written on the worksheet as year, month, and day in block P-1 of the Crossing Photopoints Module datasheet. As an example, 23 January 2003 would be entered as 20030123.

7.3.2 Time

Identify the time the photopoint survey started in block P-2. Enter time in military format. As an example, 9 A.M. is 0900 and 2 P.M. is 1400.

7.3.3 Survey Feature

Identify the crossing feature being photographed in block P-3. Selections include waterway, crossing structure, road approach AP-1, road approach AP-2, sheet/rill site, gully, or other feature. It is important not to intermix photographs from different crossing features; each crossing feature has a

separate photopoint record. Include the feature identification number for sheet/rill and gully feature photopoints.

7.3.4 Survey Crew

Write in the name of each individual that participated in the photopoint survey in block P-4. Provide the initial of the first name and spell out the last name.

7.3.5 Photographer

Identify which crewmember that took the photographs in block P-5. Provide the initial of the first name and spell out the last name.

7.3.6 Total Number of Feature Photographs

Enter the total number of feature photographs that were taken during the photopoint survey in block P-6.

7.3.7 Camera

Identify the type of digital camera used during the survey in block P-7. Include the camera make and model. Only digital cameras are to be used during photopoint surveys.

7.3.8 Camera Setting

Identify particular setting used to take the photographs (high quality, zoom, etc.) in block P-8.

7.3.9 Survey Weather

Identify the overall weather condition at the time of the survey in block P-9. Selections include rain, cloudy, partly cloudy, and sunny. Select only one weather condition variable.

7.3.10 GPS Photopoint Monuments

Identify (yes or no) if GPS photopoint monuments were established in block P-10.

7.3.11 Feature Photopoints

Establish the specifications for crossing feature photopoint photographs in blocks P-11 through P-30 as applicable. Do not intermix crossing feature photographs on the datasheets; each feature has its own photopoint datasheet. Feature datasheet specifications include monument identification and distance and bearing from the monument to the photopoint and photopoint photograph camera frame number, camera height above natural ground, and photograph bearing.

7.3.12 Photopoint Comments

Provide additional feature photopoint comments in block P-31.

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APPENDIX A
ROAD-STREAM CROSSING SURVEY DATASHEETS

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 1: BASELINE	1-1) Date:	1-2) County:
1-3) USGS Quad Sheet Name:	1-4) Subbasin:	1-5) Watershed:
1-6) River Basin:	1-7) Owner: Federal State County City Private Other:	
1-8) Road Name:		1-9) Road No.:
1-10) Longitude:	1-11) Latitude:	1-12) Traffic Service Level:
1-13) Road Closure Structures: Yes No	Next crossing: 1-14) _____ U/S miles	1-15) _____ D/S miles
1-16) Photopoints Established: Yes No	1-17) Crew:	
1-18) Period Since Last Rain: < 5 Days 1 to 4 Weeks > 1 Month Unknown		1-19) Recorder:
1-20) Survey Weather: Rain Cloudy Partly Cloudy Sunny		1-21) Site Drawing: Yes No
1-22) Comments:		

MODULE 2A: WATERWAY FEATURES LEVEL 1 SURVEY	2A-1) Feature Name:
2A-2) Waterbody Type:	Stream S1 S2 S3; Drain D1 D2; Canal C1 C2; Slough; Outlet; Bayou; Lagoon L1 L2; Reach R1 R2
2A-3) Stream Type (U/S):	Aa+ A B C D DA E E F G Other:
2A-4) Stream Feature (U/S):	Single Channel Braided Channel Wetland Lake Pond Beaver Dam Other:
2A-5) Stream Type (D/S):	Aa+ A B C D DA E E F G Other:
2A-6) Stream Feature (D/S):	Single Channel Braided Channel Wetland Lake Pond Beaver Dam Other:
2A-7) Flow Regime	Perennial Intermittent Ephemeral Ponded Other:
2A-8) Comments:	

MODULE 2B: WATERWAY CONDITIONS LEVEL 1 SURVEY								
2B-1) Channel and/or bank alteration (U/S):	Natural	Minor	Partial	High	In-stream woody vegetation:	2B-3) U/S		2B-4) D/S	
2B-2) Channel and/or bank alteration (D/S):	Natural	Minor	Partial	High		Yes	No	Yes	No
2B-5) Stream stability (U/S):	High	Moderate	Low		Channel entrenched:	2B-7) U/S		2B-8) D/S	
2B-6) Stream stability (D/S):	High	Moderate	Low			Yes	No	Yes	No
2B-9) Fish : Yes No	2B-10) Aquatic insects: Yes No				2B-11) Sedimentation: Extensive Moderate Minor				
2B-12) U/S Streamside spoil banks: Left Right Both					2B-13) D/S Streamside spoil banks: Left Right Both				
2B-14) Comments:									

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 2C: WATERWAY UPSTREAM LEVEL 2 SURVEY						
MODULE 2C-1: UPSTREAM BASELINE	2C-1) Total Baseline Distance: _____ ft				2C-2) Location: LB RB	
2C-3) Distance between monuments M1 and M2: _____ ft.			2C-4) Total Channel Reach Distance: _____ ft.			
2C-5) Comments:						
MODULE 2C-2: UPSTREAM SURVEY					2C-6) Channel gradient: _____ %	
Wetted channel width:	2C-7) _____ ft. at _____ ft.		2C-8) _____ ft. at _____ ft.		2C-13) Listed flora: Yes No	
Bankfull channel width:	2C-9) _____ ft. at _____ ft.		2C-10) _____ ft. at _____ ft.		2C-14) Exotic flora: Yes No	
Average bankfull depth:	2C-11) _____ ft. at _____ ft.		2C-12) _____ ft. at _____ ft.			
2C-15) Left bank (LB) cover:	0 – 20 %	20 – 60 %	>60%	2C-16) LB slope: _____ °	2C-17) LB height: _____ ft.	
2C-18) Right bank (RB) cover:	0 – 20 %	20 – 60 %	>60%	2C-19) RB slope: _____ °	2C-20) RB height: _____ ft.	
2C-21) Instream Cover:	UC Banks	OH Plants	Deep Pools	Aquatic Plants	Debris	2C-22) Flow velocity: ____ ft/sec
2C-23) Comments:						

MODULE 2C: WATERWAY DOWNSTREAM LEVEL 2 SURVEY						
MODULE 2C-3: DOWNSTREAM BASELINE	2C-24) Total Baseline Distance: ____ ft				2C-25) Location: LB RB	
2C-26) Distance between monuments M3 and M4: _____ ft.			2C-27) Total Channel Reach Distance: _____ ft.			
2C-28) Comments:						
MODULE 2C-4: DOWNSTREAM SURVEY					2C-29) Channel gradient: _____ %	
Wetted channel width:	2C-30) _____ ft. at _____ ft.		2C-31) _____ ft. at _____ ft.		2C-36) Listed flora: Yes No	
Bankfull channel width:	2C-32) _____ ft. at _____ ft.		2C-33) _____ ft. at _____ ft.		2C-37) Exotic flora: Yes No	
Average bankfull depth:	2C-34) _____ ft. at _____ ft.		2C-35) _____ ft. at _____ ft.			
2C-38) Left bank (LB) cover:	0 – 20 %	20 – 60 %	>60%	2C-39) LB slope: _____ °	2C-40) LB height: _____ ft.	
2C-41) Right bank (RB) cover:	0 – 20 %	20 – 60 %	>60%	2C-42) RB slope: _____ °	2C-43) RB height: _____ ft.	
2C-44) Instream Cover:	UC Banks	OH Plants	Deep Pools	Aquatic Plants	Debris	2C-45) Flow velocity: ____ ft/sec
2C-46) Comments:						

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 3: CROSSING STRUCTURE	3-1) Crossing Type: Culvert Bridge Ford
	3-2) Total Number of Culverts: _____

MODULE 3A-1: CULVERT LEVEL 1 FEATURES SURVEY	3A-1) Culvert Identification Number: _____
3A-2) Culvert Type: Round Pipe Elliptical Open Arch Box Trough Box Open Box Other:	
3A-3) Culvert Material: Corrugated Metal Polyvinyl Chloride High Density Polyethylene Reinforced Concrete Iron Clay Other:	3A-4) Culvert Embedded: Yes No
3A-5) Culvert Inlet Type: Projecting Headwall Wingwall Mitered Other:	
3A-6) Culvert Outlet Type: Projecting Headwall Wingwall Mitered Other:	
3A-7) Culvert Inlet Configuration Existing channel width Widened Other:	
3A-8) Upstream Culvert Skew Angle: Straight 5 – 10 Degrees 10 – 20 Degrees 20 to 30 Degrees >30 Degrees	
Crossing Fill Height: 3A-9) Above Culvert: _____ ft.	3A-10) Above End Wall: _____ ft.
3A-11) Fill Cover: Herbaceous Woody Nonnative Bare Ground Concrete Other:	
3A-12) Comments:	

MODULE 3A-2: CULVERT LEVEL 1 CONDITIONS SURVEY	Culvert Identification Number: _____
3A-13) Crossing fill condition: Good Fair Poor	
3A-14) Culvert structural condition: Good Fair Poor	
3A-15) Culvert inlet condition: Not Impaired Scouring Sediment Islands Blocked Other:	
3A-16) Culvert outlet condition: Not Impaired Scouring Sediment Islands Blocked Other:	
3A-17) Comments:	

MODULE 3A-3: CULVERT LEVEL 2 SURVEY	Culvert Identification Number: _____			
3A-18) Culvert Length: ____ FT	3A-19) Culvert Diameter: ____ FT			
3A-20) Rise: ____ FT	3A-21) Span: ____ FT	3A-22) Height: ___ FT	3A-23) Width: ____ FT	3A-24) Grade: ____ %
Culvert Inlet 3A-25) Invert: ___ FT	3A-26) Above Channel ___ FT	3A-27) Below Channel ___ FT	3A-28) Pool: ____ FT	
Culvert Outlet 3A-29) Invert: ___ FT	3A-30) Above Channel ___ FT	3A-31) Below Channel ___ FT	3A-32) Pool: ____ FT	
3A-33) Culvert Outfall Drop: ____ FT	3A-34) Culvert Water Depth: ____ FT	3A-35) Eroded Volume: _____ c.y.		
3A-36) Potential Volume: ____ c.y.	3A-37) Sediment Delivery: 0- 25 % 25 – 50 % 50 – 75 % 75 – 100 %			
3A-38) Comments:				

:

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 3B-1: BRIDGE LEVEL 1 FEATURES SURVEY					3B-1) Bridge Type:	Permanent	Temporary
3B-2) Deck Materials:	Concrete	Metal	Wood	Other:	3B-3) Comments:		

MODULE 3B-2: BRIDGE LEVEL 1 CONDITIONS SURVEY					
3B-4) Extent of deck coverage by road materials:	Clear	Semi-Covered	Covered	3B-5) Deck cover	_____ FT.
3B-6) Deck sediment delivery features:	None	Lip Damage	Deck Holes	Other:	3B-7) Comments:

MODULE 3B-3: BRIDGE LEVEL 2 SURVEY				3B-8) Span: _____ FT.	3B-9) Width: _____ FT.
3B-10) Span to Streambed Depth: _____ FT.			Bridge Deck:	3B-11) Potential Eroded Volume:	____ c.y.
3B-12) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %	3B-13) Comments:

MODULE 3C-1: FORD LEVEL 1 FEATURES SURVEY					3C-1) Ford Type:	Improved	Unimproved
3C-2) Ford Materials:	Native	Rock	Concrete	Synthetic	Other:	3C-3) Comments:	

MODULE 3C-2: FORD LEVEL 1 CONDITIONS SURVEY				
3C-4) Overall stability of the ford crossing:	Good	Fair	Poor	3C-5) Comments:

MODULE 3C-3: FORD LEVEL 2 SURVEY						
Road AP-1:	3C-6) Length: _____ FT.	3C-7) Width: _____ FT.	3C-8) Approach Gradient: _____ %	3C-9) Flow depth: ____FT.		
	3C-10) Potential Eroded Volume: ____ c.y.	3C-11) Sediment Delivery:	0 - 25 %	25 – 50 %	50 – 75 %	75 – 100 %
Road AP-2:	3C-12) Length: _____ FT.	3C-13) Width: ____ FT.	3C-14) Approach Gradient: _____ %			
	3C-15) Potential Eroded Volume: ____ c.y.	3C-16) Sediment Delivery:	0 - 25 %	25 – 50 %	50 – 75 %	75 – 100 %
3C-17) Comments:						

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 4A-1: APPROACH AP-1 LEVEL 1 FEATURES SURVEY								
4A-1) Lanes:	One	Two						
4A-2) Configuration:	Crowned	Outslope	Inslope	Flat				
4A-3) Surface Material:	Native Soil	Sand/Clay	Aggregate	Amended	Other:			
4A-4) Road Elevation:	At Natural Grade	Above Grade: _____ ft.	Below Grade: _____ ft.	4A-5) Maintenance Berms:	Left	Right	Both	None
4A-6) Road Maintenance Level:	Extensive	Minor	Other:					
4A-7) Broad-Based Dip(s):	Yes	No	4A-8) Waterbar(s):	Yes	No			
4A-9) Improved Drain:	Left	Right	Both	4A-10) Unimproved Drain:	Left	Right	Both	
4A-11) Ditch Berm:	Left	Right	Both	4A-12) Ditch Turnout:	Left	Right	Both	
4A-13) Armored Drain:	Left	Right	Both	4A-14) Holding Pond:	Left	Right	Both	
4A-15) Hay Bales/Silt Fence:	Left	Right	Both	4A-16) Improved Outlet:	Left	Right	Both	
4A-17) Unimproved Drain Outlet:	Left	Right	Both	4A-18) No Drain Outlet:	Left	Right	Both	
4A-19) Other Practices:								
4A-20) Ditch Ground Cover:	Bare Soil	Vegetation	Synthetic	Concrete	Other			
4A-21) Dominant roadside vegetation type:	Woodland Left	Wetland Left	Grassland Left	Shrubland Left	Bare Soil Left			
	Woodland Right	Wetland Right	Grassland Right	Shrubland Right	Bare Soil Right			
	Woodland Both	Wetland Both	Grassland Both	Shrubland Both	Bare Soil Both			
4A-22) Are nonnative plants present?	Yes	No						
4A-23) Dominant landuse:	Commercial Left	Residential Left	Row Crops Left	Pasture Left	Barren Left	Borrow Pit Left	Silviculture Left	Forested Left	Other Left:
	Commercial Right	Residential Right	Row Crops Right	Pasture Right	Barren Right	Borrow Pit Right	Silviculture Right	Forested Right	Other Right:
	Commercial Both	Residential Both	Row Crops Both	Pasture Both	Barren Both	Borrow Pit Both	Silviculture Both	Forested Both	Other Both:
4A-24) Were prehistoric or historic features identified?	Yes	No	4A-25) Comments:					

MODULE 4A-2: APPROACH AP-1 LEVEL 1 CONDITIONS SURVEY				
4A-26) Cohesive condition of the road prism?	Compact	Loose	Rills	Gullied
4A-27) Condition of the drainage system?	Good	Fair	Poor	4A-29) Comments:
4A-28) Condition of the drainage outlets?	Good	Fair	Poor	

MODULE 4A-3: APPROACH AP-1 LEVEL 2 SURVEY					
4A-30) Road Length: _____ FT.	4A-31) Road Width: _____ FT.	4A-32) Road Slope: _____ %			
4A-33) Potential Erosion Volume: _____ c.y.	4A-34) Sediment Delivery:	0 - 25 %	25 – 50 %	50 – 75 %	75 – 100 %
4A-35) Comments:					

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 4B-1: APPROACH AP-2 LEVEL 1 FEATURES SURVEY								
					4B-1) Lanes:	One	Two	
4B-2) Configuration:	Crowned	Outslope	Inslope	Flat				
4B-3) Surface Material:	Native Soil	Sand/Clay	Aggregate	Amended	Other:			
4B-4) Road Elevation:	At Natural Grade	Above Grade: _____ ft.	Below Grade: _____ ft.	4B-5) Maintenance Berms:	Left	Right	Both	None
4B-6) Road Maintenance Level:	Extensive	Minor	Other:					
4B-7) Broad-Based Dip(s):	Yes	No	4B-8) Waterbar(s):	Yes	No			
4B-9) Improved Drain:	Left	Right	Both	4A-10) Unimproved Drain:	Left	Right	Both	
4B-11) Ditch Berm:	Left	Right	Both	4B-12) Ditch Turnout:	Left	Right	Both	
4B-13) Armored Drain:	Left	Right	Both	4B-14) Holding Pond:	Left	Right	Both	
4B-15) Hay Bales/Silt Fence:	Left	Right	Both	4B-16) Improved Outlet:	Left	Right	Both	
4B-17) Unimproved Drain Outlet:	Left	Right	Both	4B-18) No Drain Outlet:	Left	Right	Both	
4B-19) Other Practices:								
4B-20) Ditch Ground Cover:	Bare Soil	Vegetation	Synthetic	Concrete	Other			
4B-21) Dominant roadside vegetation type:	Woodland Left	Wetland Left	Grassland Left	Shrubland Left	Bare Soil Left			
	Woodland Right	Wetland Right	Grassland Right	Shrubland Right	Bare Soil Right			
	Woodland Both	Wetland Both	Grassland Both	Shrubland Both	Bare Soil Both			
4B-22) Are nonnative plants present?	Yes	No						
4B-23) Dominant landuse:	Commercial Left	Residential Left	Row Crops Left	Pasture Left	Barren Left	Borrow Pit Left	Silviculture Left	Forested Left	Other Left:
	Commercial Right	Residential Right	Row Crops Right	Pasture Right	Barren Right	Borrow Pit Right	Silviculture Right	Forested Right	Other Right:
	Commercial Both	Residential Both	Row Crops Both	Pasture Both	Barren Both	Borrow Pit Both	Silviculture Both	Forested Both	Other Both:
4B-24) Were prehistoric or historic features identified?	Yes	No	4B-25) Comments:					

MODULE 4B-2: APPROACH AP-2 LEVEL 1 CONDITIONS SURVEY				
4B-26) Cohesive condition of the road prism?	Compact	Loose	Rills	Gullied
4B-27) Condition of the drainage system?	Good	Fair	Poor	4A-29) Comments:
4B-28) Condition of the drainage outlets?	Good	Fair	Poor	

MODULE 4B-3: APPROACH AP-2 LEVEL 2 SURVEY					
4B-30) Road Length: _____ FT.	4B-31) Road Width: _____ FT.	4B-32) Road Slope: _____ %			
4B-33) Potential Erosion Volume: _____ c.y.	4B-34) Sediment Delivery:	0 - 25 %	25 – 50 %	50 – 75 %	75 – 100 %
4B-35) Comments:					

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 5A: ROADSIDE SOIL EROSION LEVEL 1 FEATURES SURVEY					5A-1) Total Number of Soil Erosion Features: _____
5A-2) Roadside Soil Erosion Types:	Sheet	Rill	Gully	None	5A-3) Comments:

MODULE 5B: SHEET/RILL EROSION FEATURE LEVEL 2 SURVEY					5B-1) Erosion Feature Number: _____		
5B-2) Orientation:	Road AP-1 Left	Road AP-1 Right	Road AP-2 Left	Road AP-2 Right	5B-3) GPS Boundary Points:	Yes	No
5B-4) Erosion Feature Activity Class:	Active	Semi-Active	Stable		5B-5) Area: _____ sq. ft.		
5B-6) Hydrologic Connection:	Direct	Indirect	5B-7) Site Drawing:	Yes	No	5B-8) Photopoints:	Yes / No
5B-9) Eroded Volume: _____ c.y.	5B-10) Potential Volume: _____ c.y.	5B-11) Soil Series:					
5B-12) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %	5B-13) Comments:		

MODULE 5C: GULLY EROSION FEATURE LEVEL 2 SURVEY						5C-1) Erosion Feature Number: _____		
5C-2) Orientation:	Road AP-1 Left	Road AP-1 Right	Road AP-2 Left	Road AP-2 Right	5C-3) GPS Cross Sections:	Yes	No	
5C-4) Erosion Feature Activity Class:	Active	Semi-Active	Stable	5C-5) Hydrologic Connection:	Direct	Indirect		
Headwall	Tier 1	5C-6) Height: _____ ft	5C-7) Top Width: _____ ft	5C-8) Bottom Width: _____ ft				
	Tier 2	5C-9) Height: _____ ft	5C-10) Top Width: _____ ft	5C-11) Bottom Width: _____ ft				
Corridor	Sec. 1	5C-12) Height: _____ ft	5C-13) Top Width: _____ ft	5C-14) Bottom Width: _____ ft				
	Sec. 2	5C-15) Height: _____ ft	5C-16) Top Width: _____ ft	5C-17) Bottom Width: _____ ft				
	Sec. 3	5C-18) Height: _____ ft	5C-19) Top Width: _____ ft	5C-20) Bottom Width: _____ ft				
	5C-21) Total Length: _____ ft	5C-22) Sidewall Cover: _____ %	5C-23) Bottom Cover: _____ %					
Fan	5C-24) Total Length: _____ ft	5C-25) Toe Width: _____ ft	5C-26) Cover: _____ %					
Catchment:	5C-27) Slope: _____ %	5C-28) Cover:	Bare	Grassland	Shrubland	Grass/Shrub	Woods	Other
5B-29) Eroded Volume: _____ c.y.	5B-30) Potential Volume: _____ c.y.	5B-31) Site Drawing:	Yes	No				
5B-32) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %	5B-33) Photopoints:	Yes	No	
5B-34) Soil Series:	5B-35) Comments:							

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 6: BASELINE CROSSING PHOTOGRAPHS					B-1) Date:
B-2) Photographer:					B-3) Time:
B-4) Survey Weather:	Rain	Cloudy	Partly Cloudy	Sunny	B-5) Camera:
B-6) Camera Settings:					B-7) Total Photos: _____

Photograph ID	Frame No.	Photograph Description
B-8) DS-1		
B-9) DS-2		
B-10) DS-3		
B-11) DS-4		
B-12) DS-5		
B-13) DS-6		
B-14) DS-7		
B-15) DS-8		
B-16) DS-9		
B-17) DS-10		
B-18) DS-11		
B-19) DS-12		
B-20) DS-13		
B-21) DS-14		
B-22) DS-15		
B-23) DS-16		
B-24) DS-17		
B-25) DS-18		
B-26) DS-19		
B-27) DS-20		
B-28) DS-21		
B-29) DS-22		
B-30) DS-23		
B-31) DS-24		
B-32) DS-25		

B-33) Comments:

ROAD-STREAM CROSSING SURVEY DATASHEETS

CROSSING ID: _____

MODULE 7: CROSSING FEATURE PHOTOPOINTS	P-1) Date:	P-2) Time:
P-3) Photo Feature: Waterway Crossing Structure AP-1 AP-2 Sheet/Rill Site ID: _____ Gully ID: _____ Other		
P-4) Survey Crew:	P-5) Photographer:	P-6) Total Photos:
P-7) Camera:	P-8) Camera Settings:	
P-9) Survey Weather: Rain Cloudy Partly Cloudy Sunny	P-10) GPS Monument Points: Yes No	

Photopoint ID	Monument	Distance (ft.)	Photopoint Bearing	Frame No.	Camera Height (ft.)	Photo graph Bearing
P-11) PP-1						
P-12) PP-2						
P-13) PP-3						
P-14) PP-4						
P-15) PP-5						
P-16) PP-6						
P-17) PP-7						
P-18) PP-8						
P-19) PP-9						
P-20) PP-10						
P-21) PP-11						
P-22) PP-12						
P-23) PP-13						
P-24) PP-14						
P-25) PP-15						
P-26) PP-16						
P-27) PP-17						
P-28) PP-18						
P-29) PP-19						
P-30) PP-20						

P-31) Comments:

CROSSING ID: _____

SITE DRAWING OF _____

Crossing ID_____ **Erosion Feature ID**_____

DATE_____

CROSS ID_____

PHOTO ID_____

By _____

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EXTRA CROSSING SURVEY DATASHEETS

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EXTRA ROAD-STREAM CROSSING SURVEY CULVERT DATASHEET

ONLY USE WHEN MORE THAN ONE CULVERT IS PRESENT

CROSSING ID: _____

MODULE 3A-1: CULVERT LEVEL 1 FEATURES SURVEY							3A-1) Culvert Identification Number: _____
3A-2) Culvert Type:	Round	Pipe Elliptical	Open Arch	Box	Trough Box	Open Box	Other:
3A-3) Culvert Material:	Corrugated Metal	Polyvinyl Chloride	High Density Polyethylene	Reinforced Concrete	Iron	Clay	Other:
3A-4) Culvert Embedded:	Yes	No					
3A-5) Culvert Inlet Type:	Projecting	Headwall	Wingwall	Mitered	Other:		
3A-6) Culvert Outlet Type:	Projecting	Headwall	Wingwall	Mitered	Other:		
3A-7) Culvert Inlet Configuration	Existing channel width	Widened	Other:				
3A-8) Upstream Culvert Skew Angle:	Straight	5 – 10 Degrees	10 – 20 Degrees	20 to 30 Degrees	>30 Degrees		
Crossing Fill Height:	3A-9) Above Culvert: _____ ft.	3A-10) Above End Wall: _____ ft.					
3A-11) Fill Cover:	Herbaceous	Woody	Nonnative	Bare Ground	Concrete	Other:	
3A-12) Comments:							

MODULE 3A-2: CULVERT LEVEL 1 CONDITIONS SURVEY						Culvert Identification Number: _____
3A-13) Crossing fill condition:	Good	Fair	Poor			
3A-14) Culvert structural condition:	Good	Fair	Poor			
3A-15) Culvert inlet condition:	Not Impaired	Scouring	Sediment Islands	Blocked	Other:	
3A-16) Culvert outlet condition:	Not Impaired	Scouring	Sediment Islands	Blocked	Other:	
3A-17) Comments:						

MODULE 3A-3: CULVERT LEVEL 2 SURVEY					Culvert Identification Number: _____
3A-18) Culvert Length: ____ FT	3A-19) Culvert Diameter: ____ FT				
3A-20) Rise: ____ FT	3A-21) Span: ____ FT	3A-22) Height: ___ FT	3A-23) Width: ____ FT	3A-24) Grade: ____ %	
Culvert Inlet	3A-25) Invert: ___ FT	3A-26) Above Channel ___ FT	3A-27) Below Channel ___ FT	3A-28) Pool: ____ FT	
Culvert Outlet	3A-29) Invert: ___ FT	3A-30) Above Channel ___ FT	3A-31) Below Channel ___ FT	3A-32) Pool: ____ FT	
3A-33) Culvert Outfall Drop: ____ FT	3A-34) Culvert Water Depth: ____ FT	3A-35) Eroded Volume: _____ c.y.			
3A-36) Potential Volume: ____ c.y.	3A-37) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %
3A-38) Comments:					

:

EXTRA CROSSING DATASHEET: SOIL EROSION FEATURE

USE ONLY WHEN MORE THAN ONE EROSION FEATURE IS PRESENT

CROSSING ID: _____

MODULE 5B: SHEET/RILL EROSION FEATURE LEVEL 2 SURVEY					5B-1) Erosion Feature Number: _____		
5B-2) Orientation:	Road AP-1 Left	Road AP-1 Right	Road AP-2 Left	Road AP-2 Right	5B-3) GPS Boundary Points:	Yes	No
5B-4) Erosion Feature Activity Class:	Active	Semi-Active	Stable		5B-5) Area: _____ sq. ft.		
5B-6) Is the roadside sheet/rill site hydrologically connected to the waterway?	Yes	No			5B-7) Hydrologic Connection	Direct	Indirect
5B-8) Eroded Volume: _____ c.y.		5B-9) Potential Volume: _____ c.y.			5B-10) Site Drawing:	Yes	No
5B-11) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %	5B-12) Photopoints:	Yes	No
5B-13) Soil Series:					5B-14) Comments:		

MODULE 5C: GULLY EROSION FEATURE LEVEL 2 SURVEY					5C-1) Erosion Feature Number: _____		
5C-2) Orientation:	Road AP-1 Left	Road AP-1 Right	Road AP-2 Left	Road AP-2 Right	5C-3) GPS Cross Sections:	Yes	No
5C-4) Erosion Feature Activity Class:	Active	Semi-Active	Stable				
5C-5) Is the roadside sheet/rill site hydrologically connected to the waterway?	Yes	No			5C-6) Hydrologic Connection	Direct	Indirect
5C-7) Is the roadside gully hydrologically connected or potentially connected to the waterway?					Yes	No	
Headwall	Tier 1	5C-8) Height: _____ ft			5C-9) Top Width: _____ ft	5C-10) Bottom Width: _____ ft	
	Tier 2	5C-11) Height: _____ ft			5C-12) Top Width: _____ ft	5C-13) Bottom Width: _____ ft	
Corridor	Sec. 1	5C-14) Height: _____ ft			5C-15) Top Width: _____ ft	5C-16) Bottom Width: _____ ft	
	Sec. 2	5C-17) Height: _____ ft			5C-18) Top Width: _____ ft	5C-19) Bottom Width: _____ ft	
	Sec. 3	5C-20) Height: _____ ft			5C-21) Top Width: _____ ft	5C-22) Bottom Width: _____ ft	
	5C-23) Total Length: _____ ft				5C-24) Sidewall Cover: _____ %	5C-25) Bottom Cover: _____ %	
Fan	5C-26) Total Length: _____ ft				5C-27) Toe Width: _____ ft	5C-28) Cover: _____ %	
Catchment:	5C-29) Slope: _____ %				5C-30) Cover:	Bare	Grassland	Shrubland	Grass/Shrub	Woods	Other
5B-31) Eroded Volume: _____ c.y.		5B-32) Potential Volume: _____ c.y.			5B-33) Site Drawing:	Yes	No
5B-34) Sediment Delivery:	0- 25 %	25 – 50 %	50 – 75 %	75 – 100 %	5B-35) Photopoints:	Yes	No
5B-36) Soil Series:					5B-37) Comments:		

EXTRA CROSSING DATASHEET: BASELINE PHOTOGRAPHS

CROSSING ID: _____

MODULE 6: BASELINE CROSSING PHOTOGRAPHS						B-1) Date:
B-2) Photographer:						B-3) Time:
B-4) Survey Weather:	Rain	Cloudy	Partly Cloudy	Sunny	B-5) Camera:	
B-6) Camera Settings:						B-7) Total Photos: _____

Photograph ID	Frame No.	Photograph Description
B-8) DS-1		
B-9) DS-2		
B-10) DS-3		
B-11) DS-4		
B-12) DS-5		
B-13) DS-6		
B-14) DS-7		
B-15) DS-8		
B-16) DS-9		
B-17) DS-10		
B-18) DS-11		
B-19) DS-12		
B-20) DS-13		
B-21) DS-14		
B-22) DS-15		
B-23) DS-16		
B-24) DS-17		
B-25) DS-18		
B-26) DS-19		
B-27) DS-20		
B-28) DS-21		
B-29) DS-22		
B-30) DS-23		
B-31) DS-24		
B-32) DS-25		

B-33) Comments:

EXTRA CROSSING DATASHEET: CROSSING PHOTOPOINT

USE ONLY WHEN MORE THAN ONE PHOTOPOINT FEATURE SURVEY IS CONDUCTED

CROSSING ID: _____

MODULE 7: CROSSING FEATURE PHOTOPOINTS	P-1) Date:	P-2) Time:
P-3) Photo Feature: Waterway Crossing Structure AP-1 AP-2 Sheet/Rill Site ID: _____ Gully ID: _____ Other		
P-4) Survey Crew:	P-5) Photographer:	P-6) Total Photos:
P-7) Camera:	P-8) Camera Settings:	
P-9) Survey Weather: Rain Cloudy Partly Cloudy Sunny	P-10) GPS Monument Points: Yes No	

Photopoint ID	Monument	Distance (ft.)	Photopoint Bearing	Frame No.	Camera Height (ft.)	Photograph Bearing
P-11) PP-1						
P-12) PP-2						
P-13) PP-3						
P-14) PP-4						
P-15) PP-5						
P-16) PP-6						
P-17) PP-7						
P-18) PP-8						
P-19) PP-9						
P-20) PP-10						
P-21) PP-11						
P-22) PP-12						
P-23) PP-13						
P-24) PP-14						
P-25) PP-15						
P-26) PP-16						
P-27) PP-17						
P-28) PP-18						
P-29) PP-19						
P-30) PP-20						

P-31) Comments:

APPENDIX B
LIST OF EQUIPMENT AND SUPPLIES

LIST OF EQUIPMENT AND SUPPLIES

Road-Stream Crossing Datasheets
Extra Road-Stream Crossing Culvert Datasheets
Clipboard/Field Notebook
Ruler/Straight Edge
Road-Stream Crossing Procedures (this document)
Pencils and Leads
Black Permanent Markers
Zip Lock Bags
Rain Slicker/Tarp
Waders
Sunscreen
First Aid Kit

Surveyor's Level (Self-Leveling Level or Laser Level)
GPS Receiver (if available)
Level Tripod
Level Rod (25 foot telescopic)
Solar Powered Calculator
Digital Camera
Camera Batteries
Compass
Right Angle Prism
Clinometer
Water Flow Measuring Device (ripe orange)
Cellular Phone
Watch

100 and 300 Foot Tapes (plastic coated graduated to 0.1 feet)
Chaining Pins
2 Canvas Tote Bags
2 Machetes
2 Shovels
Pliers with Wire Cutters
Eight-inch Spike
Flagging
Wire Flags
Four-foot rebar
Sledge Hammer
Hammer
Wooden Grade Stakes
Nylon String (500 feet)
String Level
Rope (100 feet)
Gloves

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APPENDIX C
NORTHWEST FLORIDA FLORA

LISTED NATIVE AQUATIC PLANTS

State and federally listed aquatic native plants that occur in Northwest Florida are presented in Table A-1.

Table A-1. Listed Native Aquatic Plants

Scientific Name	Common Name	State Rank	Federal Status	Northwest Florida Counties
Drosera intermedia	Spoon-Leaved Sundew	T	N	Escambia, Santa Rosa, Okaloosa, Walton, Washington, Bay, Calhoun, Gulf, Liberty, Franklin, Leon
Lachnocaulon digynum	Pineland Bog Button	T	N	Escambia, Santa Rosa, Okaloosa, Walton, Bay, Calhoun, Gulf, Liberty
Lilium iridollae	Panhandle Lilly	E	MC	Escambia, Santa Rosa, Okaloosa, Walton, Leon
Litsea aestivalis	Pondspice	E	N	Okaloosa
Lindera melissifolia	Pondberry	E	E	Gadsden
Sarracenia leucophylla	White-Top Pitcherplant	E	MC	Escambia, Santa Rosa, Okaloosa, Walton, Holmes, Washington, Bay, Calhoun, Gulf, Liberty, Franklin
Sarracenia rubra	Sweet Pitcherplant	T	MC	Escambia, Santa Rosa, Okaloosa, Walton, Holmes, Bay

T = Threatened; E = Endangered; N = Not currently listed or currently being considered for listing as endangered or threatened; MC = Not currently listed, but of management concern to the U.S. Fish and Wildlife Service

Spoon-Leaved Sundew

Pondspice

Pineland Bog Button

Pondberry (Photo by NRCS)

Panhandle Lilly

Sweet Pitcher Plant

White-Top Pitcher Plant

NONNATIVE INVASIVE PLANTS

Exotic species are nonnative, invasive organisms. Organisms are considered *nonnative* (alien, exotic, foreign, introduced, nonindigenous) if they occur artificially in areas beyond their natural ranges, whereas a *native* organism is one that occurs in a particular habitat without human actions. Displaced nonnative species originated in other continents, regions, ecosystems, or habitats. Some nonnative plant species introduced from other countries have become naturalized and, in some instances, have replaced native North American species.

An *invasive* species is characterized by rapid growth and reproduction that allows it to out-compete other native species and become established over large areas. Some invasive plant species tend to be aggressive because of botanical characteristics such as rapid vegetative growth, abundant seed production, high seed germination rates, rapid maturity to seed producing stage, and the absence of herbivore, insect, and disease controls present in their native lands. The combination of these factors, allow invasive species to overwhelm, out-compete, and in some instances displace existing vegetation and form potentially expansive monocultures of a single species. Dominance of single species generally degrades overall ecosystem biodiversity and habitat value.

The Florida Exotic Pest Plant Council (FEPPC) is a nonprofit society founded in 1984 to foster public awareness concerning the serious threats to natural ecosystem posed by nonnative invasive plants and to develop management and control methods to prevent the spread of exotic plants. Nonnative invasive plant species identified by the FEPPC as *Category I* problems known to occur in the Florida Panhandle are presented in Table A-2. These are species known to have invaded Florida natural areas and are displacing native plants or otherwise disrupting natural community structure and/or function (Langeland and Burks, 1999).

Table A-2. Florida Panhandle Category I Nonnative Invasive Plants

Scientific Name	Common Name	Panhandle Distribution (county)
Trees		
Cinnamomum camphora	Camphortree	Throughout
Melia azedarach	Chinaberry	Throughout
Schinus terebinthifolius	Peppertree	Throughout
Sapium sebiferum	Tallowtree	Throughout
Shrubs		
Ardisia crenata	Spiceberry	Franklin, Gadsden, Leon, Liberty,
Lantana camara	Lantana	Throughout
Ligustrum sinense	Chinese privet	Throughout
Nandina domestica	Heavenly bamboo	Escambia, Gadsden, Leon
Vines		
Dioscorea alata	Water yam	Escambia, Gadsden, Leon, Levy
Dioscorea bulbifera	Air potato	Jackson, Franklin
Ipomoea aquatica	Water-spinach	Bay
Lonicera japonica	Japanese honeysuckle	Throughout
Macfadyena unguis-cati	Cat's-claw vine	Escambia, Leon
Paederia foetida	Skunk vine	Gadsden
Pueraria montana	Kudzu	Throughout
Grasses		
Imperata cylindrica	Cogongrass	Throughout
Panicum repens	Torpedo grass	Throughout

Table A-2. Florida Panhandle Category I Nonnative Invasive Plants Cont'd

Scientific Name	Common Name	Panhandle Distribution (county)
Ferns		
Lygodium japonicum	Japanese climbing fern	Throughout
Nephrolepis cordifolia	Boston fern	Escambia, Leon
Forb/Herb		
Colocasia esculenta	Taro	Throughout
Eichhornia crassipes	Water hyacinth	Throughout
Hydrilla verticillata	Hydrilla	Throughout
Hygrophila polysperma	Hygro	Throughout
Pistia stratiotes	Waterlettuce	Locally throughout
Solanum viarum	Tropical soda apple	Throughout
Tradescantia fluminensis	Small-leaf spiderwort	Leon, Calhoun

Source: Langeland and Burks, 1999

Camphortree

Peppertree

Chinaberry

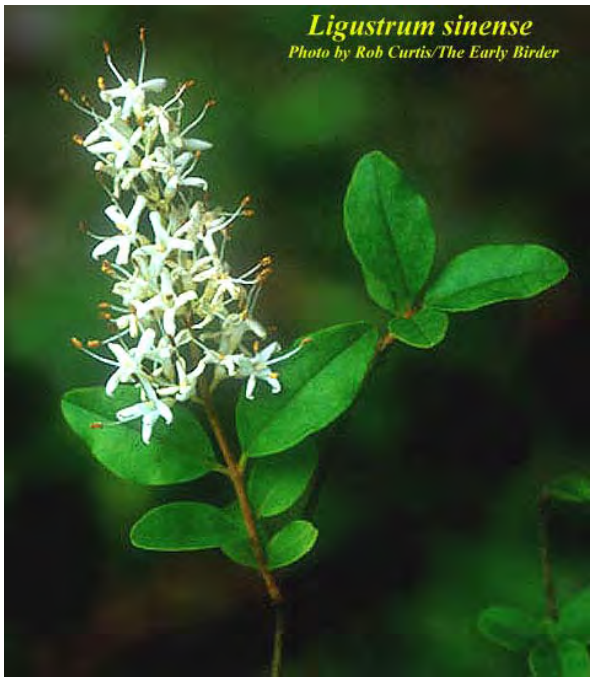
Peppertree

Tallowtree

Spiceberry

Lantana

Lantana (Photo by Agnes Rinehart)



Chinese privet

Chinese privet

Heavenly bamboo

Air potato

Air potato

Japanese honeysuckle

Cat's-claw vine

Skunk vine

Kudzu

Kudzu

Cogongrass

Cogongrass

Torpedo grass

Torpedo grass

Japanese climbing fern

Taro

Japanese climbing fern

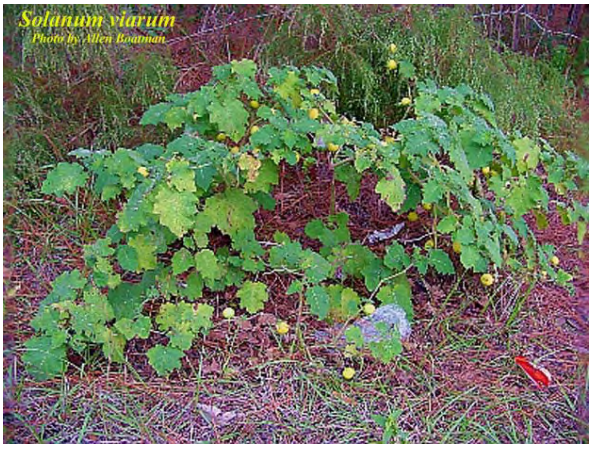
Waterhyacinth

Boston fern

Hydrilla (Photo by Agnes Rinehart)

Hygro

Waterlettuce



Tropical soda apple

Tropical soda apple

Small-leaf spiderwort

Small-leaf spiderwort

APPENDIX D
SOIL EROSION FEATURES

SOIL EROSION FEATURES

This appendix describes the soil erosion process and it's primary surface features including rainsplash, sheet, rill, and gully erosion.

INTRODUCTION

Soil erosion is a three-phase process of detachment, transport, and deposition of surface materials by water, wind, ice, or gravity initiated by drag, impact, or tractive forces acting on individual soil particles. It is a relentless process that is nearly impossible to stop, difficult to control, and easily accelerated by humans. Accelerated erosion caused by humans occurs at rates much greater than natural erosion conditions and has been shown to have detrimental effects on soils and ecosystems. Soil is a nonrenewable resource — once removed it is gone forever.

Rainfall erosion is primarily controlled by climate, soil, topography, and vegetation. According to Wischmeir and Smith (1958), the intensity and duration of precipitation is the most important climatic factor controlling rainfall erosion. The susceptibility of the soil to erosion (erodibility) is primarily dependent on factors such as soil texture, moisture content, pH, and ionic strength of the eroding water. Soil erodibility generally decreases with increasing clay and organic matter content, whereas uniform silts and sands tend to have high soil erodibility (Gray and Leiser, 1982).

Slope angle and length are the primary topographic variables influencing rainfall erosion. Slope length influence tends to increase with increasing slope angle. As an example, doubling slope length from 100 to 200 feet on a 6 percent slope would increase potential soil loss by 29 percent, whereas the same slope length doubling on a 20 percent slope would increase potential soil loss by 49 percent. Vegetation plays a pivotal role in the interception and diffusion of water energy from rainsplash and overland water flows (Wischmeir and Smith, 1958).

The process of water erosion is directly linked to the behavior of water as it encounters and/or moves over the ground. Overland flow erosion constitutes a form of geomorphic work that is performed whenever driving forces (impact, drag, and traction) exceed the resistance forces (surface friction) encountered (Toy and Hadley, 1987). Under conditions of absent litter layers and compacted soil, infiltration is reduced. As a result, a given volume of stormwater is able to produce a greater proportion of overland flow than would otherwise occur, giving rise to increased expenditures of energy on the soil surface (USEPA, 1980). The immediate on-site net effect of erosion is loss of productivity that may alter the capability of the land to support plant and animal species and off-site problems may develop because of sediment deposition.

The three categories of overland flow are sheet erosion, rill erosion, and gully erosion. Generally, soil particles undergo numerous cycles of transport and deposition that typically span single events as well as geologic time. Soil particle detachment associated with rainfall-induced erosion is initiated by raindrop impact and/or shear stress from overland water flow (Morgan, 1995; Gray and Leiser, 1982; USEPA, 1980).

The following discussion describes water erosion associated with rainsplash, sheet, rill, and gully erosion features.

RAINSPLASH EROSION

Rainsplash is a result of individual raindrops impacting exposed soil or thin layers of water covering the surface. Raindrop impacts are the most important detaching agent and cause the breakdown of soil structure and detachment of individual soil particles and aggregates. Raindrop velocities normally range from 20 to 30 feet per second (USEPA, 1980).

Morgan (1995) estimated that during a heavy storm up to 100 tons per acre could be splashed into the air by raindrop impacts. On level surfaces, splashed particles may move more than 2 feet vertically and 5 feet laterally. Normally, soils with a silt loam, loam, fine sand, and sandy loam textures are most prone to detachment. Coarse sands are relatively resistant to detachment because of their weight, and clayey particles are resistant because of their adhesion and bonding to other particles (Morgan, 1995).

In the absence of raindrop energy interception, dispersion, and absorption by vegetative cover and litter, rain impacts also can destroy porous soil structure and reduce infiltration. Since splash erosion occurs uniformly over an area, evidence of the effects are best seen where plant roots or surface debris have protected the underlying soil causing the creation of splash pedestals. As shown in Figure D-1, the effect of a surface area resistant raindrop impact can be dramatic.

Figure D-1. Rainsplash Pedestal Formation Adjacent to a Gully (Photo by Mike Rainer)

Soil consolidation and compaction in the top one-inch layer of bare topsoil has been shown to increase by 15 percent as a result of raindrop impacts (Gray and Leiser, 1982). This type of soil consolidation is typically exhibited as a surface crust generally less than a few millimeters thick. The most important effect of a surface crust is reduced infiltration and increased runoff. Since surface crusting decreases with increasing contents of clay and organic matter, loams and sandy loams are most vulnerable to crust formation (Morgan, 1995).

Vegetation canopies and ground litter play primary roles in minimizing the effects of rainsplash on surface soils. The reduction of rainfall energy by vegetation canopies, whether is it a timber stand or grassland stems and foliage, is not considered significant, but canopies play an important role in replenishing the litter layer. If the depth of the litter layer exceeds the penetration depth of the raindrops, it is assumed that surface soil particle detachment potential is near zero (USEPA, 1980). This emphasizes the importance of the surface mulching of bare ground and incorporation of organic matter into the soil.

SHEET EROSION

Soil particle detachment by raindrop impact normally removes soil in a uniform manner over a broad area of exposed soil known as sheet erosion. The work performed by sheet erosion is a function of the depth and velocity of runoff for a given size, shape, and density of soil particles and aggregates. Sheet flow is unique in that it occurs only where the flow surface is nearly featureless and where the flow is not mechanically disrupted by raindrop impact. This type of erosion may go undetected to the untrained eye. It is important to remember that rainsplash and sheet erosion work in concert to effectively detach, entrain, and transport materials (Toy and Hadley, 1987).

Sheet erosion can be a source of slope retreat and sediment on road cut slopes (Gray and Leiser, 1982). Slope wash occurs when rainfall erodes without causing rillying or gullying (Figures D-2 and D-3). However, slope wash to a uniform depth occurs infrequently and more commonly water flows in a mass of watercourses with no pronounced channels (Morgan, 1995).

Figure D-2. Roadside Slope Sheet Erosion (Photo by Mike Rainer)

Figure D-3. Roadside Slope and Archaeological Site Damaged by Sheet Erosion (Photo by Mike Rainer)

RILL EROSION

Rill erosion is the removal of soil by water flows that have been disengaged from shallow overland flow and concentrated by surface irregularities and/or disturbance into small but well-defined micro-channels or rills with depth and velocity water flows greater than adjacent areas (Toy and Hadley, 1987; Gray and Leiser, 1982) (Figure D-4). Rill migration upslope occurs by retreating rill headcuts and downslope extension is determined by the strength of the soil and shear stress of the flowing water (Morgan, 1995). Rill erosion is more serious than sheet flow because of the increased velocity of the concentrated runoff, and its considerable erosive power is responsible for the bulk of soil-eroded slopes (Gray and Leiser, 1982).

GULLY EROSION

As water flows continue to concentrate at greater depths and velocities, gullies may form. Concise definition of a gully is elusive because it is a transitional type of channel between a rill and a stream. However, their uniqueness lies in their steep sidewalls (>50 percent slope), headcuts, tier steps along their courses, and sediment deposition fans or cones that occur in the lower portions of some gully systems. Generally, in comparison to stable channels, gullies have greater depth and smaller width and carry larger sediment loads.

Gullies are almost always associated with the landscape instability of accelerated erosion (Morgan, 1995; Toy and Hadley, 1987). The four principal stages of gully development are downward cutting, headward erosion and enlargement, healing, and stabilization (Gray and Leiser, 1982). A gully is considered stable once a stable grade of repose is achieved through the excavation and transport of soil material by the forces of concentrated water flows.

Figure D-4. Roadside Rill and Sheet Erosion (Photo by Mike Rainer)

Gully erosion produces incisions in the land that range from one foot in depth and width and a few feet long to several tens of feet deep, hundreds of feet wide, and miles long. Gully erosion nearly always starts for one of two reasons: either there is an increase in the amount of runoff or the runoff remains the same but the capacity of waterways to carry the runoff is reduced. The most common causes of increased runoff or deterioration in channel stability are changes in vegetative cover, especially removal of trees (Toy and Hadley, 1987).

A gully is normally composed of a headwall(s), transport zone, and in some cases a fan apex (Figures D-5 to D-10). The upper portions of the gully are source zones, middle sections are transport zones, and lower sections are deposition zones. Headwalls are source areas with very steep to almost vertical sidewalls that are susceptible to gross rates of erosion. These areas frequently experience headcutting at the base of the sidewalls that results in the collapse and mass wasting of gross amounts of soil material.

Material transport zones are characterized by steep, unstable to partly unstable banks that may constitute a confined, V-notched ravine or flat bottom channels. Fan apexes or cones that occur in the lower portions of some gully systems may be composed of single or multiple channels ranging from deeply incised to fully confined channels with steep to gently sloping banks exhibiting extensive sediment deposition.

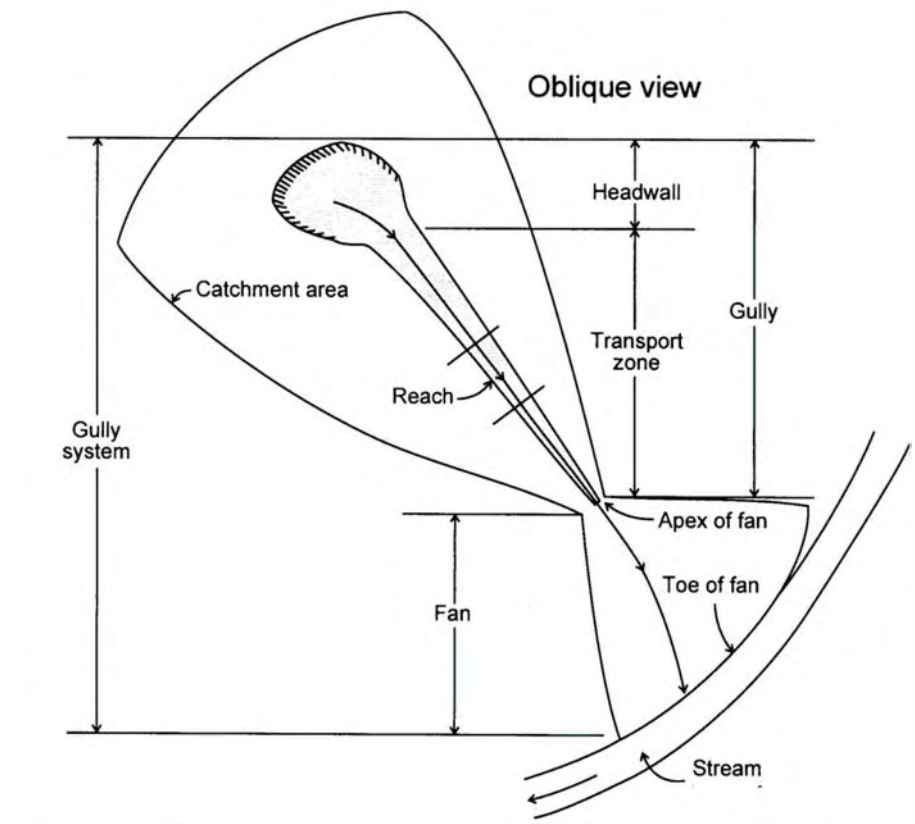
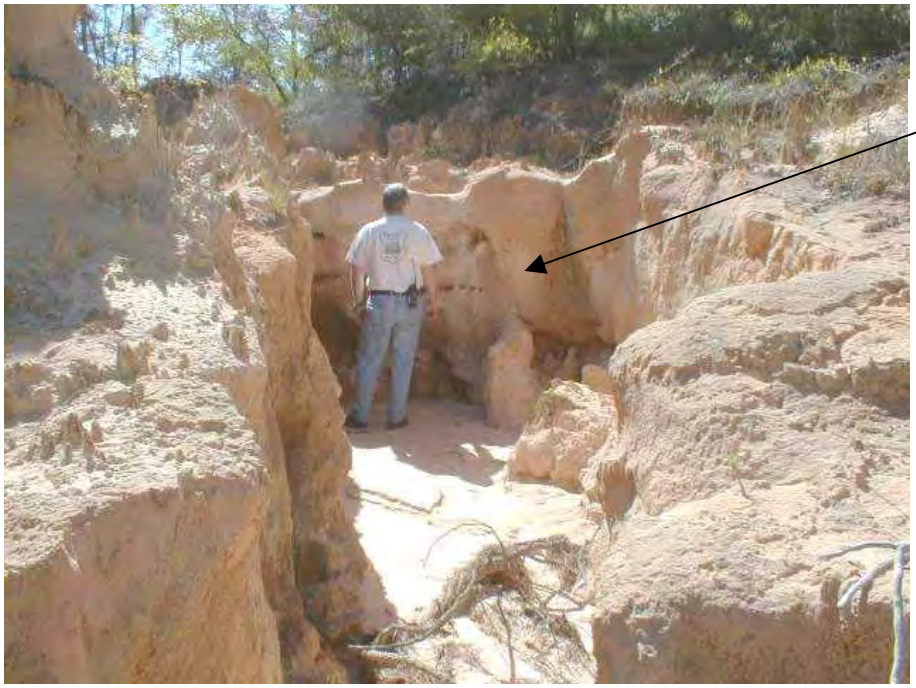


Figure D-5. Gully System Components (B.C. Ministry of Forests, 2001)

Figure D-6. Roadside Two-Tier Gully System (Photo by Mike Rainer)



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NORTHWEST FLORIDA UNPAVED ROAD-STREAM CROSSING MANUAL

CHAPTER V
STREAM CROSSING PRACTICES

Roadside Erosion
(Photo by Sandy Pizzolato)

STREAM CROSSING TECHNICAL CENTER

Facilitating informed decision-making and measurable improvements in watershed management, aquatic resource restoration, and water quality

NORTHWEST FLORIDA UNPAVED ROAD-STREAM CROSSING MANUAL

CHAPTER V
STREAM CROSSING PRACTICES

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APRIL 2005

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1. INTRODUCTION

This section defines stream crossing practices (SCPs) discussed throughout this chapter and outlines important characteristics and concepts used in their development.

SCPs are the methods, measures, processes, features, and/or techniques that are selectively applied to SCs in a manner that maintains the purpose, utility, and integrity of the road system and minimizes on- and off-site environmental impact potentials. Specifically, the SCPs in this manual are presented for use as practical, cost-effective measures designed in accordance with the uniqueness of the northwest Florida landscape to provide solutions for environmental and road maintenance issues. Characteristics of the SCPs included in this manual follow.

- SCPs are based on scientific studies and testing. Their effectiveness in erosion, runoff, and/or sediment control is evaluated for type cases, and best professional judgments are employed to assess their applicability to other situations.
- The form, function, and application of SCPs can be broad or quite narrow in the realm of their effectiveness in achieving or contributing to the attainment of a desired condition.
- SCPs are designed to be feasible in the sense that they are unlikely to eliminate all erosion and sediment production; however, their design and correct application can minimize impacts within the constraints of political, economic, and/or technical factors.
- SCPs are site specific in that their selection is dependent on an understanding of site characteristics and influencers.
- The implementation of SCPs comes with a level of risk and responsibility. Since their effectiveness is not measured against water quality compliance standards, it is assumed that their correct application would result in acceptable results. It is the responsibility of end users to take calculated risks in the interpretation of site variability and extrapolate best available information to formulate and implement project plans.
- SCPs are not “build and walk away” features. All SCPs require a level of inspection, monitoring, and maintenance to ensure their longevity and effectiveness. Repairs or replacement may also be required.
- A measure of SCP effectiveness is the ability of field personnel and engineers to make practice modifications to accommodate site-specific characteristics. This requires knowledge and understanding of natural features and processes and the functional capabilities of the SCP practice.

The SCPs presented in this chapter are categorized as:

- Soil Stabilization Practices
- Runoff Management Practices
- Sediment Control Practices
- Crossing Structure Practices
- Stream Restoration Practices

The SCPs discussed in this chapter are presented in Table 1-1.

Table 1-1. Stream Crossing Practices Summary

Practice	Identification	Description
Soil Stabilization Practices		
Slope Grading	SS-1	Disturbed slope repair
Road Prism Slope Grading	SS-1A	Road approach road prism reconstruction
Roadside Slope Grading	SS-1B	Mechanical shaping of disturbed roadside slopes
Streambank Slope Grading	SS-1C	Reconstruction and stabilization of eroded streambanks
Soil Conditioning	SS-2	Damaged soil repair
Soil Testing	SS-2A	Collection of soil physical and chemical data prior to revegetation
Liming Acid Soil	SS-2B	Liming procedures
Compost Incorporation	SS-2C	Using mature compost to improve soil conditions
Mycorrhizal Inoculation	SS-2D	Restoration of soil mycorrhizae-plant associations
Revegetation	SS-3	Establishing vegetative cover on disturbed sites
Droughty Soil Protocol	SS-3A	Native grass, forb, vine, and shrub species for droughty soils
Dry Soil Protocol	SS-3B	Native grass, forb, vine, and shrub species for dry soils
Wet Soil Protocol	SS-3C	Native grass, forb, vine, and shrub species for wet soils
Temporary Seeding Protocol	SS-3D	Establishing temporary cool season grass cover on disturbed sites
Grass Sodding Protocol	SS-3E	Stabilizing soils with a permanent cover of nonnative grass sod
Riparian Revegetation Protocol	SS-3F	Riparian zone revegetation techniques
Brushlayering	SS-3F-A	Streambank bioengineering revegetation/stabilization technique
Coir Rolls	SS-3F-B	Streambank bioengineering revegetation/stabilization technique
Live Fascines	SS-3F-C	Streambank bioengineering revegetation/stabilization technique
Live Staking	SS-3F-D	Streambank bioengineering revegetation/stabilization technique
Seedbed Preparation	SS-3G	Mechanical preparation of the soil for planting
Grass and Forb Seeding	SS-3H	Revegetation protocol native species seeding mixtures and rates
Shrub and Vine Planting	SS-3I	Seedling, cutting, bareroot stock, and container stock planting
Tree Planting	SS-3J	Sweetbay and Titi tree planting procedures
Irrigation	SS-3K	Temporary irrigation following planting
Fertility Management	SS-3L	Native and nonnative species pre- and post-planting fertility
Replanting	SS-3M	Stand density evaluations
Mulching	SS-4	Applying protective layers to the soil surface
Erosion Control Blankets	SS-4A	Applying commercially available blankets
Straw Mulch	SS-4B	Applying gain straw mulch
Hydromulch	SS-4C	Applying liquid slurry mulches
Compost Mulch	SS-4D	Applying compost mulch
Cellular Confinement System	SS-5	Honeycomb geocell slope structures
Straw Rolls	SS-6	Temporary slope stabilization measure
Pipe Drops	SS-7	Replacing native soil discharge points with pipe conducts
Road Reinforcement	SS-8	Stabilizing road prism soils
Road Aggregate Surfacing	SS-8A	Road prism aggregate surfacing
Road Chemical Reinforcement	SS-8B	Road prism chemical stabilization of road prism soils
Bituminous Surface Treatment	SS-8C	Liquid asphalt layer followed by an aggregate surface course
Road Asphalt Paving	SS-8D	Surfacing the roadway with asphalt paving
Road Geotextile Reinforcement	SS-8E	Reinforcing roadways with synthetic permeable textile materials
Runoff Management Practices		
Road Prism Drainage	RM-1	Road prism water removal in a nonerosive, expedient manner
Road Contouring	RM-1A	Reshaping the road prism to a crown or outslope configuration
Road Deflector	RM-1B	Intercepting down gradient water flows with deflector structures
Grade Breaks	RM-1C	Manipulating road elevation to facilitate water removal
Rolling Dip	RM-1D	Diagonal, gently sloping road excavations water removal systems
Roadside Drainage	RM-2	Roadside water drainage systems for water dispersion/discharge
Natural Drainways	RM-2A	Use for naturally vegetated roadside areas to disperse stormwater
Drainage Ditches	RM-2B	Construction/maintenance of stormwater conveyance channels
Soft Armor Waterways	RM-2C	Vegetation lined drainage ditches
Grass Hedges	RM-2D	Runoff control using self-sustaining grass hedges
Road Cross Drains	RM-2E	Culvert transfer of roadside drainage a controlled discharge point
Turnouts	RM-2F	Excavated roadside drainage discharge features
Riprap Energy Dissipator	RM-2G	Drainage discharge point protection
Temporary Slope Drain	RM-2H	Conduit that moves water over a slope during revegetation period
Seepage Drain	RM-2I	Structure that allows water to pass under the road surface

Table 1-1. Stream Crossing Practices Summary Cont'd

Practice	Identification	Description
Sediment Control Practices		
Sediment Basin	SC-1	Temporary sediment holding pond
Silt Fence	SC-2	Temporary sediment barrier
Hay Bale	SC-3	Temporary sediment barrier
Compost Berm	SC-4	Temporary or permanent sediment retention structure
Crossing Structure Practices		
Stream Culverts	CS-1	Culvert design, installation, and maintenance considerations
Flood Relief Culverts	CS-2	Flood relief culvert design and installation portable
Riprap	CS-3	Crossing structure slope stone layering
Improved Low Water Crossing	CS-4	Geocell low-water stream crossing structure
Stream Diversion	CS-5	Temporary diversion channel design and installation
Portable Bridge	CS-6	Temporary stream crossing
Stream Restoration Practices		
Stream Channel Sediment Removal	SR-1	Physical removal of sediments for a stream channel
Channel Vanes	SR-2	In-stream cross-vane, J-hook, and W-weir structures
Cross Vanes	SR-2A	Channel grade control structure
J-Hooks	SR-2B	Streambank erosion control structure
W-Weirs	SR-2C	Large stream grade control structure
Stream Habitat Features	SR-3	Aquatic habitat enhancement structures
Cover Logs	SR-3A	Selective in-stream placement of logs to provide habitat features
Tree Cover	SR-3B	Use of trees to protect streambanks and create habitat features
Rootwads	SR-4	Natural streambank stabilization practice

Principle sources of road-stream crossing practice information were:

- U.S. Department of Agriculture (USDA), Natural Resources Conservation Service. No date. *Conservation Practice Standard Codes* for Florida, Mississippi, Alabama, and/or Georgia.
- Salix Applied Earthcare. 1999. *Erosion Draw 3.0*. John McCullah, Redding, CA.

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2. SOIL STABILIZATION PRACTICES

This section describes soil stabilization practices for use on streambanks, crossing structure fill areas, road prisms, and roadside areas that have experienced soil degradation and/or loss of vegetative cover. Revegetating eroded and, in some cases, relatively sterile soil environments that frequent unpaved road-stream crossings and stabilizing the surface materials of crossing road approaches are two of the most difficult tasks facing road managers and maintenance personnel. The practices discussed in this section include: slope grading, soil conditioning, revegetation, mulching, and road reinforcement.

2.1 SLOPE GRADING (SS-1)

Slope grading is used in combination with other erosion and runoff control practices to repair SC slopes damaged by soil erosion and manage runoff in a manner that reduces water volumes and velocities. Slope grading relies on the use of hand tools or heavy equipment to shape soils to a stable grade depending on site conditions. All graded slopes are planted to permanent vegetative cover. The types of slope grading discussed in this section include:

- Road Prism Slope Grading (SS-1A)
- Roadside Slope Grading (SS-1B)
- Streambank Slope Grading (SS-1C)

2.1.1 Road Prism Slope Grading (SS-1A)

Road slope grading is performed by cutting, redistributing, and recompacting the road surface to the design width and surface shape. Road prism contouring guidelines are presented in Section 3.2.1. Road slope grading is accomplished using existing road materials or by adding new road fill. Application guidelines are presented below.

- Grading and cutting operations are performed with the outer edge of the moldboard slightly overhanging the road surface edge.
- If the roadside drain is not to be reworked, keep a minimum of one foot from the ditch line so as not to disturb vegetation. This type of grading must bring the road surface back up to and slightly above the ditch line elevation to allow the road surface runoff to flow off the road surface and into the ditch.
- Grading will not be performed in a manner that creates loose material windrows at the road's edge.
- The surface crust may require scarification before moldboard work is performed. Scarifying the surface blends the materials and improves cohesion.
- Add new fill material by running a dump truck down the center of the road, dumping material as it travels.
- Fill material is blended with the scarified existing material and compacted. Roll the roadbed a minimum of five full-width passes or until visual displacement ceases (USDA, 1996).

- The minimum weight of a static roller is 10 tons. Vibratory steel-wheel rollers shall have a minimum striking force of 20,000 pounds. Pneumatic tire rollers shall have smooth tread tires of equal size that will provide uniform compacting pressure for the full width of the roller and capable of exerting ground pressure of at least 550 kilo pascals (kPA). The compactor shall be equipped with amplitude and frequency controls, and specifically designed to compact the material on which it is used.
- A drainage system (Section 3.3) is established over the entire course of the finished roadway (Choctawhatchee, Pea, and Yellow Rivers Watershed Management Authority, 2000).

2.1.2 Roadside Slope Grading (SS-1B)

Roadside slope grading is the mechanical shaping of damaged side slopes to gradients that are less susceptible to erosion and encourage the establishment of vegetation. Eroded roadside slopes can be a significant source of sediment at SCs. In many cases, eroded slopes deliver sediment to roadside drainage features that flow directly into streams (Figure 2-1). Following grading, the soil stability of eroded slopes is improved and vegetation is more readily established. Graded slopes are also easier to maintain (Figure 2-2).

Figure 2-1. Severely Eroded Unstable Roadside Slopes (Photos by Mike Rainer)

Figure 2-2. Graded Roadside Slope (Salix Applied Earthcare)

Roadside slope grading guidelines are as follows.

- To the degree possible, slopes shall be regraded to an overall gradient of 4:1 or flatter to increase the success of erosion and runoff control measures and support potential maintenance by tractors or other equipment. Mowed slopes should be no steeper than 3:1.
- Disturb only those areas necessary for construction. Flag or otherwise delineate areas not to be disturbed.
- Utilize the surrounding natural slopes as a benchmark for designing slope lengths, angles, and contours that are compatible with endemic hydrology and design criteria.
- Areas to be graded shall be cleared, grubbed to remove trees, vegetation, roots, and other objectionable material, and stripped of topsoil.
- Stripped topsoil shall be saved in a protected location for reuse following preliminary grading activities. If topsoil is required for the establishment of vegetation, it shall be stockpiled in the amount necessary to complete finished grading, and protected from erosion during the interim. Graded areas to receive topsoil shall be scarified to a minimum depth of 3 inches prior to placement of topsoil.
- Roughen the surface of all slopes during the construction operation to retain water, increase infiltration, and facilitate vegetation establishment.
- Graded areas can be roughened by driving a bulldozer up and down the slope so the dozer cleat treads create grooves perpendicular to the slope. The tread indentations are ideal for trapping seeds and encouraging plant to establish. The tracks also slow water velocities. If the soil is not too moist, excessive compaction will not occur.
- Use mulch products to temporarily stabilize areas where final grading must be delayed (Salix Applied Earthcare, 1999).
- Following soil testing, apply soil reconditioning lime, compost, mycorrhizal inoculant, and/or commercial fertilizer as applicable (Section 2.3).
- Revegetate finished slopes according to the applicable revegetation protocol (Section 2.4.1).

2.1.3 Streambank Slope Grading (SS-1C)

Streambank slope grading may be required in circumstances where road-induced runoff has discharged over receiving streambanks or changes in channel morphology have increased lateral stress on channel banks, resulting in the loss of vegetative cover and soil erosion (Figure 2-3). The objective of streambank slope grading is to restore the channel bank to a stable grade and reestablish vegetative cover. Vegetative streambank stabilization is generally applicable in situations where bankfull flow velocity does not exceed 5 feet per second and soils are erosion resistant.

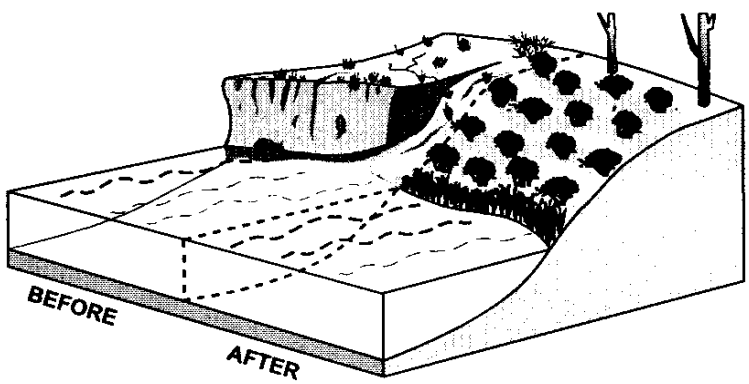


Figure 2-3. Illustration of Graded Streambank Slope Condition (FISRWG, 2001)

Guidelines for grading streambank slopes include:

- For relatively stable stream channels, use the average slope gradient as a guide for restoring eroded slope areas. As applicable, construct slopes to a grade of 4:1 or less. Use hand tools to finish grade the streambank slope to the design grade.
- Recondition disturbed soils based on soil testing results (Section 2.3) and revegetate the slope using the riparian revegetation protocol (Section 2.3.1.6).
- Apply mulching materials (Section 2.4) and riparian revegetation practices to the bank slope to stabilize soils while permanent vegetation becomes established. If the slope toe is susceptible to lateral channel stresses, use soft armor structures such as erosion control mats and coir/straw rolls to temporarily protect the slope.

2.2 SOIL CONDITIONING (SS-2)

The stability and integrity of the landscape in terms of physical, chemical, and biological form and function defines a carrying capacity beyond which the capabilities of the soil to absorb and recover from disturbance impacts are diminished. As soil quality declines, adverse impacts to on-site and off-site environments increase. Soil quality is the capacity of the soil environment to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water quality, and support organism health and habitation (Karlen et al., 1996). Since soils vary in their capacity to function, the definition of quality will be specific to each kind of soil (Doran and Parkin, 1994).

The purpose of soil conditioning as presented in this section is to restore the quality of damaged soils to support soil flora and fauna and vegetation. The soil conditioning practices discussed in this section include:

- Soil Testing (SS-2A)
- Liming Acid Soils (SS-2B)
- Compost Incorporation (SS-2C)
- Mycorrhizal Inoculation (SS-2D)

2.2.1 Soil Testing (SS-2A)

The first step in restoring soil quality is to identify the existing soil physical, chemical, and/or biological characteristics of the affected soils. Soil testing is a field and/or laboratory procedure for determining the physical and chemical nature of the soil in advance of establishing vegetation. Results of soil tests will determine the types of practices used to amend soil characteristics. On-site soil field testing can be performed using the soil testing kit and procedures developed by John Doran and Associates for the USDA Natural Resources Conservation Service, Agricultural Research Service, Soil Quality Institute. The testing procedures presented in the following section are adapted from the USDA Soil Quality Test Kit Guide (USDA, 1999).

2.2.1.1 Collecting Soil Samples

A soil test is only as accurate as the sample taken and is totally dependent upon the attention given to gathering a representative soil sample. The size of the sample is normally based on uniformity in topography, soil moisture, and soil type. Areas that differ in soil type, slope, appearance, type of vegetation, or past use history should be sampled separately. When sampling sloped areas that have been denuded of vegetation, avoid sampling sediment deposition sites that may occur at the toe-of-slope. The sediments may include eroded on- and off-site topsoil that may misrepresent the overall condition of the treatment area. It is advantageous to sample adjacent relatively undisturbed areas for comparative analysis. This is especially helpful when attempting to reestablish native plant communities. The soil test results of the undisturbed area can serve as a benchmark for interpreting the soil condition of the treatment area.

Sampling Tools

Tools that may be used to take a soil sample include a spade, shovel, soil auger, or thin-walled tube sampler. Sampling tools should be stainless steel; avoid chrome-plated implements. Spades and shovels are used for near surface sampling, whereas tube samplers and augers can be used separately or in combination for near surface and deeper soil sampling. The soil auger is especially useful when sampling heavily compacted or cemented soil. If using a pail or bucket to collect the soil samples, be sure to use plastic to avoid any contamination from trace metals; soil will pick up zinc from a galvanized pail.

When to Sample

Since soil samples can be taken throughout the year, the best time to sample the soil is whenever it best fits your time schedule. Be sure to allow ample time to get the results back from the laboratory. Soil test levels of potassium may read higher in winter months than either fall or spring. In addition,

pH can vary through the growing season due to the presence of soluble salts, CO_2, organic matter decomposition, nutrient uptake, and exchange and fertilizer applications. Nitrate-nitrogen and sulfate-sulfur are leachable; therefore, seasonal variation may occur in levels of these nutrients depending on soil types, weather, and moisture levels. Warm soils release more phosphate, so a sample taken in December will be different from one taken in June. It is generally recommended to stay consistent from year to year if sampling and testing is being repeated. If a particular treatment area is sampled in the spring, it should be sampled in the spring the following year.

Soil Sampling Procedure

Soil sample collection procedures for field and/or laboratory testing are as follows:

- Identify the soil series (Natural Resource Conservation Service County Soil Surveys), topography, and hydrologic characteristics of the treatment area(s) to be sampled. Determine the type of sampling tools that will be used.
- Send to laboratory for analysis; keep the composite sample(s) on ice in a cooler or frozen until submitted to the laboratory.
- Send samples to the laboratory as soon as possible after collection to ensure accurate results.

2.2.1.2 Field Tests

Field conditions of the soil that are easily determined in the field include soil compaction, soil infiltration, and soil pH.

Compaction

Soil compaction destroys soil structure (Busscher et al., 1995; Unger and Kaspar, 1994; Brown et al., 1992; Logsdon et al., 1992; Douglas et al., 1992; Gassman et al., 1989). Compaction occurs because soil particles are being forced closer together and filling in the pore spaces, resulting in a subsequent increase in bulk density. Soil compaction or poor physical structure results in poor or no plant development and contributes to soil erosion potentials.

An instrument called a penetrometer may be used to check for compacted soil subsurface layers. A penetrometer is a 2 to 4 foot steel rod with a cone tip and a T-shaped or round handle. The types of meters range from the simple to complex that can provide a printed readout of measurement as it passes through the profile. Most penetrometers are equipped with a gauge that provides readings in pounds per square inch (psi). Several commercial models are available. A homemade model can be constructed from basic materials by following the steps below.

1. Weld a 1/2 inch ball bearing to the end of a 3/8 inch diameter steel rod 3 to 5 feet long.
2. Weld a bolt to the other end.
3. Secure a 4 inch diameter round plywood handle painted a bright color to the bolt end of the rod, counter sinking the top to make the attachment flush.
4. The rods tip can be adjusted (bigger for soft soils, smaller for hard ones), but keep it larger than the shaft's diameter.

In using a homemade penetrometer, the resistance to pushing the rod through the soil is the indicator of compacted layers. With practice, it becomes relatively easy to identify subsurface hardpans.

Soil Infiltration Test

The soil infiltration test is a measure of the process of water entry into a soil. The rate at which water enters the soil is known as the infiltration rate. Infiltration rates are determined by soil type, texture, structure, and water content. For a given soil, infiltration rates are higher when the soil is dry than when it is wet. Compacted soils and soils that tend to form surface crusts may have severely reduced infiltration rates. Infiltration is important to understanding drainage since water that is unable to infiltrate into the soil will become runoff. Soil infiltration rates for soil types are presented in Table 2-1.

Table 2-1. Steady Infiltration Rates for General Soil Texture Groups in Very Deeply Wetted Soils

Soil Type	**Infiltration Rate** (Inches per hour)
Sand	>0.8
Sandy and Silty Soils	0.4 – 0.8
Loams	0.2 – 0.4
Clayey Soils	0.04 – 0.2

Source: USDA, 1999

Materials needed to measure infiltration include:

- Six inch diameter ring, five inches tall; cut from 1/8 inch thick aluminum irrigation pipe; one edge beveled on one side. Mark a line around the outside of the ring 2 inches from the top.
- Twelve inch wide roll of plastic wrap
- 500 mL plastic bottle or graduated cylinder
- Distilled water
- Stopwatch or timer

If the soil is saturated, infiltration will not occur. Allow the soil to dry before testing. Soil infiltration testing procedures are as follows:

1. Place the 6 inch diameter ring on a level spot and firm the surface soils only around the inside edges of the ring with your fingers to prevent seepage. Minimize disturbance to other areas inside the ring.
2. Line the soil surface inside the ring with a sheet of plastic wrap, completely covering the soil and ring. This procedure prevents disturbance of the soil when adding water.
3. Fill the plastic bottle or graduated cylinder with 444 mL of distilled water (1 inch within the ring) and pour the water into the plastic lined ring.
4. Gently remove the plastic lining leaving the water in the ring. Note the time the water came in contact with the soil.
5. Record the time it takes for the 1 inch of water to infiltrate into the soil. Stop timing when the surface is just glistening. If the soil surface is uneven inside the ring, count the time until half of the surface is exposed and just glistening.
6. Repeat infiltration test procedure steps 2 through 5 with a second inch of water and record the elapsed time (the first inch of water wets the soil and the second inch of water gives a better estimate of the soil infiltration rate) (USDA, 1999).

Guidelines for interpreting the soil infiltration test results are presented in Table 2-2.

Table 2-2. Soil Infiltration Rates and Classes

Infiltration Rate (minutes per inch)	**Infiltration Rate** (inches per hour)	**Infiltration Class**
<3	>20	Very Rapid
3 – 10	6 – 20	Rapid
10 – 30	2 – 6	Moderately Rapid
30 – 100	0.6 – 2	Moderate
100 – 300	0.2 – 0.6	Moderately Slow
300 – 1,000	0.06 – 0.2	Slow
1,000 – 40,000	0.0015 – 0.06	Very Slow
>40,000	<0.0015	Impermeable

Source: USDA, 1999

Soil pH

Soil pH is a measure of the acidity or alkalinity of a soil. Since most plant species are adapted to range of soil pH levels, it is important to revegetation success to adjust the pH value of the soil before planting. Soil pH primarily affects nutrients absorption and plant growth through the direct effect of the hydrogen ion or through its influence on the availability and presence of toxic ions. Materials for performing the pH test are as follows:

- 1/8 Cup Measuring Scoop
- Calibration Buffer Solutions
- pH Pocket Meter
- Plastic Specimen Bottle
- Squirt Bottle
- Distilled Water

Soil samples for the pH test are taken from a depth of 0 to 3 inches. Two subsamples can be taken from composite samples for analysis. Let the soil dry before proceeding with Step 1. Make sure the pH meter is calibrated before taking measurements. If the meter has not been used in a while, place the meter in tap water for about 5 minutes before calibrating or taking a reading. The recommended pH testing procedures are presented below.

1. Extract Subsample: The soil sample should be thoroughly mixed before taking a subsample. Measure a 1/8 cup level scoop subsample of soil and place it in the plastic container. Enter the subsample weight on the Soil Data worksheet.
2. Add Water to Subsample and Mix: Add 1/8 cup (1ounce) of distilled water to the container with the subsample. The resulting soil/water mixture equates to a 1:1 soil to water ratio on a volume basis. Put the lid on the container and shake vigorously about 25 times.
3. Measure and Record pH: Open the container and insert the pH meter into the topmost portion of the soil-water mixture and turn the meter on. Do not immerse the meter above the immersion level. Allow the reading to stabilize (0 to 30 seconds). Enter the digital pH reading on the Soil Data worksheet. Thoroughly rinse the electrode with distilled water and store with a few drops of the pH 7 buffer solution and replace cap (USDA, 1999).

2.2.2 Liming Acid Soil (SS-2B)

The purpose of liming acid soils is to raise the pH to target range that promotes plant growth and establishment. Lime is a material that increases pH upon contact with the soil. The threshold pH for most native plant species is 4.5. At this pH and below, adverse effects to plant growth and development may occur. In most cases, a pH between 5.5 and 7.0 is best for native plants. Soil liming recommendations include:

- For soils with a threshold pH of 4.5, apply calcitic limestone at the rates provided in Figure 2-4. For soils with a pH well below the threshold, send a sample to a soil laboratory for analysis of calcium and magnesium levels. If magnesium is determined to be moderate or low, apply dolomite at the laboratory recommended rate. Do not lime unless the field test shows that limestone is needed.

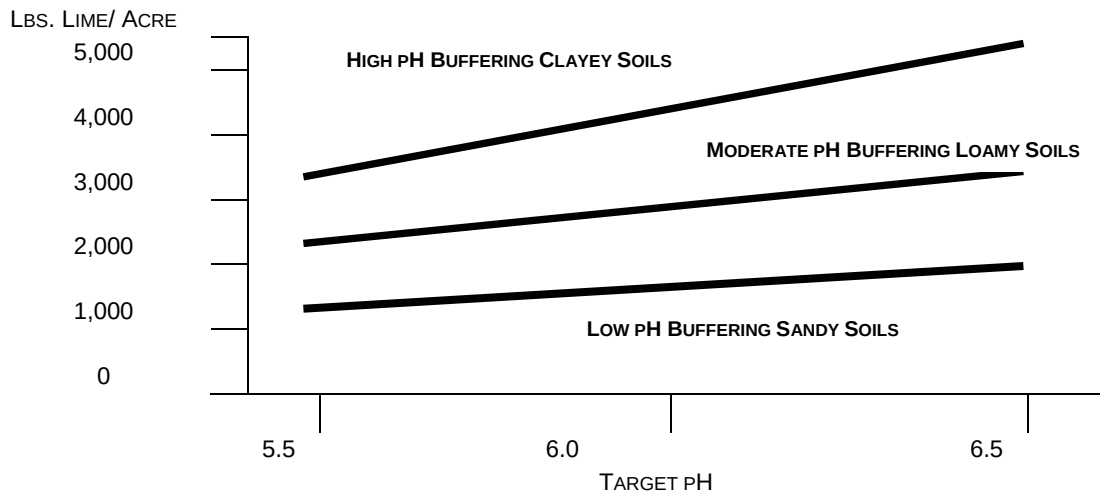


Figure 2-4. General Guidelines for Applying Lime to Raise Soil pH
(Baseline soil pH is 4.5)

- Lime can be applied any time during the year, but the period between September and November is preferred.
- For applications of 50 pounds per 1,000 square feet or greater, divide the total amount into split applications; apply one half in the spring and the other half in the fall.
- Apply calcitic or dolomite limestone to a well-prepared seedbed or site that has been thoroughly aerated. This enables the lime to react more quickly.
- When liming a new seeding, ground or pelletized lime is applied uniformly to a dry soil surface at the recommended rate and incorporated into the soil to a depth of 4 to 6 inches. For best results, apply half of the material in one direction and the remainder at a right angle to the previous application.
- If a urea fertilizer is being used, apply the fertilizer 3 to 4 weeks before lime application. If urea is applied at the same time as lime, nitrogen loss will occur because of an increase in pH around the fertilizer granules.
- Retest the site every 4 weeks to monitor changes in pH; it may take up to a year before the target pH is achieved. Dolomite is generally slower reacting than calcitic limestone. Retest the area every 3 years to check for changes in pH.

2.2.3 Compost Incorporation (SS-2C)

Organic amendments such as mature compost can assist in the establishment of live, fertile soil in areas where degraded, sterile, impoverished soils exist. Compost is widely used as a soil amendment to improve soil structure, provide plant nutrients, and facilitate the revegetation of disturbed or eroded soil. Mature compost applied to sloped areas has been shown to be more effective than straw or hydromulch in reducing erosion by enhancing planted or volunteer vegetation growth. It tends to be self-adhesive and forms a flexible, noneroding blanket when applied to the soil surface. It also facilitates thicker, more permanent plant growth due to its ability to improve and stabilize the long-term structure, fertility, and microbial activity of the soil. Plant nutrients are more readily available over extended periods because of the slow nutrient release rates of humic materials. The high water holding capability of compost also improves plant survival during droughts (USEPA, 1997). Composting involves the surface application and the mechanical incorporation of compost into the soil. Compost application recommendations are presented below.

- The optimum application rate will vary with soil conditions, compost characteristics, and revegetation species. The application of organic matter must be consistent with the anticipated impacts to vegetation establishment and productivity. If the objective is to provide plant nutrients, sizable amounts may be required. If the intent is to primarily improve soil structure, smaller amounts may be sufficient.
- The typical application rate will be 3 to 6 cubic yards per 1,000 feet. This equates to the application of a 1 to 2 inch layer of compost. The 6 cubic yard application rate will be applied to severely eroded sites that have lost all topsoil and have nondetectable levels of organic matter and extremely acid pH.
- Factors limiting application rates include heavy metals, salinity, and ammonium. Products typically high in salinity such as manure should be limited to approximately 1 cubic yard per 1,000 square feet and products high in ammonium nitrogen such as some biosolids compost should be used with caution since high ammonium may injure seedlings.
- For smaller areas, the compost can be applied using hand tools. For larger sites that compost is loaded into a manure spreader or similar equipment for surface application.
- Following application, compost is incorporated with a disk harrow or rotary tiller to a depth of 3 to 6 inches. This results in an inclusion rate of 20 percent to 30 percent compost by volume. Thoroughly incorporate the amendment to avoid pockets or layers of organic material.
- The need for additional amendments such as lime, sulfur, gypsum, or organic fertilizers is based on soil tests, chemical composition of the compost, and target plant species.
- Following incorporation, the site is seeded or planted to the desired species. Generally, commercial fertilizer will not be required; however, irrigation may be needed.

2.2.4 Mycorrhizal Inoculation (SS-2D)

Typically, the success of revegetation projects is measured on the basis of some aboveground practice. However, the component of the living soil beneath the surface is as, if not more, important than the more conspicuous aboveground features. The health and vitality of soil flora and fauna is crucial to the revegetation success. As such a dominant force, destruction of the mycorrhizal network is a central event of soil disturbance (Fitter and Garbaye, 1994). The life cycle and productivity of many plant communities is directly linked to the presence of mycorrhizal fungi to the point that the disturbance and/or absence of one will have a detrimental effect on the other (Figure 2-5).

Figure 2-5. California Revegetation Trials with Mycorrhizal Inculum; Mycorrhizae was Used on the Left and Not Used on the Right at the Time of Seeding (Photo by Neil Anderson**)**

Soil macro fauna (insects, worms, and small mammals) and micro fauna (protozoa, amoebae, nematodes, microarthropods, bacteria, and fungi) provide critical support for vegetation. These soil organisms perform the majority of nutrient cycling transformations that occur in the soil. Of these, the symbiotic relationship between plant root systems and mycorrhizal fungi is of particular importance. Mycorrhizae hyphae filaments mediate nutrients cycling, control soil microbiology, dictate plant community composition, and hold soil together.

The association of plants and mycorrhizae has a significant bearing on the physical, chemical, and biological character of disturbed sites. Severe disturbances that completely remove plants from the soil and/or physically alter soil structure may result in the complete obliteration or severe disruption in the microbial populations. Disturbance resulting in reduced root volume, soil compaction, low organic matter, and adverse soil pH are also detrimental to mycorrhizae-plant associations (Marx, 1997).

2.2.4.1 Mycorrhizae-Rhizosphere Associations

Except in the soil surface layers where energy sources such as organic matter is readily available, soil biotic activity primarily occurs in the area of the plant root rhizosphere because of the lack of food sources in the bulk soil. The rhizosphere is the soil-root interface approximately 1 to 2 millimeters wide, surrounding the epidermis of living root hairs and the boundary cells and hyphae of mycorrhizae where soil elements are absorbed into the plant. The plant root rhizosphere is the soil region with the highest soil microbial diversity, populations, and activity. This is the primary reason that soil microbial activity dramatically decreases below plant root levels (Walters, 1996).

Mycorrhizal fungi exist in mutualistic or symbiotic relationships with plant roots utilizing materials supplied by roots for energy and providing host plants with an extensive hypal network that dramatically extends the relatively limited range of plant roots in the soil. The increased surface area provided by the hyphae-root connections allow extensive, selective explorations of the soil by giving

roots access to relatively immobile nutrients that may be depleted in the immediate vicinity of the root and access to water sources that extend beyond the limits of root penetration (Figure 2-6).

Figure 2-6. Comparison of Mycorrhizae Effects on Plant Roots
(http://www.unce.unr.edu/publications/FS01/FS0129.htm)

Hyphae absorb and accumulate more nitrogen, phosphorus, potassium, and calcium more rapidly and over longer periods of time than nonmycorrhizal roots. The beneficial results include increased plant growth and tolerance of plants to drought, high soil temperatures, heavy metals, soil acidity and salinity extremes, soil toxins, fungal and bacterial root pathogens, and parasitic nematodes. The most consistent and defining difference between soil with a mycorrhizal network and soils without is soil structure.

Mycorrhizae hyphae improve soil aggregate stability by linking soil particles to each other and to roots by producing Glomalin, an important part of the glue that holds aggregates together (St. John, 1998). Mycorrhizal associations are divided into three major groups: ectomycorrhizae, vesicular-arbuscular (VA) or endomycorrhizae, and ectoendomycorrhizae. Of these, endomycorrhizae is the most common, forming associations with members of at least 200 plant families (Miller, 1985).

Vesicular-arbuscular (VA) mycorrhizae, the predominant grass forb endomycorrhizae, has been shown to be obligatory or strongly dependent on grass species such as big bluestem (*Anderpogon gerardii*), little bluestem (*Schizachyzrium scoparium*), Indiangrass (*Sorghastrum nutans*) and switchgrass (*Panacium vergatum*) (Hetrick et al., 1988). Hetrick (1994) reported increased competitiveness of mycorrhizal little bluestem with winter annuals compared to nonmycorrhizal little bluestem. Research also showed that although non-natives are normally the first to colonize disturbed sites, succession by mycorrhizal native species replaces the invasive successional plants.

2.2.4.2 Inoculation Considerations

Considerations for inoculating sites with mycorrhizae include the following.

- Candidates for mycorrhizal inoculation include areas that have experienced grading, excavation, compaction, or erosion of topsoil and have been barren of vegetative cover for an extended period of time. On sites only partly disturbed or where native plants have begun to return, it may be more important to add mycorrhizal hosts than to add more inoculum.
- It is important to note that mycorrhizal fungi are slow to disperse on their own, and they cannot grow without a host plant. It may take as long as three years for mycorrhizae to migrate a few dozen feet onto disturbed sites (St. John, 1998). Whatever the method of application, the inoculum should be within easy reach of new seedlings.
- Since the primary emphasis of this effort is revegetation with grasses and forbs, inoculation will focus on the use of vesicular-arbuscular mycorrhizae (VAM). As a general guide, VAM inocula Glomus etunicatum and Gigaspora margarita are effective in slight to strongly acid conditions.
- The best type of inoculate is a layer of stored native topsoil. Typically, native topsoil already contains mycorrhizal fungi, other soil organisms, organic matter, and native seeds. However, if the topsoil has been stored for more than 3 years or stored at a depth greater than 3 feet for clay soils and 6 feet for sandy soils, much of the mycorrhizae has likely been lost and will have to be reinoculated.
- Mycorrhizae materials may be handled by broadcasters, fertilizer boxes, and drill seeders. The most common inoculum application techniques are surface broadcasting and banding. Lightly incorporate inculum into the soil during seedbed preparation.
- Follow vender application rate recommendations.

2.3 REVEGETATION (SS-3)

Revegetation is the establishment and maintenance of perennial vegetative cover on erodible or otherwise denuded lands. The purpose of revegetation is to regenerate the naturally engineered capability of stable, self-sustaining plant communities to reduce soil erosion and improve soil quality, water quality, and wildlife habitat. The overall objective is to establish plant communities on disturbed sites that exhibit a semblance of native genotypes and characteristics.

The structure of plants, particularly their root system, physically binds soil together and effectively stabilizes slopes. A good vegetative cover can greatly offset the effects of climate, soil, and topography on erosion. Vegetation achieves this effect by intercepting rainfall and decreasing the velocity of runoff and the cutting power of water. Vegetation also increases soil aggregation and porosity. Transpiration through the leaves dries out the soil, enabling it to absorb more water.

Grasses are particularly well adapted to erosion control. A 10,000 square foot patch of dense sod can contain up to 8 million individual grass plants with an estimated 3 billion miles of root system. The shielding effect of the plant canopy and leaves is augmented by roots and rhizomes that hold the soil in place, improve the soil's physical condition, and increase the rate of infiltration, further decreasing runoff (Yost, 1996).

2.3.1 Revegetation Protocols

Mixtures of native plant species are used rather than relying on single specie plantings. Native plants have their own strengths and weaknesses and when planted together compliment each other well. By planting a mixture, a diversity of seed sources is introduced allowing Mother Nature to decide which plants eventually dominate available ecological niches. The native plant species selected for the revegetation protocols presented in this section are based on the following criteria.

- Species are established easily and resist weedy competition.
- Species have tolerances for acid soil, soil structural damage, low fertility, drought/dry conditions, wet conditions, and/or temperature extremes as applicable.
- Species offer an opportunity to exploit the beautification potential of native wildflowers.
- Plantings include species that provide long-term, low maintenance vegetative cover. Grasses, by their spreading rhizomes, stolons, and/or tillers are the workhorses that fill in the gaps, bind the soil, and prevent weedy invaders.

Revegetation mixes of niche specific native and nonnative plant species have been divided into six protocols:

1. Droughty Soil Revegetation Protocol (SS-3A)
2. Dry Soil Revegetation Protocol (SS-3B)
3. Wet Soil Revegetation Protocol (SS-3C)
4. Temporary Seeding Revegetation Protocol (SS-3D)
5. Grass Sodding Revegetation Protocol (SS-3E)
6. Riparian Revegetation Protocol (SS-3F)

Revegetation protocols species composition is primarily based on the tolerance of the plants to prevalent soil moisture conditions.

2.3.1.1 Droughty Soil Revegetation Protocol (SS-3A)

Droughty sites are characterized as excessively dry, eroded, relatively sterile upland soils that have been stripped to topsoils and barren of vegetation for extended periods of time (Figure 2-7). The native plants adapted to extremely harsh soil conditions selected for this revegetation protocol include:

- Bitter panicgrass (*Panicum amarum*)
- Needleleaf witchgrass (*Dichanthelium aciculare*)
- Black-eyed Susan (*Rudbeckia hirta*)
- Common trumpetcreeper (*Campsis radicans*)
- American beautyberry (*Callicarpa americana*)

These grass, forb, shrub, and vine species are described in Table 2-3.

Figure 2-7. Severely Eroded Droughty Roadside Area Void of Topsoil
(Photo by Mike Rainer)

The root systems and organic matter produced by these pioneer species initiate the rebuilding of the soil environment. Once the quality and capacity of the soil environment to support an increased diversity of soil flora and fauna and other plants occurs, additional plants associated with the dry soil revegetation protocol can be introduced to the site. The adaptation of needleleaf witchgrass to extreme soil conditions is exemplified in Figure 2-8. The root system of the plant has bound a six-inch pedestal of soil despite repeated washing by stormwater runoff. The soil water conditions experienced by the plant are characterized as excessively droughty. Other types of vegetation that occupied the site have long since died off because of lack of adaptation to the changing soil conditions.

Figure 2-8. Needleleaf Witchgrass Erosion Pedestal (Photo by Mike Rainer)

Table 2-3. Droughty Soil Revegetation Protocol (Grasses and Forb)

Common Name	Description
Grasses and Forb	
Bitter Panicgrass	Bitter panicgrass is a native robust, long-lived, perennial, warm season bunchgrass growing to a height of up to 7 feet (Figure 2-9). It spreads slowly from short rhizomes to form open clumps. It is well adapted to very dry and sterile soil conditions and extended periods of drought. It is salt tolerant and somewhat winter hardy. Best growth is achieved on sandy, well-drained soils. It has low water requirements and grows in full and partial sunlight. It produces a small quantity of poor quality seeds and averages 325,000 seeds per pound of seed. Pure live seed (PLS) values and germination rates vary considerably, which is why it is frequently propagated vegetatively. Because of its adaptations to dry and sterile soil conditions and extended drought periods, bitter panicgrass has value as a soil stabilization species on derelict soils. It traps sand but resists being covered. Aerial stems that are covered will take root and strengthen the old plant and give rise to new ones. It is principally used for coastal dune erosion control but has also been used to revegetate roadsides and minespoils sites with shallow, infertile soils, poor moisture retention, and hostile exposure. It is a persistent survivor of hostile sites. Generally minimal to no site preparation is required when planting bitter panicgrass. Plants are established using freshly dug bareroot shoots and rooted and unrooted stem cuttings. Cuttings are planted in the late fall, potted plants are planted in late winter or early spring, and young tiller are planted in late spring (beginning of the rainy season). Potted and bare root plants are planted 8 to 10 inches deep in staggered rows 2 to 3 feet apart with plantings 2 feet apart in the rows. Unrooted stems are placed end to end in trenches 4 to 6 inches deep and 2 to 3 feet apart with 6 to 10 inches of the stem exposed. Unrooted cuttings are planted 3 to a hole staggered in rows 2 to 3 feet apart in holes 2 feet apart in each row. Place plants 8 to 10 inches or deeper in moist soil. Irrigation is beneficial until plantings are established. It shows little response to fertilizer, and once established, the stand will perpetuate itself indefinitely. It will tend to decline as site conditions improve and other species become more competitive. Once the site is stabilized, other dry soil mix native species can be planted. Adapted cultivars include Northpa and Southpa.
Needleleaf Witchgrass	Needleleaf witchgrass is a native, perennial, warm season low growing bunchgrass (Figure 2-9). It is densely tufted, has thickened rootstocks, and winter rosettes of leaves. It is well adapted to very dry and sterile soil conditions and extended periods of drought. It is adapted to a variety of sites but grows best on sandy, well-drained soils. Needleleaf witchgrass is an effective soil stabilizer and useful for restoring derelict sites. It flowers between May and October, reproduces by seed, and averages approximately 210,000 seeds per pound. Plants are established in the same manner as bitter panicgrass. It will typically decline in importance as other better-adapted species increase in cover.
Black-eyed Susan	Black-eyed Susan is a native, annual/biennial/or short-lived perennial, pioneer forb species (Figure 2-9). It is a mycorrhizal species that is adapted to a variety of soils ranging in texture from clayey loam to sand. Best growth is achieved on sandy, well-drained soils. It performs acceptably on droughty soil during years with average or above average rainfall. It has low to moderate water requirements and grows in full and partial sunlight. It reproduces by seed and vegetatively by sprouting from the root crown. Black-eyed Susan is an important component in disturbed area plantings for erosion control. It is used as a cover crop to protect grass seedlings of prairie restoration projects. It has been used to revegetate roadside sites with shallow, infertile soils, poor moisture retention, and hostile exposure. It responds well to propagation and is a persistent survivor of hostile sites. The forb is typically incorporated with native grassland plantings. It's PLS values and germination rates vary considerably. Seeds are very small (average 1,746,000 seeds per pound) and may be drilled or broadcast. Generally, one-half pound of seed per acre is sufficient in mixes with other grassland species. Where the intent is to maximize the impact of the forb component, utilize bunchgrasses rather than aggressively spreading grasses. Once established, new seedlings will be produced from the proceeding crop; the stand will perpetuate itself indefinitely. It shows little response to fertilizer treatments. It will decline as site conditions improve and other species become more dominant. Once the site is stabilized, other dry soil mix natives species can be planted. Adapted cultivar is Golden Jubilee.
Vine	
Common Trumpetcreeper	Trumpetcreeper is an herbaceous, rapid growing, long-lived groundcover or climbing vine (Figure 2-9). It can climb to heights of up to 35 feet or more to remain in sunlight. The vine can grow up to 10 feet in one year under favorable conditions. Good seed crops are produced annually. Stems occasionally die back to the ground during severe winters. Disease susceptibility is rare but could include powdery mildew, blight, or leaf spots. It is intermediately tolerant of shade and frequently occurs in disturbed open areas. The species is tolerant of low fertility, drought, and soil compaction. It can be found in a diversity of habitat types including moist to droughty soil conditions in open woodlands, fencerows, roadside thickets, floodplain forests, hillsides, and streambanks. It grows best on low fertility, acidic sandy soil sites but can also be found on sandy loams, fine silt loams, silty clay loams, and stiff clays. The plant is intermediately tolerant of flooding. The vine is generally classified as a facultative upland species. It is propagated by bareroot and container stock, cuttings, and seeds. The optimal soil pH ranges from 4.9 to 6.8. The minimum planting density is 1,200 plants per acre and the maximum planting density is 1,700 plants per acre. Seed capsules should be gathered by hand flailing when they turn grayish brown in the fall before splitting open. There are approximately 136,000 seeds per pound. If seeds are dried to about 10 percent moisture, they should store as well as other types of seeds. Pretreatment is not necessary for germination. However, cold, moist stratification for 60 days at 5 to 10 °C is required to ensure quick uniform germination. Seedlings should be grown from untreated seeds sown in the fall or stratified seeds sown in the spring. Softwood cuttings taken in June to September are easily rooted without rooting hormone treatment. Adapted cultivars include Flava, Paecox, and Speciosa.
Shrub	
American Beautyberry	American beautyberry is a large, deciduous, drought tolerant, low fertility-requiring shrub that can reach heights of 3 to 10 feet (Figure 2-9). The shrub is a prolific seed producer that primarily reproduces from seed but also regenerates by sprouting. The seeds have a hard seed coat and germinate slowly. The species does not compete with trees being grown for restoration or timber production. It is intermediately tolerant of shade and is a common pine understory species that does best in the open or beneath high, fairly thin pine canopies. It also grows well along roads and forest edges. It is an early invader of openings created by disturbance and grows best on clay or loamy soils but also grows on sandy sites. It is easily propagated. Seeds collected in the fall can be sown in the field or nursery the next spring. Nursery stock can be planted the following winter. The plants may also be rooted from stem cuttings in September. Nursery propagated September cuttings can be field planted in late winter. There are approximately 85,000 seeds per pound. Cold stratification is not required before planting. Minimum pH for planting is 4.8 and maximum pH is 7.0. Minimum planting density is 1,200 plants per acre and maximum planting density is 2,700 plants per acre. Fruits are easily collected by hand in the fall when their rose to purple color indicated maturity. The soft fruit disintegrates quickly when macerated with water; filled seeds sink and the pulp floats off. Proper seed cleaning should result in a purity of almost 100 percent. Seeds can be stored in soil for up to one year. Long term storage at or below freezing should be successful with seeds dried to below 10 percent moisture.

Black-eyed Susan (USDA photograph)

Bitter panicgrass

Needleleaf witchgrass (USDA photograph)

Common trumpetcreeper

American beautyberry

Figure 2-9. Droughty Soil Revegetation Protocol Species

2.3.1.2 Dry Soil Revegetation Protocol (SS-3B)

Dry sites are characterized as relatively dry upland soils that have not experienced extensive erosion or wholesale removal of topsoil; physical soil damage is generally less extensive than for droughty sites. Native plants selected for this revegetation protocol include:

- Big bluestem (*Andropogon gerardii*)
- Black-eyed Susan
- Indiangrass (*Sorghastrum nutans*)
- Little bluestem (*Schizachyrium scoparium*)
- Showy partridge pea (*Chamaecrista fasciculate*)

- Switchgrass (*Panicum vigatum*)
- Virginia wildrye (*Elymus virginicus*)
- Common trumpetcreeper
- Virginia creeper (*Pathenocissus quinquefolia*)
- American beautyberry
- Blackberry (*Rubus* spp.)

Dry soil revegetation protocol grass, forb, vine, and shrub species are described in Tables 2-4 to 2-6.

Table 2-4. Dry Soil Revegetation Protocol

Common Name	Description
	Grasses and Forbs
Big Bluestem	Big bluestem is a native, sod-forming, perennial, warm season grass that frequently reaches a height of 6 feet (Figure 2-10). The plant spreads by short rhizomes and becomes densely tufted as in true bunchgrasses. Mature plants produce an extensive root system with laterals extending 2 to 6 inches and main roots penetrating up to 10 feet. It is best adapted to deep, fertile silt and clay loam soils of lowlands, developing best on low, mesic, mixed-grass prairie sites; however, it has been known to grow abundantly during wet periods on shallow, gravelly ridges and limestone ledges. It is shade tolerant. In mixed-grass communities where precipitation is limited, it normally occupies riparian areas, ravines, and the lower portions of gentle slopes that have high soil moisture resulting from surface runoff. It often comprises up to 90% of the plant community in these areas, forming a well-developed sod. Generally, it is a minor component of upland sites primarily due to its lower tolerance for low soil moisture content. On drier sites, it grows in isolated clumps as a bunchgrass. Although capable of both vegetative and sexual regeneration, vegetative reproduction from short, scaly rhizomes is most prevalent. Once a clone is produced from a parent tiller, it is reported that it may live and reproduce for centuries. Seeds germinate in the spring when the soil temperature is at least 55 °F. Big bluestem produces a chaffy seed that may make seed drilling difficult. Seed planting depth is 0.25 to 0.5 inches, target planting soil pH is 5.5, and planting date is in the spring when soil temperature is at least 55 °F. Adapted cultivars include Kaw and Roundtree.
Black-eyed Susan	See description in Table 2-3.
Indiangrass	Indiangrass is a native, perennial, warm-season, bunchgrass that grows from 3 to 6 feet high (Figure 2-10). It produces abundant, short rhizomes, which may extend to depths of 6 feet. It grows in grassland and woodland prairies, bottomlands, open woods, and meadows. It is moderately tolerant of salt and acid. It has been found on soils with a pH as low as 4.5. It tolerates brief or periodic flooding, water tables in the second foot of soil, imperfect drainage, and drought. Soils that support Indiangrass include sandy- and medium-textured soils, limestone breaks, and silty clay loams. The vigorous seedlings endure a wider range of drought conditions than most lowland grasses. It reproduces vegetatively from rhizomes. It may decrease during drought, but recovers immediately when precipitation returns to normal. It may be incorporated with cool-season grasses since maximum production occurs while cool-season grasses are dormant. Direct seeding with a grass drill is the most effective planting method. Hydroseeding and broadcast seeding have produced mixed results. Cold stratification is a requirement for germination. Seeds germinate readily unless they are buried deeper than 0.5 inches. Cutting at monthly intervals during the summer causes little or no decrease in plant densities. Seed planting depth is 0.25 to 0.5 inches, target planting soil pH is 5.5, and planting date is in the spring when soil temperature is at least 55 °F. Early-spring planting should be used in areas where summer moisture stress may be a problem. Adapted cultivars include Cheyenne, Llano, Lometa, Osage, and Rumsey.
Little Bluestem	Little bluestem is a native, perennial, warm season bunch or sod-forming grass (Figure 2-10). The bulk of the plant's fine root system extends vertically to depths of 4 to 6 feet. It is abundant in grasslands and woodland understories on dry upland sites such as ridges, hillsides, midslopes, shallow ravines, and level uplands. It is most often found on dry sites where it forms distinct clumps 5 to 10 inches apart. Seedlings are more drought resistant that the seedlings of big bluestem, switchgrass, and Indiangrass. It is adapted to a wide range of soils including sand and clay-loam. It regenerates by seeds, tiller expansion, or growth from short rhizomes. Seeding rates are generally best on upland sites except during droughts when inflorescence may not develop. Field seed germination is usually low. Seeds may remain viable for decades. Optimum germination occurs at temperatures from 68 to 86 °F. After prechilling, seeds frequently germinate within 28 days. Direct seeding with a grass drill is the most effective planting method. It produces a chaffy seed that may make seed drilling difficult. Seed planting depth is 0.25 to 0.5 inches, target planting soil pH is 5.5, and planting date is in the spring when soil temperature is at least 68 °F. Adapted cultivars include Aldous, Cimarron, and Pastura.
Showy Partridge Pea	Showy partridge pea is a native, annual, nitrogen-fixing legume that generally ranges in height from 1 to 3 feet (Figure 2-10). It is common on disturbed sites and often forms extensive colonies along firelines, roadside ditches, and old fields. It also grows on prairies, bluffs, riverbanks, and river bottoms and upland sandy flatwoods. It is most common on sandy to sandy loam soils, grows best in full sunlight, and has low water requirements. It has a low pH limit of 5.0. Seed germination is improved by scarification and stratification. It usually reseeds. It is considered an excellent species for planting on disturbed areas for erosion control and improving soil fertility. It establishes rapidly, fixes nitrogen, reseeds, and slowly decreases over a period of a few years as other species dominate the site. Nitrogen fixation is normally greatest during the flowering stage. If seed is broadcast, seeding rate should be increased and seed lightly covered. Seed planting depth is 0.25 to 0.75 inches and planting date is March through May. Adapted cultivars include Comanchee and Lark.
Switchgrass	Switchgrass is native, perennial, warm season, bunch (upland habitats) and sod-forming (lowland habitats) grass that grows to a height of between 3 and 5 feet (Figure 2-10). Its roots may reach depths of 10 feet or more. It is a mesic species that grows on a wide variety of soils provided soil moisture is adequate. It is tolerant of spring flooding but not of high water tables. The capacity of its deep root system to access soil water allows it to grow well on sandy sites. It tolerates moderate salinity and acidity and grows in soils ranging in pH from 4.5 to 7.6. It reproduces sexually by seeds and vegetatively by rhizomes. It is a prolific seed producer. Seeds shed in fall or winter and require winter dormancy before they germinate in the spring. Germination rates are normally high (40% to 70%) and begin when soil temperatures reach 68 °F. It is used in a wide variety of erosion control purposes seeded alone or mixed with other species. It can take 2 to 3 years to develop good ground cover. It is frequently planted along waterways to control erosion. Its deep root system is particularly effective in binding soils against erosion. Of the warm season grasses, switchgrass is most susceptible to damage from clipping. It should be used sparingly in mixed plantings; otherwise it tends to dominate the site. Seed planting depth is 0.25 to 0.75 inches, target planting soil pH is 5.5, and planting date is in the spring when soil temperature is at least 68 °F. Adapted cultivars include Alamo, Blackwell, Cave-In-Rock, and Kanlow.
Virginia Wildrye	Virginia wildrye is a native, robust, perennial, cool season bunchgrass that attains a height of 2 to 5 feet (Figure 2-10). The noncoarse root system is fibrous forming a wide-spreading branched root system. The relatively shallow root system (generally less than 2.5 feet) may spread over 2 feet in each direction. It tolerates dry and moist sites and shade and full sun. It is normally found on disturbed open ground associated with streambanks, lakeshores, and ditches. It is intolerant of drought conditions. It is tolerant of a wide variety of soils including gravelly, sand, or clay soils and low soil fertility particularly phosphorous deficiencies. It may reproduce by seed or vegetative production, with persistence generally being maintained by seed production. Seeds normally mature in late summer or early fall. Seeds germinate best in soil with high water content. Cold stratification (storing seed at 40 °F for two months) generally increases seed germination compared to unstratified seed. Its seedlings are vigorous and usually establish quickly. Seed planting depth is 0.25 to 0.75 inches, target planting soil pH is 5.5, and planting date is in the spring when soil temperature is at least 68 °F. Adapted cultivar is Omaha.

Big bluestem

Little bluestem

Indiangrass

Showy partridge pea

Virginia wildrye

Switchgrass

Figure 2-10. Dry Soil Revegetation Protocol Grass and Forb Species

Table 2-5. Dry Soil Revegetation Protocol (Vines)

Common Name	Description
Vines	
Common Trumpetcreeper	See description in Table 2-3.
Virginia Creeper	Virginia creeper is an herbaceous, fast growing, long-lived ground cover or climbing vine. It can climb to heights of up to 60 feet or more (Figure 2-11). The vine climbs to remain in sunlight. It can grow from 6 to 10 feet in one season when well established. The vine's climbing mechanism is aerial rootlets. It has a fibrous, shallow lateral spreading root system. Natural germination is epigeal (close to the ground) and occurs during the first or second spring following dispersal. The plant also sprouts from horizontal aboveground stems. It is very tolerant of shade and occurs in dry to moist conditions. The species is tolerant of low fertility, drought, and soil compaction. Common habitats include woodland edges, open woods, alluvial woods, ravines, and fencerows. It grows best on low fertility, moist sandy soil sites but can also be found on a wide variety of soil types including sandy loams to fine silty loams, silty clay loams, and stiff clays. The plant is very tolerant of flooding. The vine is generally classified as a facultative upland species. It is occasionally susceptible to diseases such as stem canker, downy or powdery mildew, leaf spot, anthracnose, thread blight, and root rot. Seeds can be sown in fall or spring after stratification. Germination is improved by stratification in moist sand or compost at 41° F for about 60 days. The seeds should be covered with 3/8 inch of soil or mulch after planting. The optimal soil pH ranges from 5 to 7.5. Optimal planting density is 10 plants per square foot. It can also be propagated by hardwood cuttings. Adapted cultivars include Englemannii, Saint-Paulii, and Hirsuta.

Figure 2-11. Virginia Creeper

Table 2-6. Dry Soil Revegetation Protocol (Shrubs)

Common Name	Description
Shrubs	
American Beautyberry	See description in Table 2-3.
Blackberry	The blackberry is a deciduous, fast growing, upright, woody shrub that can attain a height of up to 8 feet within 20 years (Figure 2-12). It tends to form dense thickets from root suckers in dry and wet areas. The tips of the canes take root when they touch the ground. The plant is classified as a facultative upland species. It follows herbaceous weeds in invading disturbed sites. It is tolerant of most soil types and low soil fertility. It does best in sandy well-drained soil. The plant favors soil disturbance, fire, and overstory removal conditions, growing best in full sunlight. It is intolerant of shade. Over time, overtopping trees and other persistent shrubs shade blackberry thickets out. Blackberries can be propagated by bareroot and container stock, seeds, cuttings, and sprigs. The minimum pH for planting is 4.5 and the maximum is 7. The minimum planting density is 1,746 plants per acre and the maximum planting density is 3,450 plants per acre. Cold stratification of seeds is required before planting.
Southern Bayberry	Southern bayberry is an evergreen, rhizomatous shrub or small tree that grows to a maximum height of 40 feet at maturity (Figure 2-12). It is clonal, with several stems growing from a common root collar. Underground runners extend growth laterally. It is an early successional species that inhabits thickets, swamps, sandy uplands, and low, acidic prairies. It grows well on dry or wet heavy clay soils and sandy soils in open or wooded areas and is relatively intolerant of shade. The shrub is a heavy user of soil water. It is adapted to low fertility conditions. An important characteristic of this nonlegumous species is its ability to fix atmospheric nitrogen at rates that exceed most legumes. Nitrogen is fixed by a symbiotic actinomycete associated with the root nodules (Permar, 1983; Lane, 1988). The soil is enriched with plant available nitrogen as southern bayberry roots die and plant materials decompose. Plants are best propagated by planting stratified seed in moist, acid sand. There are approximately 84,000 seeds per pound. The optimal soil pH ranges from 5.5 to 7. Seeds can be harvested by hand or shaken onto a canvas. The waxy coating must be removed before the seeds can germinate. The waxy seed coating is removed by mechanical agitation or rubbing over a dry screen before planting. Before sowing, the seeds must be stratified at 34 to 40 degrees for 90 days. The seeds can be planted in rows 8 to 12 inches apart and covered with 0.25 inch of firmed soil. The minimum planting density is 700 plants per acre and the maximum planting density is 1,700 plants per acre. Fall planting should be mulched.

Blackberry

Southern bayberry

Figure 2-12. Dry Soil Revegetation Protocol Vine and Shrub Species

2.3.1.3 Wet Soil Revegetation Protocol (SS-3C)

In contrast to droughty and dry soils, the wet soil revegetation protocol is used on areas that experience periodic or long-term wet mesic conditions as a result of groundwater seepage, runoff ponding, or occasional flooding. Soils classified as mesic remain moist for a significant but sometimes-short portion of the growing season. Adapted native plant species selected for this protocol include:

- Big bluestem
- Eastern gamagrass (*Tripsacum dactyloides*)
- Indiangrass
- Showy partridge pea
- Switchgrass
- Virginia wildrye
- Common trumpetcreeper
- Virginia creeper
- Southern bayberry
- Sweetbay (*Magnolia virginiana*)
- Titi (*Cyrella racemifloria*)

These grass, forb, vine, shrub, and tree species are described in Table 2-7.

Table 2-7. Wet Soil Revegetation Protocol

Common Name	Description
Grasses and Forbs	
Big Bluestem	See description in Table 2-3.
Eastern Gamagrass	Eastern gamagrass is an erect native, perennial, warm season, bunch grass that grows up to 7 feet in height (Figure 2-13). Minimum root depth is approximately 20 inches. Shoots are interconnected through several tiller generations by a 0.5 to 1 inch thick woody stembase (proaxis) chain network that remains intact for several years acting as a considerable deterrent to erosion. The crown has the ability to elevate coarse aerial foliage above sediment coverage and to anchor the plant in place with stout brace roots. It is best adapted to moderately well drained to somewhat poorly drained soils. It tolerates extended periods of flooding. It is relatively intolerant of shade and has medium drought tolerance. It produces seeds from June through September. Seeds consist of grain enclosed in a hard woody fruitcase that protects the grain and inhibits germination of the grain until cold stratification. Under some situations, it exhibits low seed production and seed dormancy, which may inhibit stand establishment. The dense network of shoots, reproductive tillers, and stout brace roots make eastern gamagrass a good candidate for erosion control and grass hedges. Eastern gamagrass can be established vegetatively and with seed. Plants can be established vegetatively by transplanting crown material during the dormant season before spring growth. Propagules are obtained by splitting off portions of the crown with a shovel and replanting the material. Transplant plugs should have at least three or four viable shoots. Plugs should be placed in a row about 6 inches apart to promote dense grass hedge growth. Good quality eastern gamagrass seed should have at least 95 percent purity, a PLS of 80 percent or better, and 6,000 or fewer seeds per pound. In most cases seed is purchased from dealers already stratified. Eastern gamagrass seeds must be stratified for eight weeks before spring planting. To stratify artificially, fill burlap bags half full with seeds and soak in a 1 percent solution of fungicide for 10 to 12 hours. Then drain and seal the seeds along with the burlap bag in a plastic bag. The seeds are then stored at 35 to 45 °F. Seeds can also be stratified by fall planting after the first of November. For spring planting, seeds should not be planted until soil temperatures stabilize in the range of 65 to 85 °F to a soil depth of 1 inch. A standard corn planter is commonly used for planting; however, the seed can also be broadcast into a clean seedbed and lightly rolled into place. Stratified seed is planted to a depth of 1 to 1.5 inches. Planting dates typically range from March to May in the south. *Do not broadcast seeds.* Adapted cultivars include Jackson, Luka, and Pete.
Indiangrass	See description in Table 2-4.
Showy Partridge Pea	See description in Table 2-4.
Switchgrass	See description in Table 2-4.
Virginia Wildrye	See description in Table 2-4.
Vines	
Common Trumpetcreeper	See description in Table 2-3.
Virginia Creeper	See description in Table 2-5.
Shrub	
Southern Bayberry	See description in Table 2-6.
Trees	
Sweetbay	Sweetbay is a medium growth rate small- to medium-sized evergreen tree that can attain heights greater than 40 feet (Figure 2-14). It produces a deep, fibrous coarse lateral root system. It inhabits sites that are very to moderately poorly drained most of the year. Typical habitats include boggy wooded stream courses, swamps, wet flatwoods, alluvial forests, pocosins, springs, bogs, and seepage slopes. It can endure prolonged flooding, but winter droughts can cause extensive dieback. It occurs on loams to fine sands, fine sandy loams, heavy clays, organic soils, peats, and mucks that have a pH ranging from about 5.0 to 6.5. It is an intermediate shade tolerant species that invades pine and hardwood stands and tends to migrate onto mesic sites where it establishes itself as a climax species in mixed hardwoods. A light frost can cause seedling mortality. It reproduces primarily by seed. Seedlings are difficult to transplant. Seeds exhibit embryo dormancy that can be broken by three to six months of cold stratification at 32 to 41 °F. Normally seed germination rates range from 32 to 50 percent. There are approximately 7,500 cleaned seeds per pound. Cultivars include Havener, Mayer, and Australis.
Titi	Titi is a thicket-forming, semi-evergreen small tree that can grow to a height of 30 feet. It has a dense fibrous, shallow to deep lateral root system (Figure 2-14). Titi is an early invader to disturbed sites that is tolerant of soil compaction and drought. It eventually crowds out shade tolerant species and becomes part of the dominant overstory. Habitats include high sandy ridges above streams, acid bogs, rich shaded alluvial flats, streambanks, bay, dunes, pocosins, cypress swamps, and limestone sinks. It is known to grow in swamps inundated for three-quarters of the year. Occupied soils include coarse maritime sand and gravel, sandy loams to fine sands, peats, heavy clay, and mucks with a soil pH ranging from 5.1 to 8.5. Soil drainage is normally very poor to moderately poor although it can tolerate short-term dry conditions. The primary mode of reproduction is sprouting from adventitious root buds following disturbance. Seeds are produced but most do not germinate. The plants tend to transplant well. It grows well in full sunlight and under a closed canopy.

Eastern gamagrass, Virginia wildrye, and switchgrass can withstand periodic flooding throughout the growing season but will not grow in standing water. Big bluestem can withstand periodic flooding but does not like to be wet for extended periods. Little bluestem and switchgrass are adapted to dry upland sites, and bitter panicgrass is best adapted to droughty sterile sites. The relative adaptations of planting mix species to soil moisture gradients are presented in Figure 2-15.

Figure 2-13. Eastern Gamagrass
(Photo by Mike Haddock)

Titi

Sweetbay

Figure 2-14. Wet Soil Revegetation Protocol Tree Species

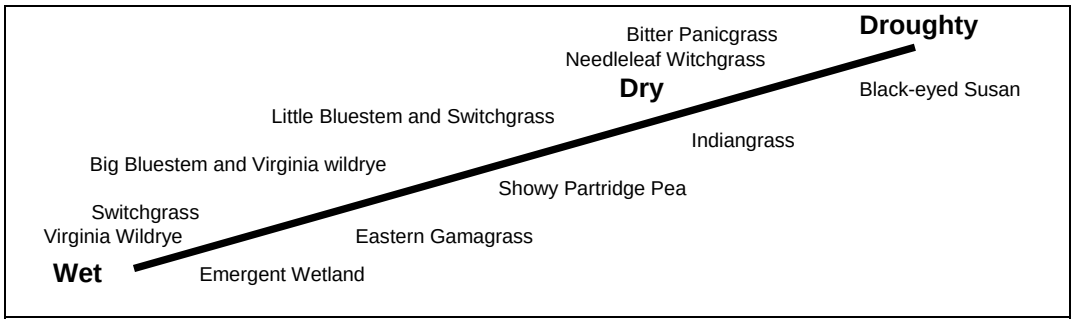


Figure 2-15. Relative Adaptation of Grasses to Moisture Gradients

Native plants that temporarily blanket the surface include bitter panicgrass, showy partridge pea, black-eyed Susan, American beautyberry, and trumpetcreeper. After a couple of growing seasons, these species give way to more permanent species such as big bluestem, little bluestem, Indiangrass, switchgrass, and Virginia wildrye that are more competitive over time. Native nitrogen fixing plants such as showy partridge pea and southern bayberry also become an important component of seed mixes because of their ability to fix atmospheric nitrogen and make it available to the soil. The recommended long-lived, low maintenance native species included as primary components of native plant seed mixes include big bluestem, little bluestem, Indiangrass, and switchgrass. Flowering species such as black-eyed Susan and showy partridge pea also offer aesthetic value.

2.3.1.4 Temporary Seeding Revegetation Protocol (SS-3D)

Temporary seeding is the establishment of temporary vegetative cover on disturbed areas in lieu of establishing permanent vegetative cover. This type of planting is normally used under circumstances where protective ground cover is needed yet the spring to mid-summer window for planting and establishing permanent plant species has passed. Temporary plantings consist of seeding fast growing plants. Cool-season annual small grains such as oats (*Avena sativa*) and rye (*Secale cereale*) and/or clovers such as ball clover (*Trifolium nigrescens*) and crimson clover (*Trifolium incarnatum*) provide ground cover during fall and winter. Brown top millet (*Panicum ramosum*) and/or alyceclover (*Alysicarpus vaginalis*) can be planted as temporary summer cover. The annual cover is replaced by a planting of perennial species once weather conditions accommodate. This emphasizes the need for scheduling site construction activities within the planting season for permanent grasses and forbs to the degree possible. Guidelines for establishing temporary vegetative cover are presented below.

- Plant oats and/or rye into a prepared seedbed less than 1 inch deep between September and November (September 20 to October 5 is ideal) at a rate of 130 pounds per acre. The seeding rates are based on a minimum acceptable pure live seed (PLS) of 80 percent. When PLS is below 80 percent, adjust rates accordingly. Although drilling normally provides the best result, seeds can also be broadcast or hydroseeded. Based on soil test kit analysis, adjust soil pH to a target of 5.5 if required. In lieu of laboratory analysis, apply 200 pounds of 40-40-40 fertilizer per acre. Mulch the planted site with compost or straw to encourage grasses establishment and protect the site during germination.
- Plant ball and/or crimson clover to a well prepared seedbed; a light disking is normally sufficient. Plant ball clover between September 1 and December 1 at a rate of 2 to 4 pounds per acre at a depth of .25 inches. Crimson clover is planted at a rate of 15 to 25 pounds per acre between September and October to a depth of .25 to .75 inches. The target pH for ball

clover is 5.5 and the target for crimson clover is 6.0. In lieu of laboratory analysis, apply 0-12-12 fertilizer at a rate of 200 pounds per acre.

- Plant brown top millet into a prepared seedbed in late to early summer at a rate of 20 to 30 pounds drilled or 8 to 10 pounds broadcast. In lieu of laboratory analysis, apply 20-40-40 fertilizer at a rate of 150 pounds per acre.
- Plant alyceclover into a prepared seedbed in late to early summer at a rate of 5 to 10 pounds per acre. In lieu of laboratory analysis, apply 0-20-20 fertilizer at a rate of 200 pounds per acre.
- Most importantly *do not let the annuals go to seed*; otherwise it will germinate new plants that will compete with the permanent vegetation. Be sure to cut the oats before seedheads form.
- Temporary vegetated areas will be maintained until permanent vegetation or other erosion control practices can be established. Newly seeded areas need to be inspected frequently to ensure the grass is growing. Spot seed small areas that fail to establish adequate cover. If the seeded area is damaged due to concentrated runoff, additional practices may be needed (USDA, No date).

2.3.1.5 Grass Sodding Revegetation Protocol (SS-3E)

Grass sodding is the laying of a continuous layer of grass sod to quickly and permanently stabilize soils. Sodding is a method of establishing immediate vegetative cover in critical areas where persistent conditions of concentrated runoff such as waterways or runoff discharge sites prevent establishing vegetative cover by seeding or planting vegetative materials. It is normally more costly to install sod than to establish plants by seeding or vegetative plantings. Use high quality sod of known genetic origin that is free of noxious weeds, diseases, and insect problems. Sod may be laid during times of the year when grassing seeding would normally not be successful. However irrigation is essential at all times of the year when installing sod. Generally, Pensacola bahiagrass sod is planted on dry sandy upland sites and common bermudagrass sod is planted on wet sites.

General guidelines for installing and maintaining sod are presented below.

- Establish the final level grade and clear the surface of trash, debris, roots, rocks, and clods in excess of 2 inches in diameter or length. Based on soil testing results, condition the soil (Section 2.2.1) and prepare the seedbed (Section 2.3.2.1).
- Sod should be machine cut at a uniform soil thickness of 3/4 inch plus or minus 1/4 inch at the time of cutting. This thickness shall not exclude shoot growth and thatch. Sod should be cut and laid within 48 hours. Upon delivery, store the sod in the shade prior to installation and moisten the sod immediately after it is unrolled. Rake the soil surface before sod installation.
- Lay the first row of sod in a straight line with subsequent rows placed parallel to and butting tightly against the other. Install strips of sod with their longest dimension perpendicular to the slope. On slopes 3:1 or steeper or in areas where erosion is a problem, secure the sod with pegs or staples. Stagger the sod strips during laying in a brick-like fashion. Within waterways, lay the sod strips perpendicular to the direction of flow with the lateral joints staggered. Secure the sod with netting and staples. Do not stretch or overlap the sod strips. Trim irregular shaped edges to prevent voids.
- After laying the sod use a roller to ensure that the sod roots are in contact with the soil. After rolling, irrigate the sod until the soil is wet 4 inches below the sod. Keep sodded areas moist

until the grass takes root. Check for rooting by tugging the sod gently, resistance indicates the grass has taken root.

- After the first week, irrigate as necessary to maintain moisture in the root zone (to a depth of 4 inches) and to prevent sod dormancy. Wait a few weeks before mowing to allow the grass to become firmly rooted. Do not remove more than one-third of the shoot in any mowing (USDA, No date).

2.3.1.6 Riparian Revegetation Protocol (SS-3F)

Riparian areas are the wetlands, floodplains, terraces, and/or terrestrial drainage slopes that occur along waterbodies at variable widths (Chapter III, *Stream Ecosystems*, Section 1.6.3). In some instances work performed in proximity to road crossings can result in mild to severe disturbance of adjacent riparian corridors along streams and wetlands. Disturbance may range from vegetation damage to complete vegetation removal and physical disturbance of streambank soils. In the case of the latter, it may be necessary to install practices that reestablish vegetation and stabilize slopes to prevent soil erosion and sediment delivery into water resources.

Options for repairing riparian areas include construction of hard structures, installation of bioengineering techniques, or a combination thereof. Hard structures include such techniques as concrete lined channels, gabians, cribs, and headcut structures. These expensive engineering techniques rely heavily on the strength of synthetic materials to stabilize the surface and resist the hydrologic stresses created by flowing water. If damaged, these structures require immediate and sometimes costly repair and the structure life may be somewhat limited. The results of hard structure damage, even if relatively minor with regard to the overall integrity of the structure, often results in catastrophic soil erosion and sedimentation (Figure 2-16).

Figure 2-16. Catastrophic Failure of a Concrete Lined Roadside Drain on a Riparian Slope (Photo by Chris Metcalf)

Emphasis is being placed on the use of ecologically sound bioengineering techniques to restore and maintain biological systems. Bioengineering techniques address aesthetic and ecological concerns by encouraging the reestablishment and long-term maintenance of native vegetation communities and wildlife habitat. Bioengineering techniques rely on the attributes of woody plants and native material structures to function together in mutually reinforcing and complimentary rolls. The primary benefits of woody vegetation on slope stability are root reinforcement, soil mass buttressing, and soil moisture depletion. Riparian slope revegetation bioengineering techniques discussed in this section include:

- Brushlayering (SS-3F-A)
- Live fascines (SS-3F-B)
- Coir rolls (SS-3F-C)
- Live staking (SS-3F-D)

Brushlayering (SS-3F-A)

Brushlayering is a slope stabilization technique where easily rooted tree branches are horizontally layered in successive tiers (horizontal step in a slope) into the slope surface (Figure 2-17). Branches are placed by hand in slope tiers excavated by heavy equipment. This practice is particularly useful on moderate to steep slopes including streambanks, gullies, and road slopes that have been heavily disturbed. The embedded rows of branches provide resistance to slope fill movement, and the tight network of branches reduces the overall slope length, establishes stabilizing woody vegetative cover, slows surface runoff, promotes stable soil moisture regimes, and reduces soil erosion potentials.

Figure 2-17. Streambank Slope Brushlayering (Salix Applied Earthcare)

Brushlayering planning and construction specifications (Figure 2-18) are as follows:

- Select brushlayering woody plant materials that root easily, are long and flexible, and are in plentiful supply. Potential materials include woody plants in the *Salix* (willow), *Baccharis* (false

willow), *Cornus* (dogwood), and *Populus* (cottonwood) genus. Willow (*Salix*, spp.) makes an ideal brushlayering material. Select native plant materials based on adaptability to site conditions.

- Plant material harvesting and installation should be conducted during dormant periods (late fall to early spring).
- When using willow cuttings, mix young (less than 1 year old) and older (1 to 4 years old) wood to get the best results. Use small to medium size shrub, rhizomatous, or creeping willow species for streambank applications. Larger tree type willow species perform best on upper bank and floodplain areas.

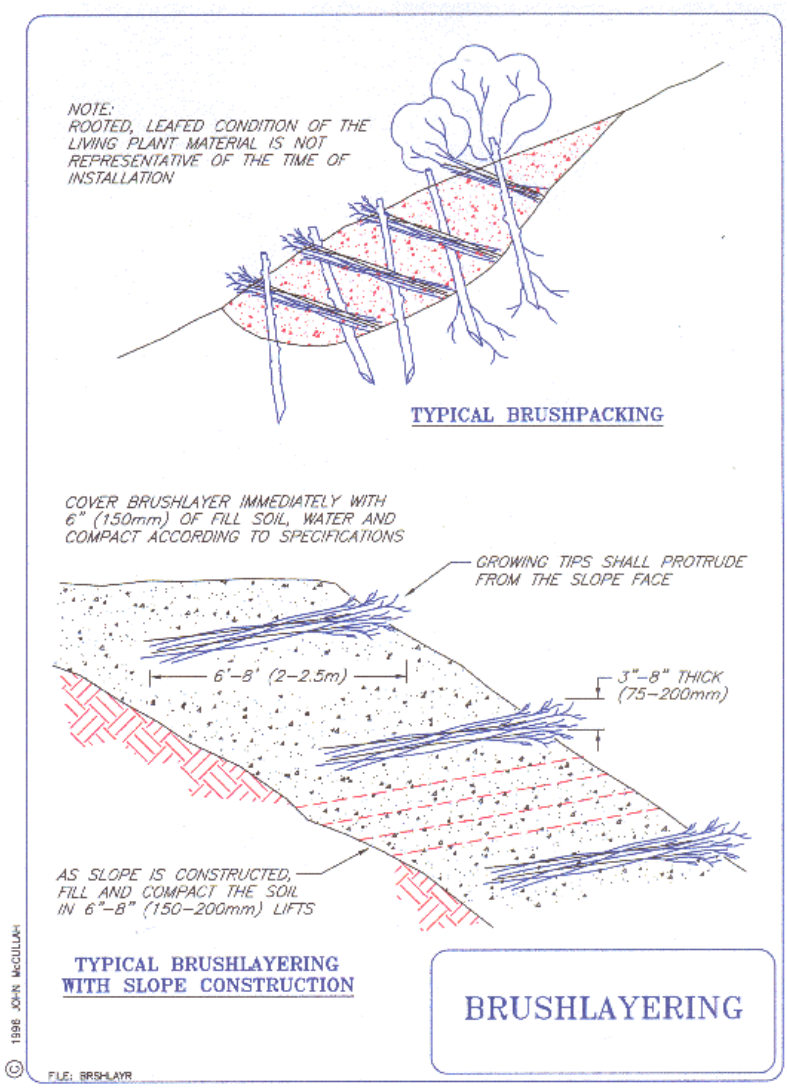


Figure 2-18. Brushlayering (Salix Applied Earthcare)

- Presoak the woodcuttings a minimum of 2 days and a maximum of 14 days prior to installation. Keep the cutting moist and cool prior to installation. Harvest no earlier than 48 hours prior to installation if the cuttings are not going to be presoaked. Transport materials in wet burlap bundles during transport and site storage.

- Generally, brushlayer tiers are spaced 3 to 8 feet apart; spacing on longer slopes is closer at the bottom and increases near the top. It is recommended that steeper (1:1) slopes not exceed 30 feet in length. As a general rule, slope height should not exceed three times the width of the stabilized volume.
- Brushlayering cuttings should be approximately 4 to 8 feet long and 3/4 to 2 inches in diameter.
- Excavate each tier in a sloped fashion so that the outside edge is higher than the inside edge, which allows the butt of the cutting to angle down into the bank slope.
- Place the cuttings 3 to 8 inches thick in an overlapping pattern with the tips extending 6 to 12 inches from the slope edge. Live stakes (Section 2.3.4.4) can be used to provide added support.
- Cover the cuttings with no less than 6 inches of soil, compact the brushlayer, and water. Do not allow heavy equipment to travel over or approach within 6 inches of the brushlayer. Construct brushlayer tiers from the bottom to the top of the slope.
- Seed soils between brushlayers with the appropriate revegetative protocol (Section 2.3.1) and mulch (Section 2.4). Hydroseed grasses and forbs on steeper slopes (Section 2.3.2.2).
- Inspect the site regularly the first year, particularly following major rainfall events. Make necessary repairs of brushlayering failures as required.

Coir Rolls (SS-3F-B)

Coir rolls are manufactured cylinders of durable, high tensile strength coconut fibers used to stabilize streambanks and shorelines. Rolls are most frequently placed along the toe of disturbed or unstable streambanks and shorelines (Figure 2-19). These soft armor structures also accumulate sediment and provide relative stability for the establishment and development of plantings. Once the fiber roll biodegrades, the plantings and their root systems provide primary soil stabilization (Figure 2-20).

Figure 2-19. Coir Roll Installation
(http://www.earthsourceinc.net/installation.html)

Figure 2-20. Deteriorating Coir Roll and Established Vegetation
(http://www.forester.net/ec_0103_biotech.html)

These fiber rolls have high moisture retention features and generally last from 4 to 12 years. They are commercially available in diameters of 12, 16, and 20 inches and may vary considerably in density, tensile strength, unit weight, and open area thickness. Coir roll planning and construction specifications (Figure 2-21) include:

- Identify and stake the location of the coir roll installation. Mark the mean water elevation with a stake 2 feet offshore. Remove debris and other obstacles prior to installation. Rolls should be placed at a height sufficient to protect the bank from stream flows or waves. The height of the structure is increased by adding rolls above the lower one.
- Use high-density (9 lbs/ft^3) coir if protection from high wave and stream energy and plant establishment is the objectives.
- Stakes for securing the rolls are 1.5 $\times$ 1.5 inches diameter wood that is pointed and not wedged. The total length of each is dependent on the diameter of the roll and type of substrate.
- Always begin the installation on the downstream end. Install the rolls level and parallel to the bank along the horizontal contour with 2 inches of the roll above the mean water elevation. Lace adjacent rolls together end to end and secure tightly.
- Typically coir rolls are secured to the substrate with a row of stakes driven through the outer edge netting or the roll on one or both sides, 1 foot on center. Rope lacing between stakes keeps the roll in place (Figure 2-22).
- Container grown plants can be planted directly into the rolls. Install plants at a density of 2, 3, and 4 plugs per linear foot for a 12, 16, and 20 inch diameter roll, respectively. Create a hole for inserting plugs into the rolls with a planting iron or metal bar. Ensure that the root system is below the water line. Install the plug firmly by covering the root ball and wrapping the roll fibers around the plant stem.
- Monitor plant growth for 3 to 4 weeks after installation. Water as required to ensure establishment. Inspect the site regularly, particularly following major rainfall events. Make necessary repairs as required.

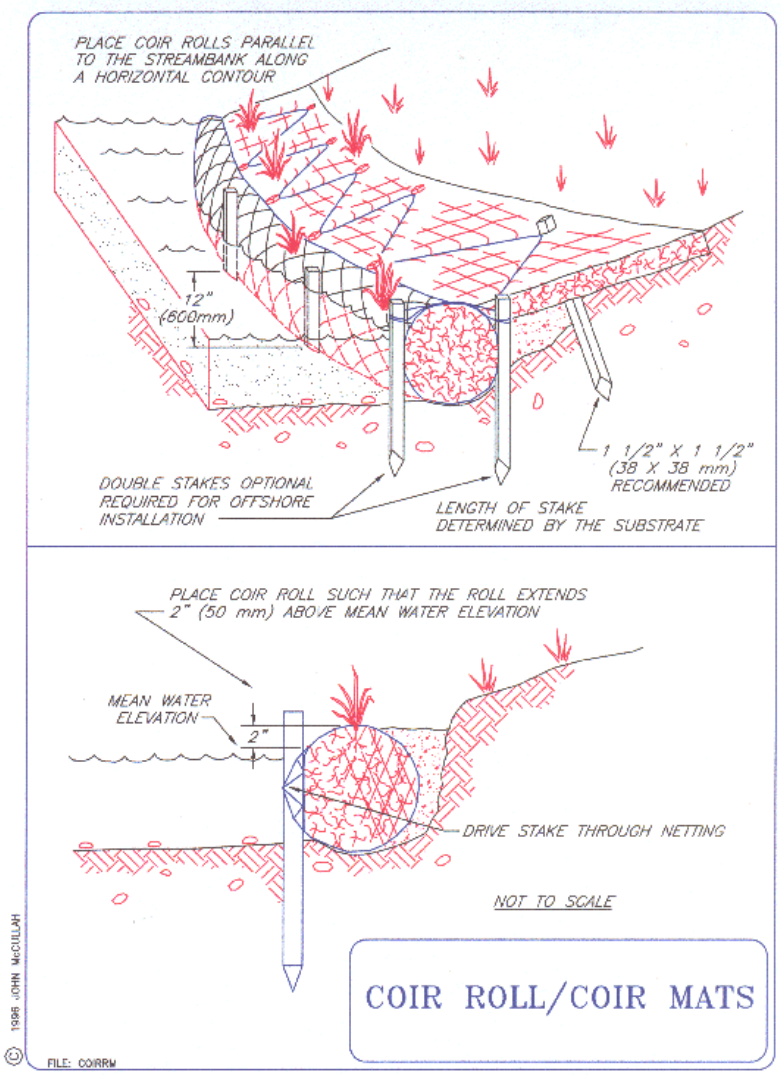


Figure 2-21. Coir Roll Installation (Salix Applied Earthcare)

Figure 2-22. Shoreline Coir Roll Installation (Salix Applied Earthcare)

Live Fascines (SS-3F-C)

Live fascine is a disturbed slope and streambank practice where bound bundles of shrub and/or tree branch cuttings (Figure 2-23) are buried across the slope face to reestablish vegetation, reduce erosion, and provide soil mass stabilization. Fascines effectively reduce the overall slope length and dissipate the erosive energy of surface runoff. These structures function as water permeable filters that slow surface water flows resulting in greater water infiltration into the soil, increased water availability for plant uptake, and sediment retention on the upslope side of the structure. Fascines may be used for road cut and fill slopes, gullies, streambanks, and other disturbed slope conditions. Fascines are constructed of species that readily sprout including willows, cottonwoods, shrub-type dogwoods, buttonbush (*Cephalanthus occidentialis*), viburnaums (*Viburnum ssp.*), hawthorn (*Crataegus ssp*.), persimmon (*Diospyros ssp*.), sycamore (*Platanus occidentalis*), and other species.

Figure 2-23. Live Fascine Bundle Ready for Installation (Salix Applied Earthcare)

Live fascine planning and construction specifications are discussed below and shown in Figure 2-24.

- Select and prepare live fascine woodcuttings as described in brushlayering (Section 2.3.4.1).
- If required, up to 50 percent of the fascine bundle may consist of dead woody material or branches that do not root easily.
- Live fascine cuttings should be 3 feet long and up to 1.5 inches in diameter. Young suckers and branch trimmings may be included in the bundles.
- Fascine cuttings are tied tightly with rope or twine in bundles 6 to 12 inches in diameter. Orient growing tips and butts in alternating directions and stagger bundle cuttings to allow even distribution of branch tips throughout the bundle. The length of the fascines may vary between 6 and 30 feet depending on site conditions and handling restrictions. Tie the bundles 12 to 15 inches apart.
- Install fascines in excavated trenches dug along the slope contour working from the bottom to the top of the slope. The trenches should be dug to a depth one-half the diameter of the bundle and width of 12 to 18 inches (Figure 2-25). Install the bundles immediately after digging the trenches. Fascine spacing is presented in Table 2-8.

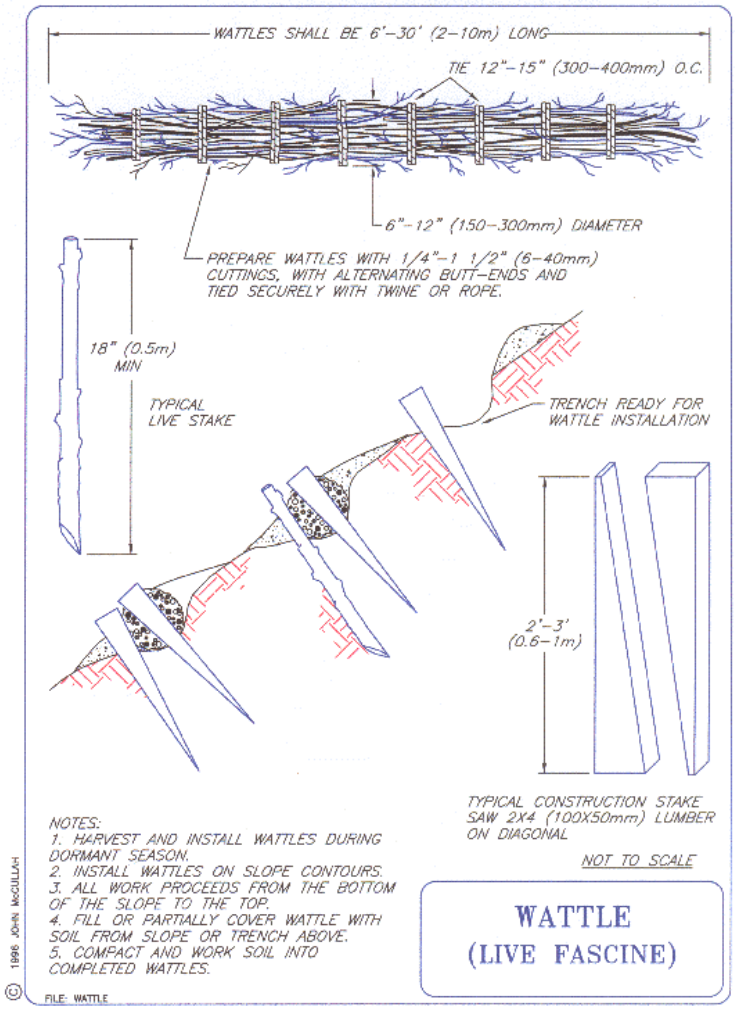


Figure 2-24. Live Fascine Construction and Installation Specifications (Salix Applied Earthcare)

Figure 2-25. Fascine Bundle Installation (Salix Applied Earthcare)

Table 2-8. Live Fascine Installation Specifications

Slope	Distance Between Fascines (feet)	Maximum Slope Length (feet)
1:1 to 1.5:1	3 to 4	15
1.5: to 2:1	4 to 5	20
2:1 to 4:1	5 to 6	40
3.5:1 to 4:1	8 to 12	50
4.5:1 to 5:1	10 to 20	60

Source: Salix Applied Earthcare

- Stake the fascines into the slope substrate with a single row of wood construction stakes on the downslope side (Figure 2-26). Stakes should be no more than 3 feet apart. Install a second row of stakes near the ties no more than 5 feet apart.

Figure 2-26. Live Fascine Staking (Salix Applied Earthcare)

- Overlap the tapered end of adjacent fascines to sustain a uniform thickness of the structure. Use two stakes at each overlap. Drive the stakes between the last ties of each bundle.
- If utilized, live stakes (Section 2.3.4.4) are placed on the downslope side of the fascine bundle.
- Backfill fascines with soil from the slope of upslope trench. Work the soil into the bundles and compact behind and below the bundles with moist soil. Following proper installation, the top of the bundles should be slightly visible.
- Seed slope soils between fascines with the appropriate revegetative protocol (Section 2.3.1) and mulch (Section 2.4). Hydroseed grasses and forbs on steeper slopes (Section 2.3.2.2).
- Inspect the site regularly the first year particularly following major rainfall events. Make necessary repairs as required.

Live Staking (SS-3F-D)

Live staking is the insertion of woody cuttings that easily root directly into slope soils (Figure 2-27). The purpose of this practice is to create a network of shrub and/or tree roots that bind and stabilize slope soils. This practice is frequently used in combination with other biotechnical practices such as brushlayering, coir rolls, live fascines, straw rolls, and erosion control mats to maximize slope revegetation and stabilization effectiveness. Willow is the most common species used for live staking.

Figure 2-27. Live Stakes Ready for Installation (Salix Applied Earthcare)

Live staking planning and construction specifications (Figure 2-28) include:

- Select live stake cuttings as described in brushlayering (Section 2.3.4.1). Stakes should be 2 to 3 inches in diameter and at least 24 inches long. If possible, stakes should be long enough to reach the summer water table.
- Generally the best wood for stakes is 2 to 5 years old with smooth bark and is not deeply furrowed; avoid current year sucker growth. Trim stake branches closely and make clean cuts; the butt should be pointed or angled and the top end cut square. Stakes are cut so that a terminal bud scar is within 1 to 4 inches of the top and 2 buds or bud scars above the ground following planting. Buds or bud scars should always point up after planting.
- Seal the top cut by dipping the top 1 to 2 inches in a 50-50 mix of latex paint and water. Sealing the cut will reduce susceptibility to desiccation and disease.
- Presoak the stakes a minimum of 2 days and a maximum of 14 days prior to installation. Keep the stakes moist and cool and do not allow them to dry out before planting. Harvest no earlier than 48 hours prior to installation if the cuttings are not going to be presoaked. Transport materials in wet burlap bundles during transport and site storage.
- Plant the stakes butt first 1 to 3 feet apart with no less than one-half the total length in the ground. Preferably 80 percent of the total length should be in the soil. In firm soil, a metal stake or bar may be required to create a pilot hole. Remove and replace stakes that are split or damaged during installation.
- Following planting, tramp around the stack to ensure good contact with the soil or if necessary pour water around the stakes to ensure good soil compaction.
- Inspect the site regularly the first year and make necessary repairs as required.

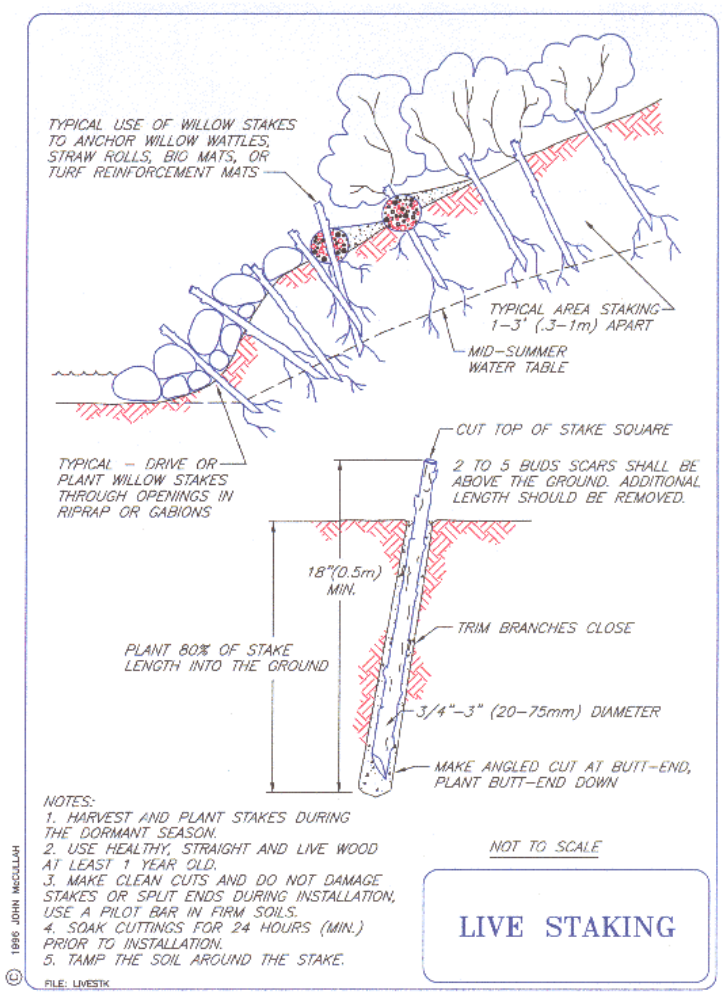


Figure 2-28. Live Staking Installation Specifications
(Salix Applied Earthcare)

2.3.2 Plant Propagation

Plant propagation is the establishment of plants primarily by seeding and planting plant materials such as cuttings, bare root, or containerized stock. Plant propagation techniques discussed in this section include:

- Seedbed Preparation (SS-3G)
- Grass and Forb Seeding (SS-3H)
- Shrub and Vine Plantings (SS-3I)
- Tree Planting (SS-3J)

2.3.2.1 Seedbed Preparation (SS-3G)

Proper seedbed preparation is a critical component of successful revegetation and one of the first steps in the revegetation process. A properly constructed seedbed will be firm enough to ensure the seed is in full contact with the soil and loose enough to allow seeds to sprout through the soil. Seedbed preparation involves physical amendment of surface and subsurface soil during ground preparation to reduce compaction, incorporating soil amendments such as lime, compost, and/or

mycorrhize, and finishing the soil surface for planting during final seedbed preparation. Steps in the process include topsoil salvage, ground preparation, and final seedbed preparation.

Topsoil Salvage

The purpose of topsoil salvage is to keep the soil alive, weed free, and protected from damage until it can be reapplied. The salvage operation also prevents the burial of topsoil into areas of the subsoil profile where its value will be lost. Topsoil salvage guidelines include the following.

- Topsoil should be salvaged when moist but not wet. During salvage operations it is important to separate the topsoil from lower soil layers; although the general guideline is 6 to 12 inches, the actual depth will vary with each site. The penetration of dark-colored organic materials can serve as a general guide for estimating salvage depth.
- The topsoil should be stockpiled as briefly and shallowly (less than 2 feet) as possible without disturbing other adjacent areas. Since the topsoil is alive, it is important assure that the soil is well aerated.
- Following grading operations, spread the topsoil to a uniform thickness over the graded slope with a minimum number of passes. However, the uniformity of application is not as important as minimizing extended machine operation over the area that could increase detrimental soil compaction (USDA, No date).

Ground Preparation

Ground preparation is the use of primary tillage implements to physically disrupt surface and subsurface layers of compacted or cemented soils. Ground preparation guidelines include:

- Employ primary tillage implements such as chisel plows, rippers or subsoilers, offset disks, and/or rotary tillers to pulverize surface soils and loosen subsurface layers (Figure 2-29).
- Minimize the use of rotary tillers in soils with high amounts of clay or silt to avoid the formation of slickened surfaces within the soil that may restrict root growth and water movement.
- Accomplish as much disturbance as possible in as few passes as practical. Make subsequent passes perpendicular to the direction of the previous pass and avoid repeated tracking in the same spot. Do not till the soil when it is wet (USDA, No date).

Final Seedbed Preparation

Once the seedbed has been pulverized and relieved of compaction, it can be prepared for planting. During final seedbed preparation, secondary tillage implements are employed to establish a firm, smooth seedbed amenable to the operation of planting equipment. Final seedbed preparation recommendations include:

- Use secondary tillage tools such as the disk harrow, spike tooth harrow, and cultipacker to bring the seedbed to a desired physical condition and ensure good soil-to-seed contact (Figure 2-29). If a substantial amount of large soil clods or clumps are present, treat the site with the disk harrow and/or spike tooth harrow. Do not till the soil when it is wet.
- Accomplish as much disturbance as possible in as few passes as practical. Make subsequent passes perpendicular to the direction of the previous pass and avoid repeated tracking in the same spot. Use the cultipacker or other techniques to firm up the seedbed and/or press broadcast seed into the soil (USDA, No date).

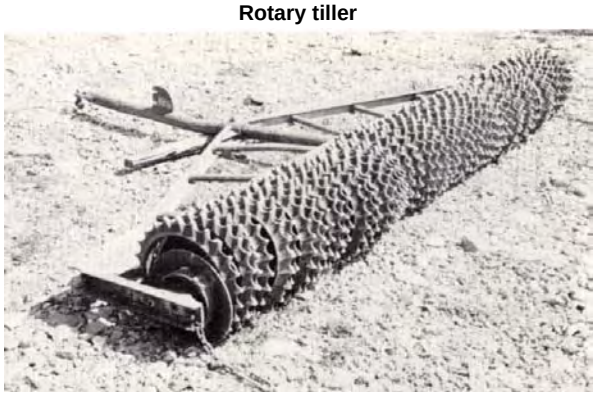
Chisel plow

Subsoiler

Ripper

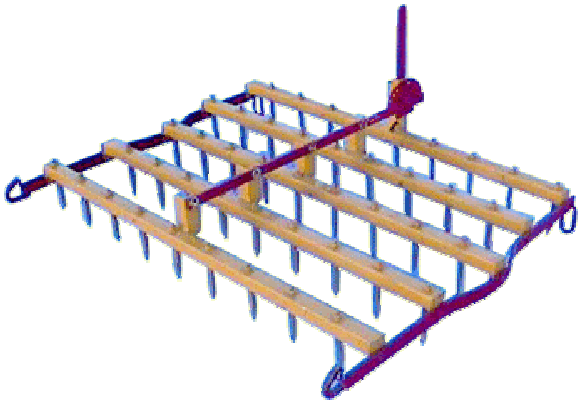
Rotary tiller

Offset disk gangs



Flexible cultipacker

Disk harrow



Spike tooth harrow

Figure 2-29. Soil Tillage Tools

2.3.2.2 Grass and Forb Seeding (SS-3H)

Planting protocol seeding mixtures are presented in Table 2-9. Based on the percent of PLS per pound, increase the bulk field planting rate to achieve the desired PLS per pound. Adjust seeding rate to accommodate the selected seeding method. Conventional broadcast seeding typically requires 25 percent more seed than drill or air seeding.

Table 2-9. Revegetation Protocol Seeding Mixtures*

Species	Percent of Mixture	Seeds/ft^2	Pounds PLS/Acre**
Droughty Soil Mix			
Bitter Panicgrass	25	10	1.3
Needleleaf Witchgrass	50	20	4.2
Black-eyed Susan	25	10	0.25
	Total	**40.00**	**5.75**
Dry Soil Mix			
Big Bluestem	20	8	2.10
Indiangrass	20	8	2.00
Little Bluestem	15	6	1.00
Black-eyed Susan	15	6	0.15
Virginia Wildrye	10	4	1.80
Switchgrass	5	2	0.20
Showy Partridge Pea	5	2	0.60
	Total	**40.00**	**7.85**
Wet Soil Mix			
Virginia Wildrye	40	16	7.30
Big Bluestem	30	12	3.15
Switchgrass	20	8	0.90
Showy Partridge Pea	10	4	1.17
	Total	**40.00**	**12.52**

* Seed drill seeding rates
** Actual pounds seeded per acre adjusted for percent PLS for each species

Seeding rates for the most part are based on science, mathematical calculations, or experience and are always expressed as pounds per acre, either as bulk or pure live seed (PLS). Seeding rates based upon science determine the number of seeds per pound then calculate the ideal number of seeds per square foot. Experience takes what science has determined and accounts for local factors including weather, soil condition and type, species growth characteristics, and use and management.

Knowing the number of seeds per square foot is an indicator of plant density. Plant density is important because it affects the health and vigor of the plant. Plantings that are too dense and overcrowded compete for food and water, resulting in poor root development and weak plants, making them susceptible to a number of problems. Drought stress, water stress, weed invasion, poor root structure, disease, and fungal vulnerability are just some of the problems of an overcrowded stand. General guidelines for determining seeding rates include:

- The overall objective is to establish a grass stand with a minimum of six seedlings per square foot (one seedling every 4 inches of drill row with 6-inch spacing). Due to the relatively poor seedling vigor, native seedling establishment is normally estimated at 20 percent to 25 percent of the PLS seeding rate. Therefore, to achieve six seedlings per square foot, a PLS planting rate of 30 seeds per square foot is required if one assumes a 20 percent seedling establishment rate.
- Most warm season plantings need to be in the 30 to 50 seeds per square foot range and cool season plantings in the 35 to 60 seeds per square foot range. Target seeding rate ranges and pounds PLS planting rates per acre for critical areas are presented in Table 2-10.

Table 2-10. Recommended Critical Area Seeding Rates

Species	Seeds/Pound	Seeds/Ft^2/ Pound	Seeding Recommendations*	
			Target Seeds/Ft^2	Target PLS Pounds/Acre
Bitter Panicgrass	325,000	7.5	50 – 60	7 – 8
Needleleaf Witchgrass	210,000	4.8	30 – 50	6 – 10
Big Bluestem	165,000	3.8	30 – 50	8 – 13
Black-Eyed Susan	1,746,000	40	20 – 30	0.5 – 1.0
Indiangrass	175,000	4.0	30 – 50	8 – 13
Little Bluestem	260,000	6.0	30 – 50	5 – 8
Showy Partridge Pea	146,000	3.4	15 – 25	4 – 7
Switchgrass	389,000	8.9	20 – 30	2 – 3
Virginia Wildrye	96,000	2.2	35 – 60	16 – 27

* Low range = moderate to low disturbance areas; Upper range = severely eroded critical areas

- Using Table 2-10 as a reference, planting 4 PLS pounds of switchgrass would produce 35.72 seeds per square foot: 389,000 seeds per pound x 4 pounds PLS = 1,556,000; 1,556,000 ÷ 43,560 = 35.72. This could also be calculated by using the number of seeds per square foot per pound: 8.93 seeds/ft^2/pound x 4 pounds PLS = 35.72.
- A mixture of 2 pounds big bluestem, 2 pounds Indiangrass, 1 pound little bluestem and 2 pounds Virginia wildrye, for a total of 7 PLS pounds would plant 25.9 seeds per square foot. At that seeding rate, there would be nearly 17 (16.8) seeds in an area roughly the size of this sheet of paper. To find out how much a mix plants, multiply the seeding rate of the individual grass by the number of seeds per square foot per pound. Repeat the process for each plant in the mix and add their totals.
- The PLS pounds per acre seeding rate is not the actual amount of seed planted in the field. Some native grass seed lots contain a higher percentage of inert material. Legumes such as showy partridge pea may have a higher percentage of dormant or hard seed. The PLS percent when added to inert materials and other seeds in each bulk pound adds up to 100 percent.
- Adjusting the PLS pounds per acres seeding rate to the actual pounds per acre planted in the field allows for the same amount of viable PLS seed per acre regardless of the varying quality of different seed lots and considerable variability that may occur in the total amount of seed planted per acre. As an example, if each bulk pound of seed is 74 percent PLS and the planned PLS seeding rate is 5 pounds PLS per acre, the amount of seed applied in the field is 6.8 bulk pounds per acre. This is calculated by dividing the target 5 PLS seeding rate by 74 percent (0.74). Seed dealers can provide assistance in determining seeding rates.
- One of the most common mistakes to avoid is overseeding, particularly in severely eroded area plantings in which healthy grass stands are most important. Initially, an overseeded area will look good and perform well; however, over time, competition between plants for limited resources will result in stressed plants that do not develop root systems to the extent they should. The sod becomes weak and weeds invade. Because the root system is not healthy and as deep in the ground as it should be, erosion problems may continue to persist.

Drill Seeding

Rangeland drills are effective pieces of equipment that provide the most cost efficient and reliable means of establishing native grasses. Difficulties in drill seeding native grasses are most frequently encountered in planting chaffy native grass seeds. Drill seeding specifications include:

- Plant seed in a well-prepared seedbed and make sure the drill is calibrated to ensure maximum performance and accurate seeding.
- The planting of chaffy native grass seeds may require specialized seed drilling equipment such as the Turex or John Deere Model 750 drill. To avoid complications, use highly conditioned big bluestem or Indiangrass seed. Purity must be very high (relative to native grasses), probably 80 percent or more, and not have any stem pieces over 1/2 inch long for the seed to flow. Many seed companies will sell debearded seed, which will flow through these drills. The drawback is that debearded seed requires extra cleaning steps, which make the seeds more expensive. Another disadvantage is that you are limited to only two species that will work this way, big bluestem and Indiangrass. Little bluestem and sideoats grama will not flow regardless of conditioning.
- Chaffy native grass seeds may also be drill planted by mixing the seed with a carrier. Products such as rolled oats and rice hulls can be used. Mix the carrier and your seed at a 2:1 ratio; for every pound of native grass seed, use 2 pounds of carrier. Seed will flow through the drill relatively well, but there are some problems. Usually an adequate amount of native grass seed in this mixture ratio cannot be applied in a single pass, which requires double planting. Additionally, as the seed box empties, there will be a certain amount of native grass seed that will "float" on top of the cracked corn and will not come out of the box. It is important to keep refilling the box and mix the seed periodically to keep from planting pure oats or rich hulls. Do not drill seed during wet conditions.

Broadcast Seeding

Broadcast seeding is the dispersal of seeds on the soil surface. Seeds can be broadcast using air seeders, conventional broadcasting equipment, mulchers, or hand spreading. Broadcasting can also be done using conventional broadcasting equipment such as a lime truck, fertilizer cart, three-point seeder, or end gate seeder. To plant chaffy seed, a carrier such as potash or lime is required. Hand seeding is used to seed small areas by evenly dispersing seeds on the surface by hand. Rack the seed in to assure adequate coverage and soil contact and pack the soil with a roller or other implements to achieve proper soil-to-seed contact. Broadcasting specifications are as follows.

- Broadcast seed in a well-prepared seedbed.
- Apply chaffy native grass seeds using 100 pounds of potash or 60 to 100 pounds of pelletized lime per acre as a carrier. Account for the carrier application of potash or lime during fertility management planning. Do not use nitrogen as a carrier.
- Do not broadcast seed during wet conditions.
- Cultipack the planted area to ensure good soil-to-seed contact (Figure 2-29).

An example of a native grass broadcast planting operation is presented in Figure 2-30.

Step 1. Seedbed Preparation

Step 2. Spreading mycorrhizal inoculum

Step 3. Incorporating the mycorrhizal inoculum

Step 4. Broadcasting Native Grass Seed

Step 5. Straw Mulching

Seed Germination

Figure 2-30. Native Grass Broadcast Seeding Operation

(http://www.mycorrhiza.org/tenaja.htm)

Air Seeding

The most reliable method, excluding drilling, is broadcasting using an air seeder. An air seeder uses a forced air system to distribute material through booms with outlets at intervals along the booms. In order to be able to distribute the chaffy native grass seeds through the air system, a carrier must be used. Air seeding guidelines are presented below.

- Plant seed into a well-prepared seedbed. Plant chaffy native grass seeds using 100 pounds of potash or 60 to 100 pounds of pelletized lime per acre as a carrier. Account for the carrier application of potash or lime during fertility management planning. Do not use nitrogen as a carrier.

- Light, chaffy seeds won't carry as far as the heavier potash or lime. It is therefore necessary to overlap swaths when broadcasting to get a somewhat even stand. To ensure proper coverage, the site can be double spread.
- After covering the field the first time, spread the field a second time, going across the field perpendicular to the first application. Broadcasting using these methods usually requires about 25 percent more seed to get similar results to using an air seeder or drilling. Do not air seed during wet conditions.
- Cultipack the planted area to ensure good soil-to-seed contact. This is particularly important if irrigation is not available. The mini-terraces created by the rollers also increase infiltration and decrease runoff.

Mulch Seeding

In mulch seeding, native grasses are harvested late in the season when seed is ripe and then spread on a prepared seedbed using a mulch spreader. The native grass hay is rolled with a cultipacker to get good seed-to-soil contact.

Hydroseeding

Hydroseeding or hydraulic planting is a method of applying erosion control materials, seeds, and soil amendments to bare soil on disturbed areas and steep, critical slopes. By using hydraulic equipment (hydroseeders and hydromulchers), seed, soil amendments, mulch and tackifying agents, bonded fiber matrix, and liquid co-polymers can be uniformly broadcast, as hydraulic slurry, onto the soil in one operation. Hydroseeding is justifiable where terrain is too steep or contains too many obstacles that would prevent the use of other methods. Hydroseeding specifications are as follows.

- The mulch is mixed with seed and soil amendments as specified and applied at a rate recommended by the manufacturer in order to achieve uniform, effective coverage and provide adequate distribution of seed.
- If using paper mulch, use approximately 50 pounds of mulch per 100 gallons of water and apply at a rate of 1500 to 2000 pounds/acre, mixed with seed and fertilizer, at recommended rates, in order to achieve uniform, effective coverage.
- Paper mulch used to tack and bind straw mulch can be specified at 750 pounds/acre.
- If using wood fiber mulch, use approximately 30 to35 pounds of mulch per 100 gallons of water applied at a rate of 1500 to 2000 pounds/acre, mixed with seed and fertilizer, at recommended rates, in order to achieve uniform, effective coverage.
- Minimum application rates for hydraulic matrices are 500 pounds/acre wood fiber mulch, 1000 pounds/acre recycled paper mulch combined with 55 gallons per acre acrylic copolymer with minimum 55 percent solids content. For bonded fiber matrix, the BFM shall be applied at rates from 3000 to 4000 pounds/acre. To achieve full coverage, apply the product in two different directions. Bonded fiber matrix shall not be applied before, during, or immediately after rainfall so that the matrix will have 24 hours to cure and dry after installation.
- When tacking or anchoring straw with paper fiber mulch, apply at a rate of 750 pounds per acre. Polymer tackifiers are to be applied at rates of 40 to 60 pounds/acre depending on manufacturer's recommendations. Plant mucilage or guar tackifiers are to be applied at rates

of 80 to 120 pounds/acre depending on manufacturers' recommendations. Apply liquid straw mulch binders heavier at the edges, in valleys, and at the crest of banks.

- Hydraulic mulch specifications include a moisture content not to exceed 12 percent +/- 3 percent, minimum organic matter content of 98 percent, maximum inorganic matter content of 2 percent, 4.9 pH, minimum water holding capacity of 1 gallon per pound of fiber, and slurry fiber is applied with a biodegradable dye to aid visual application (Salix Applied Earthcare, 1999).

If the hydraulic mulch or tackifiers are applied as stand alone (without vegetation) treatments, the product's longevity must match the length of time that the soil will remain bare or until revegetation occurs. Periodic inspections will assure the intended purposes will be met.

2.3.2.3 Shrub and Vine Plantings (SS-3I)

All planting stock and seed should be purchased from nurseries that are known to be using locally adapted seed, seedlings, or cuttings. All plant materials should comply with the minimum standards established by the American Nurseryman Standards Institute. Site preparation shall be sufficient for establishment and growth of selected species. The type and intensity of site preparation will vary according to ground cover, soils, and the species to be established. Areas with plow pans or compacted soils should be subsoiled. Use Table 2-11 to determine the spacing for achieving the desired shrub density. Shrubs may be planted at rates as high as 9,700 shrubs per acre. Guidelines for planting shrub seedlings, bareroot stock, container stock, and cuttings are presented below.

Table 2-11. Shrub and Tree Spacing Guidelines

Spacing (feet)	Number of Trees/Shrubs per Acre
1.5' × 3'	9,680
2' × 3'	7,210
3' × 3'	4,840
5' × 5'	1,742
5' × 7'	1,244
6' × 6'	1,210
6' × 7'	1,037
6' × 8'	908
6' × 10'	726
6' × 12'	605
7' × 7'	900
8' × 8'	674
8' × 10'	545
8' × 12'	454
9' × 9'	538
9' × 10'	484
9' × 12'	404
10' × 10'	436
11' × 11'	360
12' × 12'	303

Seedlings

- Shrub seedlings may be planted by hand or machine at a density that achieves the desired results. On sloping land, planting should be done on the contour where possible. Any tool or piece of equipment that gives satisfactory results may be used. Planting should be done when the soil is neither too dry nor too wet.

- Late winter is the best time to plant deciduous shrubs. Early fall is the best for evergreen shrubs. Shrubs grown in containers can be planted anytime.
- Proper planting dates and care in handling and planting of the seed or seedlings will ensure that planted materials have an acceptable rate of survival.
- Replanting will be required when survival is inadequate.

Cuttings

- When planting cuttings, 4 to 6 inches should be above the ground and 14 to 24 inches below the ground.
- Prepare soil and add soil amendments in the same manner as for bareroot shrub plantings. A fertilizer/mycorrhize seedling starter packet is added to the bottom of the planting hole prior to backfilling.
- Add straw mulch after the cuttings are planted.

Bareroot Stock

- The roots of seedlings must be kept moist and cool at all times. After lifting, seedlings should not be exposed to sun, wind, heating, drying, or freezing before they are planted. Baled seedlings may be kept up to 3 weeks if they are properly stacked, watered, and kept in a cool, shady place. When planting is delayed longer than 3 weeks, the roots of seedlings should be covered with moist soil (heeled-in) or the seedlings should be put in cold storage.
- During planting, the roots of seedlings must be kept moist, and only one seedling should be planted at a time. At the end of each day, loose seedlings should be either repacked in wet moss or heeled-in.
- Bareroot stock planting holes should be large enough to easily accommodate the entire length and width of the roots without adjusting the position of the roots.
- Lime is incorporated into the backfill material at the rate determined from soil pH testing. Mature compost is to be added to all backfill materials at a rate of 1:3 parts native soil. A fertilizer/mycorrhize seedling starter packet is added to the bottom of the planting hole prior to backfilling.
- Roots should be planted straight down and not twisted, balled, or U-shaped. It is not necessary to prune roots unless they are too long to be planted properly. If pruning is necessary, prune only the taproot enough to properly plant the tree. Lateral roots should not be pruned.
- When planting bare root plants, spread the roots in the hole and gradually add soil. Firm the soil, being careful to avoid breaking roots. Fill the hole with water and allow it to drain. Then fill the hole with soil and water again thoroughly.
- Position stock in the planting hole with the main stem(s) vertical, gradually backfill the planting hole with soil, and gently pack soil around roots. Exercise extreme care that the roots are not damaged during soil backfilling and packing.
- Stem tissue above the root collar. Saturate the soil with water to remove air pockets in the soil. Small shrubs may be planted with a dibble bar.
- Place the transplant within a mesh or ventilated plastic tube to protect the seedling against wildlife predation. The plastic tube also produces a greenhouse effect that encourages seedling growth.

- Add straw mulch after the seedlings are planted. Mulch is very important for new plantings. It conserves soil moisture, prevents soil crusting, and suppresses weeds. This results in more water being available to the plant, which helps reduce stress conditions in the first year planting.

Container Stock

- Remove containers at the time of planting. Once the plant is removed from the container it will need scoring if the plant is root-bound (roots circling the outside of the root ball). For individual shrubs, provide as large an area as possible for initial root development. The planting hole should allow the root ball to extend one inch above the soil surface and should be as big around as three to five times the diameter of the root ball.
- The width of the planting hole should be 1.5 times the diameter of the container, and the hole depth should be 1.5 times the depth of the container.
- Lime is incorporated into the planting hole fill material at a rate determined from soil testing. Mature compost is to be added to planting hole backfill material at a rate of 1:3 parts native soil. A fertilizer/mycorrhize seedling starter packet is added to the bottom of the planting hole before planting.
- For burlapped plants, remove any wire or string around the plant's stems. Do not remove the burlap; fold it back so it will be buried by the soil. Burlap, which is allowed to remain exposed after planting can act as a wick, causing the root ball to dry out. Follow the same procedures for filling the hole as that described for container plants.
- The plant should be installed so the surface of the root ball is level with the grade of the soil at each hole. No more than 1/2 inch of soil should cover the root ball. The surface of root balls shall be no more than 1 inch below grade.
- Place the transplant within a mesh or ventilated plastic tube to protect the seedling against wildlife predation.
- Add straw mulch after the shrubs are planted.

2.3.2.4 Tree Planting (SS-3J)

Guidelines for planting trees such as sweetbay and titi are presented below.

- Hardwood seedlings such as sweetbay and titi can be planted either by a machine specifically designed for planting hardwood seedlings or by a dibble bar, shovel, power auger, or posthole digger. An acceptable planting machine for hardwood seedlings would be one that has a coulter diameter of at least 32 inches and a planting foot and trencher plate assembly to allow for the creation of a trench of four inches in width and fifteen inches in depth.
- A fertilizer/mycorrhize seedling starter packet is added to the bottom of the planting hole just below the roots prior to backfilling.
- Backfill in the same manner at described for longleaf pine plantings in the previous section.
- Hardwood seedlings and cuttings should be planted at a spacing that allows 300 to 700 trees per acre. A survival of 65 percent or more of the seedlings at the end of the first growing season is considered acceptable. On areas where the survival of seedlings is expected to be low, the planting rate should be increased. The number of trees per acre for various spacings is presented in Table 2-11.

2.3.3 Vegetation Management

Generally, once native plant communities are well established, they are relatively management free; however, during the interim period, irrigation and fertility management may be required to ensure planting success. Vegetation management practices discussed in this section include:

- Irrigation (SS-3K)
- Fertility Management (SS-3L)
- Replanting (SS-3M)

2.3.3.1 Irrigation (SS-3K)

Moisture, more than any other single environmental factor, limits plant growth. Irrigation is considered to be a temporary measure for plant establishment. The use of irrigation is based on soil texture, droughts, plant density, water needs of the plant community, and incorporation of moisture conservation measures such as compost and mulch.

Improper irrigation can be detrimental to the establishment and growth of the plant community. Excessive irrigation may result in an overly productive plant community that experiences stress or dieback when irrigation terminates, whereas insufficient irrigation may result in the establishment of shallow root systems with limited drought tolerance and an inability to tap into water reserves that may be in lower soil profiles. Irrigation may competitively favor rapidly growing, short-lived species to the exclusion of long-lived, slower growing species.

Irrigation effectively extends the planting season, increases the establishment of plants during drought periods, and promotes the efficient use of nutrients. For most grass species, moisture availability during germination and root development is crucial. Irrigation applied in amounts that wet the entire soil profile encourages deep-root development and drought resistance. The types of commonly used irrigation include drip, sprinkler, and spray systems. Spray irrigation is normally the most practical water application method.

Spray systems use vehicle mounted hoses or booms to directly apply water by gravity or pumps to the site. Since compost and/or mulch is a component of all plantings, supplemental water requirements will normally be limited because of the high water holding capacity and temperature moderation characteristics of these practices.

2.3.3.2 Fertility Management (SS-3L)

Since plants are not mobile and do not have the capability to anchor themselves and collect and digest nutrients, they require separate biological systems to perform these functions. The soil environment is the living biological system designed to provide the anchorage and digestive systems for plants. Soils are the receptors of nutrient and raw material inputs that must be made readily available for plants. Soil, when it is truly biologically active, alone can account for optimal vegetative production. Soil livestock (organisms) cycle nutrients and provide other functions important to plant production and health, and organic matter is the food for the soil livestock. It is critical to understand that microbial activity generally ceases below root levels.

The first order of business is for the soil to hold nutrients in reserve for trade off with plant roots as they are needed. The soil mechanisms for holding nutrients lie in the electrical characteristics of clay and humus colloids. Humus is the well-decomposed, relatively stable part of the organic matter found in aerobic soils. The negatively charged, chemically active clay and humus colloids attract and hold positively charged base or cation nutrients by a process known as colloid adsorption (chemical binding). The important thing about the humus colloid is that the soluble elements in it are at all times available to the plant, and yet they will neither evaporate nor leach out. Humus will hold 75 percent of its own volume in water.

Since negatively charged nutrient anions are not attracted to the negatively charged soil colloids, they are free to move in the soil solution. The clay-humus complex must be operative for commercial salt fertilizers to work, yet when the clay-humus complex is maintained at peak performance, salt forms of fertilizer are no longer needed.

Cation Exchange Capacity

The capacity to exchange base elements from soil colloids is called cation exchange capacity (CEC). This represents the soil ability to act as a source of supply for the exchange base so it can give up nutrients to plants in exchange for hydrogen (a base). Humus colloids in most mineral soils account for 30 percent to 65 percent of the total CEC.

When negative colloids are neutralized by an accumulation of positive base elements, the system is said to have achieved 100 percent base saturation. A common symptom of commercial fertilization is the loading of soil colloids and not feeding plants. Commercial N, P, and K salts fertilization without sound CEC principles in tow amounts to seat-of-the-pants-fertility management. By managing organic matter, water, air, and temperature properly, dependence on commercial fertilizers for a set level of vegetative production can be diminished or eliminated.

This “horsepower rating” of the soil colloids capability to attract and hold plant nutrients is expressed in terms of milliequivalents (meq). The CEC is an index of what the soil complex can take or will require to maintain nutrient balances. Milliequivalent represents the amount of colloidal energy needed to absorb and hold to the soils colloid in the top seven inches of one acre of soil 400 pounds of calcium, or 240 pounds of magnesium, or 780 pounds of potassium, or 20 pounds of exchangeable hydrogen.

Soil horsepower depends on the type of clay and amount of humus in the soil. Kaolinite clay CEC ranges from 10 to 20, montmorillonite measures from 40 to 80, and values for organic matter are the highest ranging from 100 to 250 meq. As a consequence, pure sand has relatively undetectable CEC; however, the moment the soil begins to accumulate colloidal clay or humus, the CEC increases dramatically. Some soils have a naturally low capacity for holding plant nutrients, and they can do little to deliver the goods to plant roots.

Calcium, magnesium, potassium, and sodium are the four positively charged base elements (attracted to negatively charged soil colloids) that strongly influence pH, balanced hormone and enzyme systems and plant health, and protection against insect, bacterial, and fungal attack. Either of these major cations in excess can raise pH and in lower amounts reduce pH. They have to be in balance; otherwise the pH level is likely to be meaningless.

According to Albrecht's theory of base saturation, the desirable percentages of bases in the soil for optimum growth of most agronomic crops are calcium (60 percent to 70 percent), magnesium (10 percent to 20 percent), potassium (2 percent to 5 percent), sodium (0.5 percent to 3 percent), other bases (5 percent) (Walters, 1996). Lime and fertilizer applications are used to adjust the percentages to optimal ranges. Equilibrium of pH at 6.2 or 6.3 will prompt agronomic plants to grow well with comparable pedigree of seed and character of soil and reduce the growth of many native plant species.

Soil pH

Formally stated, pH is the logarithm of the concentration of active hydrogen or ions, not molecules. As the pH value gets smaller, the degree of acidity is higher because there are more active hydrogen ions per unit volume as the ion concentration is higher. An acid soil may represent a deficiency of calcium, magnesium, potassium, or sodium. The soil pH is important because it regulates the availability or absence of the major cation nutrients. Typically, pH can be automatically adjusted to a level suitable for plant growth by bringing calcium, magnesium, potassium, and sodium into equilibrium. An acidic pH is generally associated with leached soils.

Soil Balance

The physical state of the clay-humus soil colloid complex is determined by the acidity of the soil. In a neutral soil, colloids tend to be stable; under acidic conditions, colloids tend to be mobile. Under mobile acidic conditions, clay and humus colloids chemically interact with a greater amount of soil material and capture more nutrients in the process. Therefore, it is advantageous to maintain a mild acidity of the colloidal portion of the soil to encourage chemical interactions between colloids.

Soil Anions

The clay-humus complex cannot hold negatively charged anion nutrients, so they must be held in the soil solution and adsorbed through root hairs. The nutrients must become fixed with one or more elements in the soil before they can be of use to plants. Soil microorganisms convert the plant nutrients nitrogen, phosphorus, sulfur, chloride, boron, and molybdenum to each element's anion phase. Nitrogen is converted to nitrate, phosphorus to phosphate, sulfur to sulfate, chlorine to chloride, boron to borate, molybdenum to molybdate. Rain fixes a small amount of nitrogen, approximately five pounds per acre per year. However, the key to a healthy nitrogen cycle in the soil is dependent on the capabilities of symbiotic (legumes) and non-symbiotic soil bacteria and microorganisms to fix nitrogen to their bodies.

Commercial Fertilizer

Native and nonnative species supported by the soil amendments such as compost, liming, bioorganic fertilizer, and/or mycorrhizae will normally not require additional fertilization. Liming to the target pH for the planted species increases the availability of macro and micronutrients in the soil solution for plant use and increases the total overall soil nutrient pool. However, overly dense plantings may require the addition of nitrogen after the first year growth. Do not add more than 10 pounds of nitrogen per acre until a good stand is evident. For best results, nitrogen is applied in split applications at spring green-up and late summer. The use of phosphorous (P_2O_5) and potassium (K_2O) should not be required unless severe deficiencies are evident. Commercial fertilizer applications to native species plantings are normally not required even though natural fertility may be low. Salt fertilizer applications

may actually increase the growth and establishment of weeds and undesirable species. They do have the advantage of supplying plants with immediately available forms of nutrients, and they are often less expensive and bulky to apply than other fertilizer materials. Native species fertilizer recommendations are presented below.

- If commercial fertilizer is applied, it should not exceed 300 pounds of a 0-20-20 analysis per acre per year.
- Nitrogen should not be applied to native species planting during the first year. Subsequent applications should not exceed 10 pounds per acre per year and should be applied in split applications.
- Incorporate fertilizer into the soil during seedbed preparation.

2.3.3.3 Replanting (SS-3M)

Collecting and evaluating vegetation establishment data during the planting year is key to assuring the success or failure of a planting. The most common method for measuring stand density is counting the number of individual plants per species within a standard 1 square foot quadrant. Assuming an average size of 1 acre or less per site, minimums of 5 samples are collected from each site. Randomly disperse the sample locations over the site and account for any variables related to changes in soil type. It is advisable to sample roadside slopes and channels separately. Table 2-12 presents suggested actions based on planting year seedling densities.

Table 2-12. Seedling Density for Stand Evaluation During the Planting Year

Average Seedlings Per Square Foot	Action/Condition
<3	Reseed
3 – 5	Wait and Reevaluate Next Year
6 – 8	Successful
>8	Excellent Results

2.4 MULCHING (SS-4)

Mulching is the application of a protective layer of straw, erosion control mats, or other suitable material to the soil surface. The cover simulates the effect of a plant cover by protecting the soil from raindrop impact and reduces the velocity of runoff and wind. The types of mulch described in this section include:

- Erosion Control Blankets (SS-4A)
- Straw Mulch (SS-4B)
- Hydromulch (SS4-C)
- Compost Mulch (SS-4D)

2.4.1 Erosion Control Blankets (SS-4A)

Erosion control blankets are used to stabilize slopes or channels by controlling soil movement and assisting in the establishment of vegetation. Blankets are available from numerous commercial venders and are typically made of straw, coconut fiber, and excelsior or synthetic material enveloped

in plastic or biodegradable netting. Installation guidelines are presented below and illustrated in Figure 2-31.

- Prepare the site by grading, contouring, and constructing runoff control features (grass hedges) to control runoff.

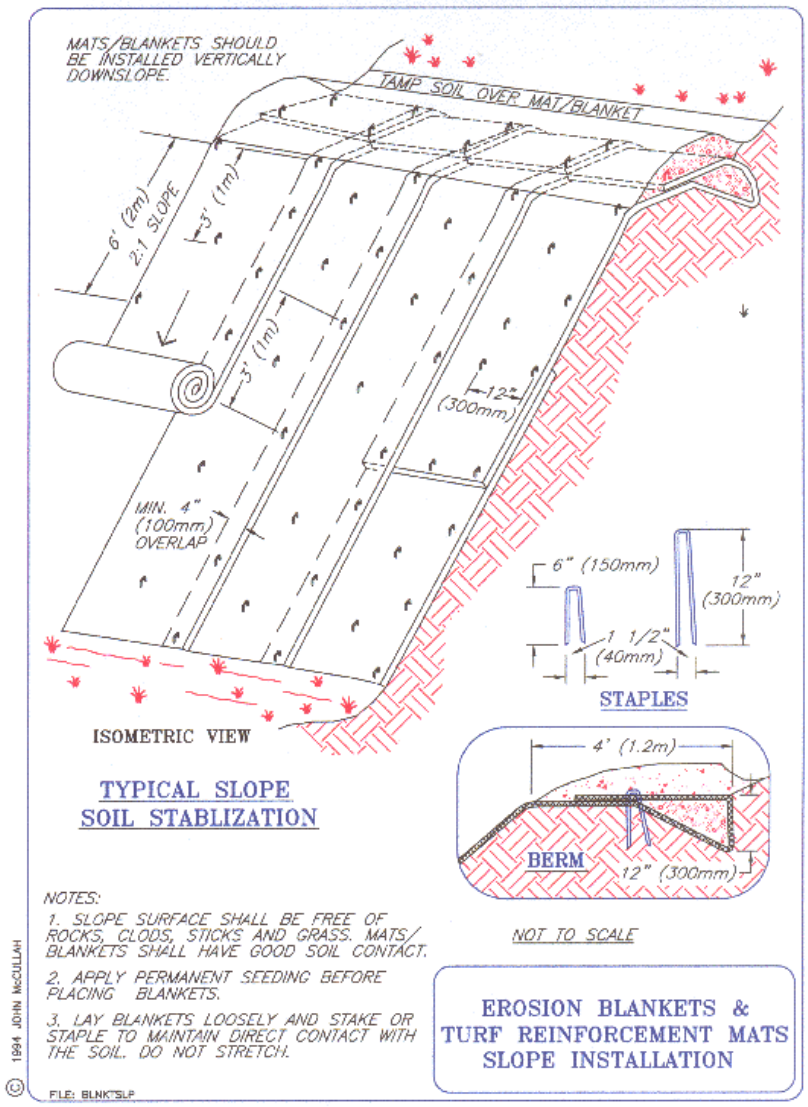


Figure 2-31. Erosion Control Blanket Slope Installation
(Salix Applied Earthcare)

- Prepare the seedbed, fertilize, and seed the site according to design specifications prior to blanket installation. When seeding prior to blanket installation, all check slots and other areas disturbed during installation must be reseeded.
- Dig a 6-inch by 6-inch trench at the top crest of the slope. Install the blanket in the trench in a U shape configuration ensuring that adjacent blankets overlap at least 6 inches.
- Staple the blanket in the trench, backfill the trench, and compact the soil.

- Unroll the blanket down the slope in the direction of water flow ensuring that there is maximum contact with the soil.
- Unroll the blanket in the proper manner and do not walk on the blanket following installation. Individuals hold the blankets in front of them at the top of the slope as they slowly back down the hill. Do not unroll the material by kicking it down the hill.
- Install the material so that it lies loosely on the soil surface. Stretching the material causes the blanket to bridge small depressions, which can pool water and initiate rill erosion under the blanket. Some plants may not be able to penetrate tented blankets.
- Insert staples through the blanket at 3-foot intervals. Overlap adjacent blankets at least 6 inches and insert staples through both blankets.
- At the end of the blanket roll, insert a second blanket in a shingle effect by overlapping the first onto the second at least 6 inches. Staple through overlapped area, approximately 12 inches apart. Install the blankets in a manner that assures secure lap joints and uniform contact with the soil; do not stretch.
- 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 (1 staple 3 feet off center). Gentle slopes require 1 staple per square yard.
- Secure the bottom edge by inserting staples 20 inches apart. Plant other vegetative materials after blanket installation.

The installation of erosion control blankets in channels is described in the Soft Armor Waterway practice (Section 3.2.3).

2.4.2 Straw Mulch (SS-4B)

Grain straw is to be used as the primary straw mulching material. Grain straw (wheat, barley, oats, and rice) normally does not contain the diversity of non-native plant seeds as does pasture hay; however; straw can be more expensive and less readily available than hay. It is important that the stems be as long as possible to increase the life expectancy of the mulch and improve the effectiveness of crimping or tracking. As a rule of thumb, 65 percent by weight should be 10 inches or longer. Mulching depth will vary with planting design specifications.

Mulching depth should correspond to the germination characteristics of the primary plant community. Mulch will normally be applied at depths of 2 to 3 inches on seeded sites and up to 4 inches on unseeded sites. Mulching at rates above 3 inches may restrict sunlight and seedling penetration. Mulching at 3 inches or greater may require soil incorporation through punching-in techniques. Straw mulch guidelines are presented below.

- Establish a stable slope grade prior to mulching and, if required, prepare the seedbed to design specifications.
- Obtain the desired mulch and store in a protected environment to prevent decay and molding. Avoid to the degree possible compacted, spoiled, or moldy mulch materials because they tend to clump and complicate uniform distribution. Schedule the date of application to correspond with the site plan. A work crew will be needed for some tasks.
- Apply the mulch at a uniform depth to match design specifications and anchor as necessary. The soil should not be visible through the mulch. One 80-pound bale of straw covers

approximately 900 square feet to a depth of 2 inches. During planting operations, the mulch will be applied immediately after seeding. Avoid trafficking during wet periods to reduce soil compaction.

- For seeded sites, apply 1.5 to 2 tons/acre to a depth of 2 to 3 inches. For unseeded sites apply 2-3 tons/acre to a depth of 3 to 4 inches. Mulching at 3 inches or greater may require soil incorporation through punching-in techniques (see Anchoring subsection below).
- Straw mulch can be applied by hand on smaller sites and mechanically blown on larger sites. Commercial straw blowers have a range of about 40 to 60 feet and a capacity of up to 15 tons/hour.

2.4.2.1 Anchoring

Mulch may need to be anchored to minimize loss by wind and water. Straw mulch is commonly anchored by:

- Crimping by tracking, disking, or punching into the soil.
- Covering with netting.
- Anchoring with pegs and twine.
- Spraying with asphalt (types SS-1, MS-3, RS-1, or RS-2) or organic tackifier at a rate of 150 to 200 gallons per acre.
- Tracking with cellulose fiber mulch at a rate of 750 pounds/acre.

Crimping and Netting

Mulch applied to small sites may be anchored by hand punching the material into the soil with a dull shovel. For larger, flatter sites, a tractor drawn mulch anchoring tool is used to punch the material to a depth of 2 to 8 inches. On 3:1 or shallower slopes, bulldozer tracking may be used to anchor the mulch. The bulldozer or other cleated track equipment is operated up and down the slope to ensure the tracks are perpendicular to water flow (Figure 2-32). A disk harrow or mulch crimping disk (Figure 2-33) may be used with the disks set straight. Paper, cotton, or biodegradable synthetic netting may be used to anchor straw mulch. However, this type of netting should be used judiciously since wildlife may become trapped in the nets.

Figure 2-32. Bulldozer Crimping (Salix Applied Earthcare)

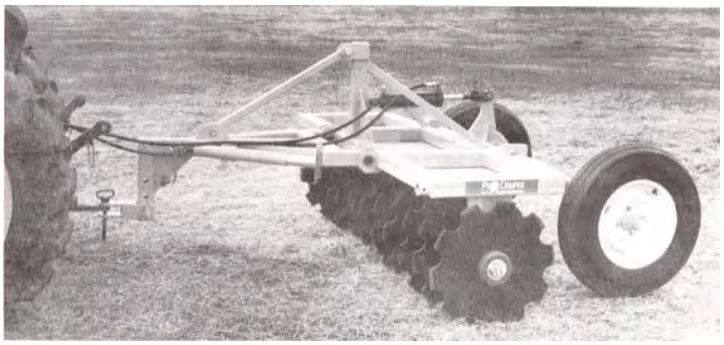


Figure 2-33. Mulch Crimping Disk (Salix Applied Earthcare)

Tackifiers

Tackifiers are hydraulically applied materials typically used to anchor or glue mulch to increase effectiveness 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 mucilage, or guars are extremely important to lubricating the slurries and increasing application performance. Liquid formulations of acrylic co-polymers can also be specified alone to control erosion and dust. These products chemically bond and stabilize the soil surface.

Generally, polymer tackifiers are applied at rates of 40 to 60 pounds per acre and organic tackifiers are applied at 80 to 120 pounds per acre; however, manufacturer recommendations may vary. Liquid tackifiers are applied uniformly over the area except for edges, valleys, bank crests, and other areas most susceptible to disturbance by wind or water.

For longer duration, select products with more solids. Since solids provide the tackifier binding power, the higher the content of solids, the stronger and more durable the product. An inferior grade dry powder tackifier may require a higher than recommended application rate to produce the same binding effect. If properly applied, little maintenance is required. The mulch should last until permanent vegetative cover is achieved. Straw mulch can last from 3 months to 2 years and erosion control blankets are effective for up to 2 years. Following high winds or significant rainstorms, the mulched areas should be checked. Apply additional mulch as required.

2.4.2.2 Soil Incorporation

Straw mulches may also be incorporated into the soil. This technique may be appropriate if vegetation will be planted after mulching. Otherwise, there may be a problem drilling or planting through mulch spread over the surface unless specialized equipment is used. Although soil incorporation of straw mulch reduces the overall surface cover, the mulch is effective in binding the soil and increasing infiltration.

The effectiveness of incorporated mulch in reducing erosion is primarily dependent on the mulch material used. Wheat straw is most effective because it produces a large number of individual elements that result in a uniform pattern of incorporation, good mulch-soil contact, and sufficient material to form miniberms on the surface to pond water and minimize crusting. Mulch materials are easily incorporated with conventional tillage equipment such as disk harrows or chisel plows.

Typically, with the introduction of raw organic matter, soil microbes will deplete soil nitrogen, decomposing the materials, which makes less nitrogen available for plant growth. The application of a

complete fertilizer with lime has been shown to hasten the decomposition of straw by immediately increasing the number of microorganisms (Baur, 1934).

2.4.3 Hydromulch (SS-4C)

Hydromulch is a liquid slurry of recycled paper or wood waste or a combination of the two that is normally machine applied to the soil surface. This technique is used to apply erosion control materials and establish vegetative cover on critical slopes that otherwise cannot be practically treated. Application specifications are presented in Hydroseeding, Section 2.3.2.2.

2.4.4 Compost Mulch (SS-4D)

Compost mulching is a simple, relatively inexpensive practice that effectively improves soil conditions, reduces erosion, and enhances the establishment of viable, self-sustaining plant communities (Section 2.3.3). Mature compost applied to sloped areas has been shown to be more effective than straw or hydromulch in reducing erosion by enhancing planted or volunteer vegetation growth.

Compost must exist in a mature and stable condition, otherwise the applied organic materials could cause additional soil stress that could jeopardize revegetation success and increase potential erosion problems. Mature compost is defined as the highly stabilized and sanitized finished product of composting that is beneficial to plant growth and has a reduction of organic matter of 40 percent to 60 percent. Mature, stable compost has experienced a level of biological activity that results in a substance with the following characteristics.

- Free of organic phytotoxic substances that can adversely affect seed germination or plant growth.
- Consumes almost no nitrogen or oxygen and generates little carbon dioxide or heat; compost that is hot (>120 °F) or becomes hot after wetting is unacceptable.
- A dark brown or black color and a soil-like or musty odor; sour or putrid smelling compost is unacceptable.
- No recognizable grass or leaves.

Compost mulch is also be used as a substitute for fertilizer. If the compost contains 1 percent nitrogen, a 20 percent mineralization will supply 4 pounds of available nitrogen per ton of compost. Applying the compost to the surface at a depth of 1 inch would provide 3.5 pounds of available nitrogen per 1,000 square feet, which is more than sufficient for meeting plant nutrient requirements (Stutz et al., 2003). The Florida Department of Transportation (DOT) has developed specifications for applying compost as a topdressing fertilizer to roadside areas (Table 2-13).

Table 2-13. Florida DOT Compost Mulch Topdressing Fertilizer Recommendations*

Bulk Density (lb/yd^3)	Weight (tons/acre)	Volume (yd^3/100 ft^2)	Thickness of Layer (inches)
700	74	0.49	1.6
800	74	0.43	1.4
900	74	0.38	1.2
1,000	74	0.34	1.1

*Based on the use of compost with a moisture content of 40 percent by weight.
Source: Kidder and Miller, 2002

Compost mulch application specifications include:

- Examine sources of commercial compost and choose compost based on the mature compost selection criteria.
- The erosion control effectiveness of compost mulch is greatest when the particle size of the compost is matched to the slope of the treatment site. Specifications for compost mulch are presented in Table 2-14.

Table 2-14. Compost Specifications for Erosion Control

Parameter	Specifications	Comments
Particle Size	Mix of fine and coarse grades; 3:1 ratio Fine: Passes through a ¼ to ½ inch screen Coarse: Passes through a 2 to 3 inch screen	Fine Grade Compost: increases water infiltration and water holding capacity, penetrates soil, enhances vegetation establishment, and provides long-term nutrient supply. Coarse Grade Compost: difficult to disturb by stormwater runoff; retains suspended soil particles.
Moisture	20-50 percent	Dry Compost: absorbs more water, binds pollutants, and is less expensive than wet compost.
Organic Matter	40-70 percent	Higher organic matter content increases water holding capacity
pH	6.0-8.0	—
Soluble Salt	3.0-6.0 mmhos/cm	—
Inerts	<1.5 percent (by weight) foreign synthetic material	—
Nutrient	N: 1-3 percent Organic N: 1-3 percent Phosphorous: 1.5-2.5 percent Potassium: 0.5-2.0 percent	Choice is dependent on nutrient content of the soil and vegetation nutrient uptake.

Source: Stutz et al., 2003

- Mechanically prepare the treatment site soil surface; subsoil or chisel plow compacted soils as required
- Evenly apply mature, stable compost to the applicable depth as specified in Table 2-15. For erosion control, apply compost at a rate of 2 to 3 inches deep, screened to ½ to ¾ of an inch placed directly over the soil. Steeper slopes will need the higher application rates, whereas gradual slopes could use application rates of 1 to ½ inch deep. Apply the compost using a stinger or blower-type unit, bulldozer, grading blade, or backhoe. For smaller areas, the compost can be applied using hand tools. Apply water to dry compost that has a moisture content of 40 percent of lower.

Table 2-15. Compost Application Rates

Thickness (inches)	Coverage/1 yd^3 of Compost (ft^2)	Required Compost Volume to Cover (yd^3)		Compost Weight/Acre* (pounds)
		1 Acre	1,000 Square Feet	
3	108	403	9.0	362,700
2	163	269	6.0	242,100
1½	217	201	4.5	180,900
1	325	134	3.0	120,600
½	648	67	1.5	60,300

* Assumes a bulk density of 900 pounds per yd^3.
Source: Stutz et al., 2003

- A calculation for determining the cubic yards of compost required to cover a specific area is as follows.

  Specific area to cover (square feet) × amount of compost to apply (depth in inches) × 0.0031 = required cubic yards of compost

- Horizontally tack the compost layer, especially on heavier soils, to prevent water from moving between the soil-compost interfaces.
- To prevent rill erosion, apply the compost layer 3 feet over the top of the slope or lattice into existing vegetation.
- Plant vegetation according to the appropriate revegetation protocol. Cultipack broadcast seeded area to assure good seed-soil contact.

2.5 CELLULAR CONFINEMENT SYSTEM (SS-5)

Cellular confinement systems are comprised of semi-rigid, interconnected polyethylene strips that form a honeycomb pattern of geocells that are packed with fill materials. Geocell systems act as semi-rigid slabs that distribute loads laterally, reduce subgrade contact pressures, and minimize load deformation and settlement. Construction specifications are presented below and illustrated in Figure 2-34.

- 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.
- 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.
- Remove unstable subgrade soils and install a geotextile underlayer as required.
- Anchor the cellular confinement system sections at the top of the slope across a 2-4 foot ledge. Expand and stretch the cellular confinement system down the slopes.
- Type of anchors and frequency of anchoring will depend on site conditions. Typically, every other cell across the top section is anchored with J-pins or other suitable anchor devices. This anchoring pattern is repeated every 6 feet down the slope.
- The cells should be anchored securely in order to prevent deformation of the panel while backfilling. Depending on the slope angle and fill soils involved, intermediate anchorage will be necessary on some interior cells in order to limit sideways deformation, ensure stability, and avoid overloading the upper sections. Additional panels are abutted together and joined with staples, hog rings, or other suitable fasteners.
- Place the fill material in the expanded cells with suitable equipment such as a backhoe, front-end loader, or conveyer. Limit drop height to 3 feet.
- Apply surface treatments following the placement of infill.
- 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 damaged and sparse areas immediately (Salix Applied Earthcare, 1999).

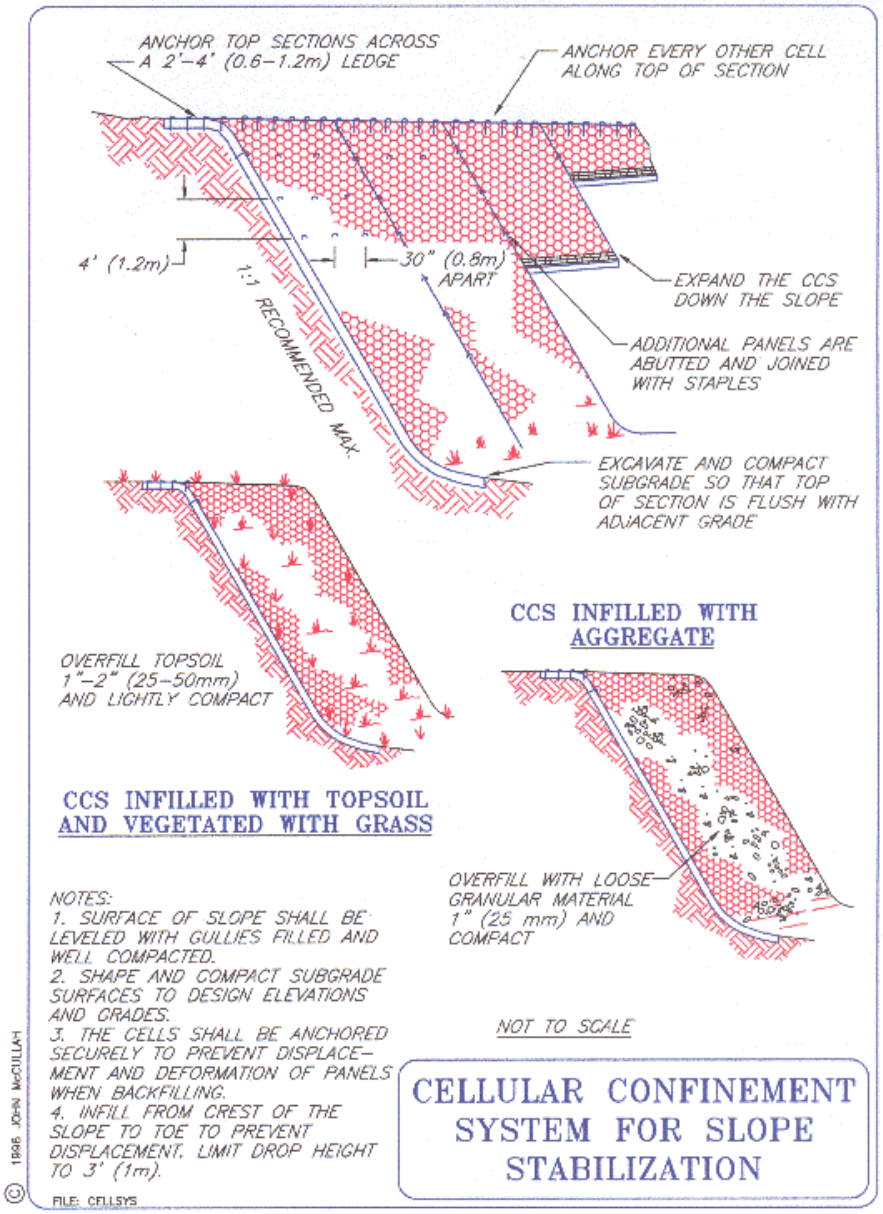


Figure 2-34. Cellular Slope Stabilization Structure (Salix Applied Earthcare)

2.6 STRAW ROLLS (SS-6)

Straw rolls are tubular black netting wrapped rolls of straw approximately 8 inches in diameter by 25 to 30 feet long, which are placed along the contour of constructed or disturbed slopes. The rolls are used as a temporary slope stabilization measure to manage runoff and reduce erosion until permanent vegetation is established. Straw rolls function in a similar manner to the vegetative barrier in that the structure interrupts water flows, captures sediment, seeds, and soil amendments, and promotes plant growth. Construction specifications for straw rolling is discussed below and illustrated in Figure 2-35.

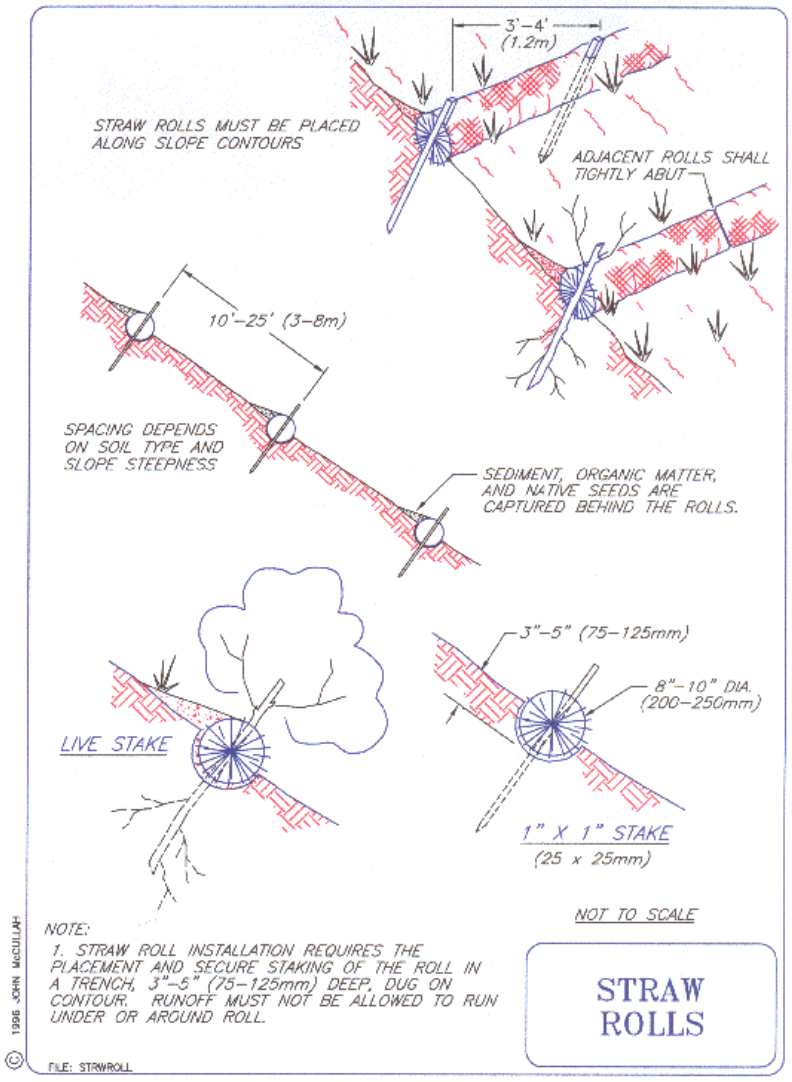


Figure 2-35. Slope Straw Rolls (Salix Applied Earthcare)

- Prepare the slope before the wattling procedure is started. Shallow gullies should be smoothed as work progresses.
- Dig small trenches across the slope on contour to place rolls in. The trench should be deep enough to accommodate half the thickness of the roll. When the soil is loose and uncompacted, the trench should be deep enough to bury the roll 2/3 of its thickness because the ground will settle.
- It is critical that rolls are installed perpendicular to water movement, parallel to the slope contour.
- Start building trenches and install rolls from the bottom of the slope and work up.
- Construct trenches at contour intervals of 3 to 12 feet apart depending on steepness of slope; the steeper the slope, the closer together the trenches.
- Lay the roll along the trenches, fitting it snugly against the soil. Make sure no gaps exist between the soil and the straw wattle.
- Use a straight bar to drive holes through the wattle and into the soil for the willow or wooden stakes.

- Drive the stake through a prepared hole into soil. Leave only 1 or 2 inches of stake exposed above roll.
- Install stakes at least every 4 feet apart through the wattle. Additional stakes may be driven on the downslope side of the trenches on highly erosive or very steep slopes.
- Inspect the straw rolls and the slopes after significant storms. Make sure the rolls are in contact with the soil.
- Repair any rills or gullies promptly. Reseed or replant vegetation if necessary until the slope is stabilized.

2.7 PIPE DROPS (SS-7)

Pipe drops are types of grade stabilization structures used to control roadside drainage runoff in situations where there are abrupt changes in elevations (overfall) between the drain bottom and the stream bottom. These structures capture concentrated runoff and lower water through the pipe to a lower discharge point. Pipe drops prevent the formation and advance of gullies and prevent channel erosion by stabilizing the channel grade and reducing the erosive forces of concentrated water flow. These measures are intended for ephemeral or intermittent channels. The principle types of pipe drops are straight pipe drops and drop inlet (weir) pipe drops of metal, concrete, or plastic. The size and type of structure used is dependent on several factors, including soil type, land use, amount of overfall, amount of water to pass through the structure, and other considerations. The design and installation of grade stabilization structures requires hydrologic engineering design and skilled backhoe operators. General pipe drop installation guidelines are illustrated in Figures 2-36 and 2-37 and discussed in the following section.

- The installation of straight and drop inlet pipe drops shall be in accordance with the manufacturer's recommendations and the design specifications of the project plan.
- Set enough well marked wooden stakes to guide the contractor during installation.
- All corrugated metal pipe shall be laid with the outside circumferential joints pointing upstream and with the longitudinal laps at the sides at about the vertical midheight of the pipe. Use cathodic protection for corrugated metal pipes as needed.
- The pipe, fittings, and appurtenances will be transported and handled in such a manner as to prevent bruising, scaling, or breaking of the galvanized or bituminous coating. After the pipe and fittings have been completely installed and while still exposed, any damage areas where the bituminous coating has been broken sufficiently to expose the base metal shall be remedied by recoating with a material similar and equal to the original coating.
- The pipe trench shall be constructed to the lines and grades as shown on the plans and as staked in the field. The side slopes of the trench will be 1:1 or flatter depending upon soil condition, depth of cut, and method of installation.
- The bottom of the trench or excavation shall be molded to fit the outer circumference of the pipe in such a manner that the depth of the molded bed shall be a minimum of one-fifth the outside diameter of the pipe below the level of the original bottom of the trench. The pipe shall be bedded on approximately 1.5 inches of moist, loose, well-pulverized soil material for the entire length of the molded bed. The trench bottom shall be free of sod, stumps, roots, and rocks.

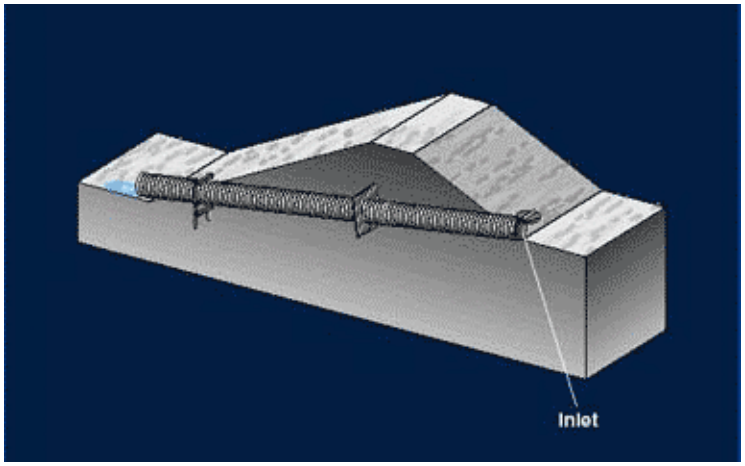


Figure 2-36. Straight Pipe Drop Grade Stabilization Structure
(Source: http:/www.thisland.uiuc.edu/60ways/60ways_19.html)

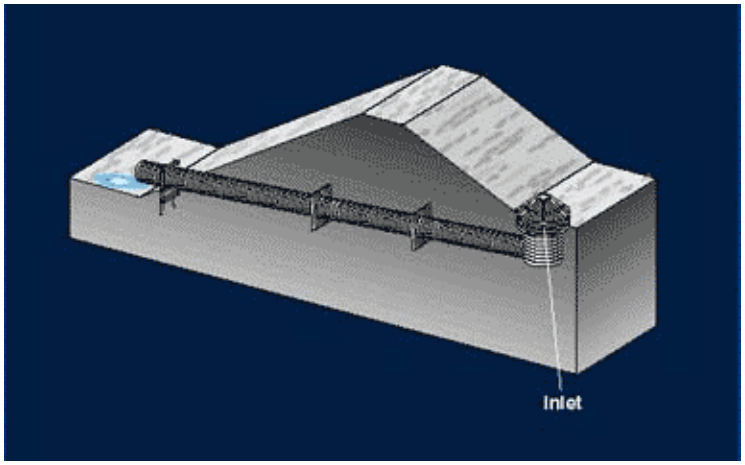


Figure 2-37. Drop Inlet Pipe Drop Grade Stabilization Structure
(Source: http:/www.thisland.uiuc.edu/60ways/60ways_19.html)

- Material for backfilling shall be similar to the soil material of the trench bottom and free of sod, roots, lumps or clods, and rocks larger than three inches in diameter. Backfill under the haunches and around the pipe shall be accomplished by placing and thoroughly tamping layers a maximum of six inches thick on alternate sides so as to keep the same elevation on both sides of the pipe at all times. Tamping is performed with hand tools or mechanical equipment. Care is taken to ensure that the pipe is not displaced during backfilling operations. Equipment or heavy loads will not be allowed to pass over the pipe until enough fill has been placed and tamped above the top of the pipe to prevent damage.
- Antivortex baffles are used if the minimum depth of flow over the lip of the drop inlet pipe riser is expected to exceed one-half the diameter of the riser pipe.
- A trash guard shall be used over the riser of a pipe drop inlet as needed to prevent pipe clogging. Trash guard openings are not to be more than one-half the diameter of the barrel. Where a trash guard is not used, a guardrail should be installed around the top of the riser. A minimum guard would consist of a single rail approximately 30 inches above the rest of the riser and not less than 3 feet from the edge of the riser at any point.

- The earthfill embankment and emergency spillway shall be constructed to the elevations, slopes, and dimensions shown on the plans or staked in the field.
- Where structures without detention storage discharge onto noncohesive soils, pipe outlets may require protection to prevent undermining of the structure. Information concerning discharge energy dissipators is presented in Section 3.2.7.
- Following construction, make a profile and cross-section survey construction check of the installed structure. Check all elevations, distances, and slopes to assure that plans and specifications have been met.
- All disturbed areas shall be planted to an applicable revegetation protocol as instructed in Section 2.3, Revegetation (SS-3).

2.8 ROAD REINFORCEMENT (SS-8)

It is also important to stabilize the soil materials that comprise the road prism. In many cases, the erosion of road prism soils is the primary contributor to stream sedimentation. The road reinforcement practices discussed in this section include:

- *Road Aggregate Surfacing* (SS-8A) – Imported aggregate materials are placed over a natural soil subgrade.
- *Road Chemical Reinforcement* (SS-8B) – Chemical products are incorporated into the unpaved road surface, binding soil particles and creating a stable interlocking matrix.
- *Bituminous Surface Treatment* (SS-8C) – Chip sealing is the application of asphalt followed immediately by an aggregate cover.
- *Road Asphalt Paving* (SS-8D) – A surface course of mineral aggregate coated and cemented together with asphalt cement are placed on supported courses such as aggregate bases.
- *Road Geotextile Reinforcement* (SS-8E) – Synthetic materials are placed between aggregate surfacing materials and soil subgrades to prevent intermixing and increase road stability.

2.8.1 Road Aggregate Surfacing (SS-8A)

Unpaved road surfacing materials include clay, gravel, and crushed rock. Of these, gravel and crushed rock aggregate provide the best road surface with regard to trafficking and erosion control. The optimum condition for encouraging surface material cohesion and durability is to construct road surfaces with a mixture of sand, clay, and gravel or crushed rock aggregates. An aggregate surfaced road is an unpaved road that is primarily surfaced with materials derived from stone such as gravel or crushed rocks. Aggregate surfacing of unpaved roads constructed of native or clay pit soils greatly increases the stability, traffic support capability, and resistance of roads to erosion. An aggregate road is constructed in three layers (Figure 2-38):

- *Surface Course* – A uniformly graded gravel or crushed stone layer 8 inches thick that is placed on top of the aggregate base.
- *Base Course* – An 18 to 24 inch thick layer comprised to free draining easily compacted gravel and crushed stone and low amount of fines (clay and silt) that produces a strong, stable matrix.

- *Subgrade* – The bottom layer roadbed made up of the native soil materials found along the road or fill brought in to fill depressions.

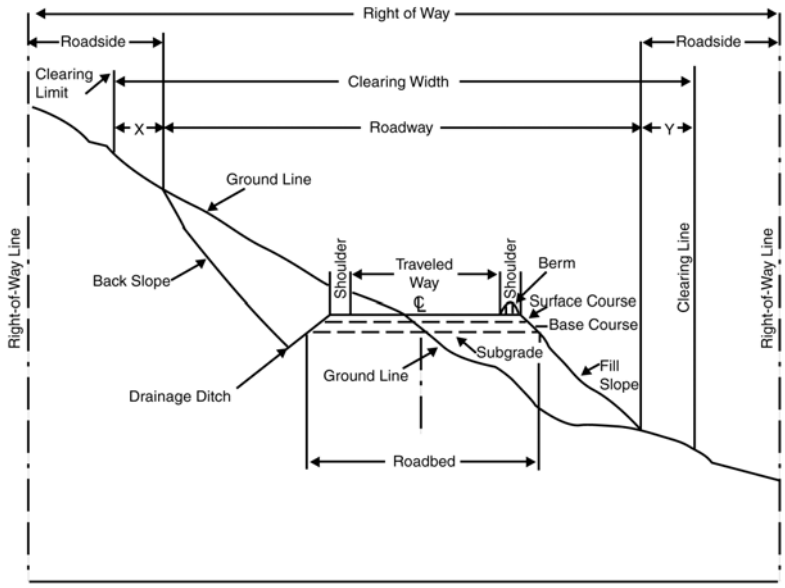


Figure 2-38. Roadway Components

The absence of the aggregate base layer can compromise the function, durability, and life span of an aggregate road. Using 1-inch crusher-run gravel or 3 inches of clean gravel can reduce erosion to less than one-half that of using 3-inch crusher-run gravel and to 12 percent that of an ungraveled road. In practice, many aggregate roads only have subgrade and surface layers.

A calculation used to estimate the amount of material needed to apply an 8 inch layer of aggregate compacted to 6 inches is as follows.

Aggregate Needed = Road Width (ft.) X Road Length X 0.042

Road aggregate application guidelines include:

- Complete all road surface preparation before delivery and placement of aggregate materials. Prepare all road drainage features (cross drains, grade breaks, rolling dips, etc.) and establish the road contour profile (Section 3.1).
- Establish proper drainage in the existing base. Establish a road slope by creating a 1/2 to 3/4 inch fall per foot. Shape slopes to gradually transition into slope adjustments without noticeable breaks.
- Apply base and subbase materials that are free of excess moisture, muck, lumps, roots, sod, and other deleterious material. Remove all rock fragments greater than 100 millimeters in the longest dimension. Mixtures of sand, clay, and aggregate increase overall material cohesion.
- Ensure that the subgrade is visibly moist during shaping and dressing. Bring low sections, holes, cracks, or depressions to grade with suitable material. Compact the subgrade and finish the roadbed using a vibratory steel-wheel roller or a rubber tired traffic roller.
- The surface layer aggregate is to be applied by a paver over the aggregate base at a minimum uncompacted uniform depth of 8 inches. The paver is used so that graders will not

be required before compaction. Keep the paver at or near capacity during aggregate application.

- To bind aggregate with the road base, scarify smooth surfaces such as oil and chip or smooth tight aggregate. Following application of the base and/or surface, coarse compact the roadbed using a vibratory steel-wheel roller or a rubber tired traffic roller. Roll the roadbed a minimum of five full-width passes or until visual displacement ceases (USDA, 1996).
- Use a static roller with a minimum weight of 10 tons. Vibratory steel-wheel rollers shall have a minimum striking force of 20,000 pounds. Pneumatic tire rollers shall have smooth tread tires of equal size that will provide uniform compacting pressure for the full width of the roller and capable of exerting ground pressure of at least 550 kilo pascals (kPA). The compactor shall be equipped with amplitude and frequency controls, and specifically designed to compact the material on which it is used.
- At the ends of cuts and at intersections of cuts and embankments, adjust slopes in the horizontal and vertical planes to blend into each other or into the natural ground.
- Finish the road surface to be reasonably smooth, uniform, and shaped to conform to the design surface shape.

2.8.2 Road Chemical Reinforcement (SS-8B)

Road chemical reinforcement is the use of soil stabilizers to increase the resistance of unpaved roads to traffic and water induced erosion by chemically binding particles into a cohesive matrix. The loose sandy fill materials that comprise many SC road approaches are readily susceptible to downhill movement by flowing water following storms. Soil stabilizers present an opportunity under some circumstances to stabilize loose, erodible road prism fill. One of the limiting factors to the use of soil stabilizers on some road approaches in northwest Florida is the high percentage of sand and low percentage of clay that constitute many road surfaces. There are numerous companies that offer soil stabilizer for use on unpaved roads. Internet sites that offer a listing of companies that offer road soil stabilizers include:

- http://www.betterroads.com/linkspages/linksmfrs.htm
- http://www.directory.net/Business/Construction_and_Maintenance/Materials_and_Supplies/Site_Construction/Soil_Stabilization/
- http://directory.google.com/Top/Business/Construction_and_Maintenance/Materials_and_Supplies/Site_Construction/Soil_Stabilization/
- http://dir.yahoo.com/Business_and_Economy/Business_to_Business/Environment/Natural_Resource_Management/Erosion_Control/Soil_Stabilization_and_Dust_Control/

2.8.3 Bituminous Surface Treatment (SS-8C)

Bituminous surface treatment (BST) or chip sealing is a type of road paving that stabilizes a soil or aggregate base course by spraying one or more applications of liquid asphalt followed immediately with an aggregate layer surface course. BST provides a skid resistant surface during wet conditions and seals the surface from water penetration. Generally, BSTs are performed on relatively low volume roads; however, with the development of improved materials and technologies, BSTs on high volume roads are becoming more feasible. Types of BST for unpaved roads include:

- *Bituminous Surface Treated Soil* – Surface course application of a BST mat one inch or less thick to a soil or sand-clay road base course.

- *Bituminous Surface Treated Aggregate* – Surface course application of a BST mat one inch or less thick to an aggregate road base course.
- *Mixed Bituminous Non-Rigid Base* – A mixed BST road where the base course is not concrete, brick, or block and the combined compacted thickness of the surface and base course is less than 7 inches. The design is such that a road is constructed with a low or non-uniform load-bearing capacity.

Generally the cost of BST is 15 to 20 percent less than the cost of other road pavements. It also provides a lower cost option when compared to a hot mix overlay for comparable uses. The general steps in the BST process are discussed below and illustrated in Figure 2-39:

1. A binder is applied at a rate of 0.4 gallons per square yard to the road using a spray truck. Types of binders include emulsified asphalt or other material, emulsified polymer asphalt, latex modified emulsified asphalt, rejuvenating oil modified asphalt emulsions, or hot applied binders with asphalt rubber or polymers.
2. Immediately after spraying, a layer of crushed road or gravel is applied by a spreader. Different aggregate sizes give different surface textures and are used for different traffic conditions. Generally sizes range from sand to 25 mm.
3. The aggregate is compacted and embedded into the asphalt by rubber-lined rollers.

2.8.4 Road Asphalt Paving (SS-8D)

Asphalt pavements are used on roads with high traffic volume or on relatively steep road-stream crossing road approaches sensitive to erosion. Routine maintenance of asphalt pavement requires crack sealing and application of a seal coat on a regular basis; seal coat life expectancies range between 1 and 8 years depending on the seal coat chosen. Asphalt paving is based on applicable engineering designs and standards.

The asphalt surface may be inverted along the centerline of the road approach to limit roadside erosion potentials (Figure 2-40). In this configuration, rainwater flows down the center of the road and is discharged into the stream at the crossing structure. Typically the crossing structure road surface is also paved and may include a discharge flue (Figure 2-41).

However, if the entire section of the road approach slope from the crossing structure to the upper slope crest is not paved, extensive sediment generation and delivery may occur. In situations where the road asphalt does not extent over the upper crest of the road approach slope, sediment generated by the unpaved portion of the road erodes onto the inverted asphalt surface and is delivered directly into the stream. Disastrous effects can also occur if the road asphalt does not extend the entire length of the lower approach slope. In the example shown in Figure 2-42, significant amounts of soil are being eroded from the site by the high velocity runoff coming off the upper slope paved road section and are being delivered directly into a receiving waterway.

Spraying the asphalt and water mix

Spreading aggregate chips over the emulsion

Refilling the chip spreader with aggregates

Compacting the new surface

Figure 2-39. Bituminous Surface Treatment Process
(http://www.ci.anchorage.ak.us/streets/chipsealprogram.cfm**)**

Figure 2-40. Asphalt Paved Stream Crossing Road Approach with an Inverted Centerline (Michael L. Rainer)

Figure 2-41. Stream Crossing Road Approach Runoff Discharge Flue
(Photo by Mike Rainer)

Figure 2-42. Intersection of a Road-Stream Crossing Road Approach, Asphalt Paved Upper Section and Unpaved Lower Section (Photo by Mike Rainer)

2.8.5 Road Geotextile Reinforcement (SS-8E)

Geotextiles are synthetic, permeable textile materials woven into a stable network that are used with soil, rock, or other geotechnical engineering related materials. Geotextiles are used under some conditions to increase the stability and lifespan of roads. The separation and reinforcement functions of geotextiles generally increase the load-bearing capacity, stability, and lifespan of road surfaces. A primary purpose of incorporating geotextiles into the roadbed is to prevent the intermixing of road

aggregate layers with subgrade soils. Without a separation matrix, the load pressures from vehicle traffic eventually cause the road aggregate base course layer to mix with underlying subgrade soils. This contamination of the road aggregate base reduces its design thickness and load bearing capacity. As a result, the road tends to physically degrade, which may increase road maintenance requirements and reduce the overall lifespan of the road. The geotextile reinforces the road by supporting tensile forces (Figure 2-43).

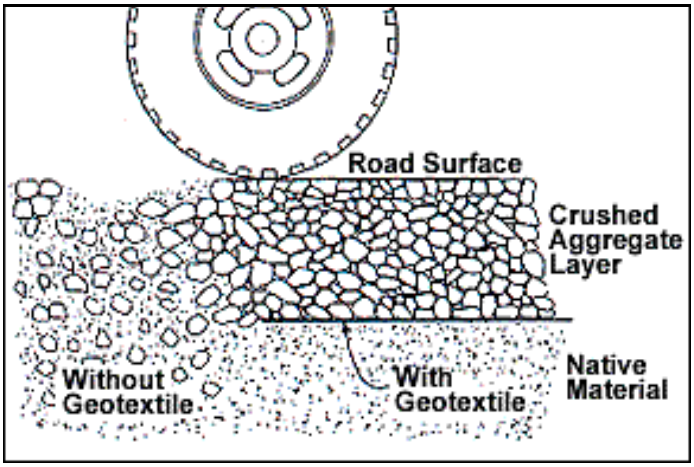


Figure 2-43. Road Geotextile Separating the Base Course from the Subgrade
(http://egweb.mines.edu/studentproject/sandhills/road_surfacing.htm)

3. RUNOFF MANAGEMENT PRACTICES

This section describes practices used to manage the behaviors of SC surface runoff. Emphasis is placed on designating practices applicable to road prism and roadside area conditions.

3.1 ROAD PRISM DRAINAGE (RM-1)

Road prism drainage concerns the use of practices within the traffic portions of the roadway to control runoff before it leaves the roadway and discharges into roadside areas. The practices discussed in this section include:

- Road Contouring (RM-1A)
- Road Deflector (RM-1B)
- Grade Breaks (RM-1C)
- Rolling Dip (RM-1D)

3.1.1 Road Contouring (RM-1A)

Road prism contouring is the raising and reshaping of the road template to a configuration that facilitates the movement of runoff into established roadside drainage systems and provide a cohesive road surface that will resist erosion and safely support trafficking requirements. To accommodate water removal, vehicular safety, and maintenance requirements, the roadway surface must uniformly slope toward one edge or have a center section that is higher than either edge. The three surface contours include insloped, outsloped, and crowned. Insloped roads drain water towards the backslope; because of the erosion issues associated with this road surface, its use on unpaved road approaches is not recommended. Road prism contouring practices presented in the following discussion include road outsloping and road crowning.

3.1.1.1 Road Outsloping

The types of road surface contouring discussed in this subsection include outsloping and crowning. Outsloped roads are used to avoid concentrating water flows by draining water toward the downhill or shoulder fill where it is dispersed over and adsorbed into the receiving slope area below the road (Figure 3-1).

The effectiveness of an outsloped road is based on its capacity to disperse runoff as sheet flow over vegetated slopes and into a natural outlet and avoid the concentration of runoff. Typically, a drainage ditch is not included in this design; however, rolling dips and grade breaks are commonly used as primary drainage features. It is particularly useful on relatively flat road grades. Outsloping may cause erosion if the fill slope is not protected from runoff. Outslopes on road curves are also prone to concentrate runoff, which increases fill slope erosion potential. Outsloping is most effectively used under the following conditions.

- Road would require frequent cross drains.
- Road is on less steep or relatively level road grades and has short backslopes.
- Road has seasonal road use and light traffic.

- Where road insloping could cause excessive erosion of the toe of an unstable back slope.
- On closed or obliterated roads to redevelop dispersed hillside drainage.

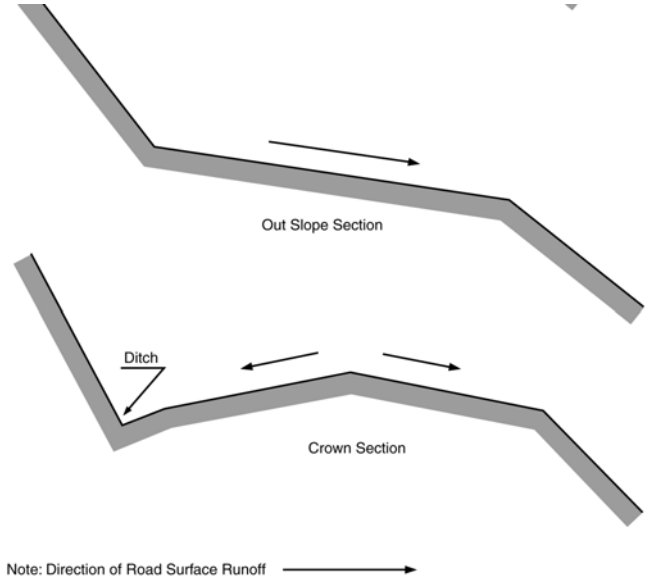


Figure 3-1. Outsloped and Crowned Road Configurations

3.1.1.2 Road Crowning

Crowned roads have a high point in the center of the roadway (Figure 3-1). Drainage ditches or natural drainways at the roadsides are used to manage road runoff. The crowned surface shape may be used on flat ground as well on steep grades greater than 7 percent. The primary attribute of the crown is the splitting of stormwater runoff, which reduces erosion potentials compared to other surface shapes. The volume of water per unit length of road flowing over fill slopes and in ditches is less than for outsloped roads. Crowing may be used on single as well as double lane roads. On single lane roads, half of the travelway runoff is drained to the backslope. Back slope failures may divert accumulated ditch water to the outsloped side of the travelway as concentrated flow, which could cause considerable damage to fill slopes and receiving drainage outlets. The crown is most effective when used for double lane roads and single lane roads with steep grades and planned road cross drains.

3.1.2 Road Deflector (RM-1B)

A deflector is a strip of rubber embedded in the roadbed that intercepts and diverts water off the road surface (Figure 3-2). Deflectors provide a low cost alternative to an open-top culvert for moving water off the road surface. Deflectors are used on low volume, low maintenance, unpaved roads in combination with other runoff control measures to expedite the removal of water from the road surface. Their use is limited to low water flows. The deflector is a piece of rubber belting 5/16 inch to 1/2 inch thick fastened between treated timbers. The only part of the deflector showing is the 3 inches of rubber belting (Figure 3-3).

Figure 3-2. Deflector Installed on an Unpaved Road

Because there is no abrupt grade change, deflectors can be used on grades over 10 percent. Once established, the deflectors stay in place and they do not impede traffic. They can also be used on roads where vehicle traffic may have difficulty negotiating broad-based dips. However, this type of road cross drain has a low capacity and durability and limited life.

Figure 3-3. Road Surface Deflector Installation

3.1.3 Grade Breaks (RM-1C)

A grade break is a small intentional increase in road elevation on a downhill slope that causes water to flow off the road surface to road drainage features or natural drainage areas (Figure 3-4). The purpose of grade breaks is to prevent road material erosion caused by increased water volumes and velocities on the road prism. Grade breaks are highly effective, inexpensive to build, are easily constructed with normal road maintenance machinery, and tend to reduce traffic speeds.

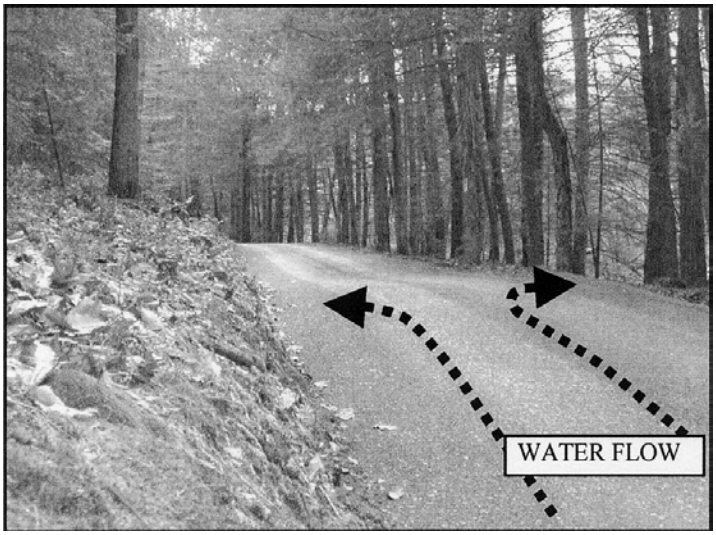


Figure 3-4. Slope Grade Break
(Center for Dirt and Gravel Road Studies)

Grade breaks are used on sloping sections of unpaved roads that exhibit water velocity damage to the road surface. They can be effectively used to divert water before it reaches road-stream crossings. On long sloped roads, multiple grade breaks can be used in succession to remove water from the road and prevent buildup of erosive water volume and velocity. On steeper slopes, grade breaks are constructed closer together because of the more rapid buildup of runoff. The recommended distance between grade breaks is presented in Table 3-1.

Table 3-1. Recommended Distance Between Grade Breaks

Road Grade (percent)	Distance (feet)
2	250
5	135
10	80
15	60
20	45
25	40
30	35

Source: Kochenderfer, 1970

General grade break installation specifications include:

- Construct the grade break to the design height at a 30 to 45 degree angle from the centerline of the road with a minimum positive grade of 2 percent.
- Grade breaks should have a stable natural or constructed outlet that is protected as necessary from erosion.

3.1.4 Rolling Dip (RM-1D)

Rolling or broad-based dips are gently sloping excavations running diagonally across the road surface. A rolling dip is similar to a grade break except it conveys water from the uphill road ditch and road surface. Rolling dips are more difficult to construct than a grade break, but are much easier to traverse and require less maintenance. Frequent rolling dips are often preferable, both economically and hydrologically, to road cross drain culverts. Dips in roads that support high traffic or heavy

vehicles should have a minimum freeboard (hydraulic depth) of 1 foot. Depths less than this will render the dip ineffective because ruts will cut through the top of the dip. Dip geometry could also twist or rack vehicle frames if the orientation is not 90 degrees.

Dip orientation (skewed or perpendicular to the road centerline) depends on the type of traffic expected, length of the dip, and road grade. It dips are shorter and the traffic will include large trucks with longer frames, then the dips should be oriented perpendicular to the direction of traffic. Dips skewed from perpendicular to centerline more effectively drain steep road grades, are more comfortable for vehicle occupants, and will not cause severe twisting of truck frames. Dips are not recommended for grades over 10 percent because of the steepness of the dip approach grade that would be required. The recommended distance between dips is presented in Table 3-2.

Table 3-2. Recommended Distance Between Dips

Road Grade (percent)	**Distance** (feet)
2 – 4	**300 – 200**
5 – 7	**180 – 160**
8 - 10	**150 – 140**

Source: Kochenderfer, 1970

General installation guidelines are shown in Figure 3-5 and discussed below.

- For rolling dips, the height from channel bottom to the top of the settled ridge should be 18 inches and the side slopes of the ridge should be 2:1 or flatter.
- For drivable dips, the minimum freeboard should be 0.5 feet with a rollout length of at least 20 feet. The dip can be armored with crushed rock or gravel. Adding geotextile material to dips can substantially improve the stability and drainage characteristics.

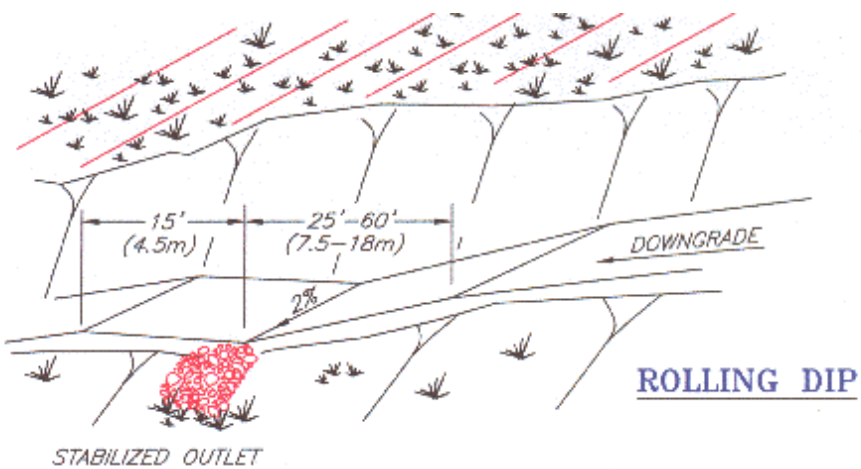


Figure 3-5. Rolling Dip (Salix Applied Earthcare)

3.2 ROADSIDE DRAINAGE (RM-2)

Just as runoff is moved off the road prism in an expedient yet non-erosive manner, roadside areas must also be treated to minimize runoff induced soil erosion. Roadside runoff management practices discussed in this section include:

- Natural Drainways (RM-2A)
- Drainage Ditches (RM-2B)
- Soft Armor Waterway (RM-2C)
- Grass Hedges (RM-2D)
- Road Cross Drains (RM-2E)
- Turnouts (RM-2F)
- Riprap Energy Dissipator (RM-2G)
- Temporary Slope Drain (RM-2H)
- Seepage Drain (RM-2I)

3.2.1 Natural Drainways (RM-2A)

The best type of road drainage system is the movement of stormwater off the road and directly into vegetated roadside areas natural drainways. Drainways are used to promote the sheet flow dispersion of water into areas of standing grasses, forbs, shrubs, and trees and over ground litter layers that subsequently act as effective infiltration sinks and filtering buffers. These areas are intended to be featureless in that the flow of water is allowed to move unencumbered off the road and into the natural, undisturbed drainage system of the adjourning lands. The high infiltration rates of sandy soils that typify many areas in Northwest Florida and the soil binding and water transpiration rates of native woody and herbaceous vegetation make the use of natural drainways a preferred system of water disposal.

This type of drainage system avoids the construction and maintenance of ditches and other costly drainage features that further concentrate water flows. Generally if the construction of drainage ditches can be avoided, it is advantageous from an economic and environmental perspective to do so. Guidelines for the use of natural drainways are presented below.

- Candidates for natural drainways are generally limited to relatively flat to gently sloping road segments that are slightly above the grade of adjoining natural ground. Investigating and understanding of hydrologic character of the natural terrain is crucial to determining the suitability of natural drainway systems to the area.
- Roadside runoff is not allowed to drain directly into stream steephead features or over slopes with limited vegetative cover. Water flow over a steephead could result in the erosion and instability of these environmentally sensitive features. If runoff is directed over slopes with limited vegetative cover, the impacted area is to be planted to native species that will increase the buffering capacity of the slope and avoid erosion.
- Natural drainway areas are not to be used as road sediment traps.
- Generally native land drainways should not be used as primary water disposal on moderate to steeply sloped road segments that intersect streams.
- If rills or gullies begin to form within the drainway area, the runoff is to be channelized into a roadside ditch and transported to an appropriate discharge site.
- It is important to regularly survey these areas to ensure that damage is not occurring.
- The accumulation of sediment in the drainway is an indication that erosion and runoff management are ineffective in controlling sediment generation and require immediate attention.

3.2.2 Drainage Ditches (RM-2B)

In areas that are not amenable to the use of natural drainways, the construction and maintenance of water conveyance or ditch systems is required. A road ditch is an excavated channel that intercepts and collects non-stream flow water that runs off sloped road surface, as well as runoff contributions from the adjacent watershed.

As important as it is to get water off the road as quickly and nonerosively as possible, it is equally important to make provisions for the transport and disposal of runoff. The purpose of a roadside ditch is twofold: 1) prevent water ponding alongside of the road by moving runoff water to a designated discharge point, and 2) remove suspended sediments from the channelized runoff to the degree possible. Under certain conditions, ponded water can create a saturated road subgrade that results in severe road rutting, siltation, and/or movement of the road prism. It is therefore mandatory that the ditch is constructed with a carrying capacity adequate for the intended water flows and the channel surface is stabilized to function as a potential sediment sink and not a sediment source.

One of the most important concepts to the use of these types of drainage systems is to construct the ditch as far away from the edge of the roadway as the available right-of-way allows. The reason for this is threefold.

1. Water should be drained away from the surface, base, and subgrade layers of the road prism. The further a ditch is away from the road, the less chance of road prism degradation from extended wetness.
2. The proper functioning of ditches is partly dependent on keeping them free of sediment and debris. A vegetated buffer between the road and the ditch allows for the filtering of materials in the runoff before they enter the ditch.
3. Increasing the distance between the traveled roadway and the ditch reduces the potential for vehicles to drop into drainage features, which prevents damage to the ditch and maintenance requirements and increases traffic safety.

The proper function of a ditch is based on the application of good hydraulic channel design and installation of in-channel erosion and runoff control features. In the following section, general design considerations with regard to ditch configuration and length are discussed.

3.2.2.1 Ditch Configuration

Ditch configuration design – profile and cross-section – is critical to ensuring the control of channel water flows. The size or area of a ditch is determined by considering the ditch gradient, area intercepted, estimated intensity and volume of runoff, and the amount of sediment that may be deposited in the ditch during low flow conditions. The primary components of ditch configuration are gradient and path. Ditch configuration guidelines are presented below.

- Generally, ditches should be kept at the same grade as the road. For ditches that are adjacent to the roadway, the ditch full flow water surface should be at least one foot below the roadway subgrade. This prevents ditch water from saturating subgrade materials.
- On side hill roads, ditches should be installed on the uphill sides of roads to intercept seepage and runoff.

- Generally ditches should be constructed in a parabolic shape, have side slopes flatter than 2:1, and depths between 1 and 2.5 feet. The exact configuration of the ditch will vary with design. The preferred equipment for ditch construction is a rubber-tired excavator with an articulated bucket.
- At a minimum, all ditches will be lined with vegetation.
- Design the ditch to have a minimum gradient of 2 percent to restrict water ponding. Gradients less than 2 percent may need to be employed; however, routine inspection and maintenance requirements may also increase.
- For non-cohesive soils, ditch designs with gradients greater than 2 percent applied in consideration of ditch length should be just steep enough to keep water moving to relief structures without carrying excessive sediments.
- For non-cohesive soils, ditch gradients of 8 percent or greater generally increase the risk of ditch erosion and sediment transport. In these cases, shorter ditch length and channel soft armor and in-channel grass hedges may be required.
- If water must be carried further than desired, such as might occur in areas where a proper discharge point is not available, the increased use of additional water control features such as channel soft armor and in-channel grass hedges may be required.

3.2.2.2 Ditch Length

The distance water is to be carried before discharge is dependent on the water volume and velocity, soil type, slope aspect and gradient, vegetation, rainfall intensity and duration, and downslope conditions. With so many variables potentially influencing ditch length, site-specific prescriptions are typically required. The ditch length is effectively determined by the location of ditch relief structures such as cross drains or turnouts that fully or partly terminate ditch flow and define the effective length of the ditch segment.

In general, sloped road segments that intersect stream valleys should have shorter ditch lengths than road segments on gently sloping uplands or bottomlands. The road segments that intersect stream watershed drains tend to have steeper gradients and increased potential for ditch erosion and stream sedimentation. On these road segments, mid- and upper-slope ditch relief to reduce water volume and velocity is critical. All ditches are to be periodically inspected and cleaned if obstructed by debris or sediment. Regrade ditches only when necessary. General ditch length guidelines are discussed below.

- Locate a runoff control structure at the top of a steep gradient in order to disperse channelized water before the downgrade has the opportunity to increase the erosive energy of water volume and velocity.
- Locate a structure at the downgrade side of zones that experience localized overland flow with no defined channel(s). Otherwise, water flow will carry on to the next ditch segment, increasing the erosive energy of ditch flow.
- Based on estimated runoff volumes and velocities and design characteristics of the channel (lined or not lined), locate a structure at candidate ditch points where accelerated erosion is probable.

Locate ditch relief structures at low points in the road profile that are prone to pond water. Ponded water will work to create its own outlet at the point of least resistance, which in most instances results in the formation of a gully.

3.2.3 Soft Armor Waterway (RM-2C)

A soft armor waterway is a water conveyance channel that is lined with vegetation alone or combined with turf reinforcement to provide protection against erosion while increasing permissible channel water velocities. Conversely a hard armor channel would be lined with a material such as concrete or rock riprap (Section 5.3). Turf reinforcement is a method by which the natural ability of plants to prevent soil erosion is enhanced through the use of geosynthetic materials.

Soft armor waterways are used on roadsides and other areas where a vegetative lining can provide sufficient stability for the channel grade by increasing maximum permissible velocity, slopes are generally less than 5 percent, and required site conditions (climate, soils, and topography) for establishing vegetation are present. The implementation of the soft armor waterway practice requires design surveys, as-built surveys, precision grading, and detailed engineering designs.

Vegetative lining is normally not allowed within channels where expected velocities exceed 8 feet per second or shear stress is greater than 3.7 pounds per square foot. However, geosynthetic mattings have a proven ability to increase the erosion resistance of natural vegetation within channels subjected to high velocities and soil shear stress. Fully vegetated geosynthetic mattings may withstand short (0.5 hours) flow velocities of 20 feet (6 meters) per second and flow rates in excess of 13 feet (4 meters) per second for durations of up to two days (Theisen and Agnew, 1993).

3.2.3.1 Geosynthetic Turf Reinforcement Mats (GTRMs)

There are two general categories of GTRMs: temporary degradable and long-term nondegradable. Temporary degradable materials prevent erosion until permanent vegetative cover is established. These products are employed in situations where vegetation alone is sufficient to protect the site. Hydraulic mulch geofibers, erosion control netting, open-weave meshes, erosion control blankets, and fiber roving systems are the most common types of temporary degradable GTRMs.

Long-term nondegradable GTRMs furnish erosion protection and extend the erosion control limits of vegetation. Overall, these materials are more expensive, but they are stronger and perform better and longer than temporary, degradable products. Typically, these materials are manufactured of durable polymer materials. Common long-term nondegradable GTRMs include Turf Reinforcement Mats (TRMs), Erosion Control Revegetation Mats (ECRMs), and Permanent Erosion and Reinforcement Mats (PERMS).

TRMs are mechanically or melt-bonded polymer netting, monofilaments, or high strength fiber mats that rely on the entanglement of plant roots and shoots for permanent anchoring to the soil. Polymers include polypropylene, polyethylene, nylon, and polyvinyl chloride. TMRs are not designed to replace hard armor at sites with constant water flow that do not support vegetation. TRMs are installed on a prepared seedbed, then overtopped with seed and soil. The soil filling provides for proper soil-seed contact, eliminates voids, accelerates germination and growth, and allows roots to grow in and around the mat matrix.

ECRMs and PERMs are constructed similar to TRMs but are thinner and lighter. These mats are UV-stabilized and provide at least a 65 percent ground cover, shading, and sufficient mat voids to enhance vegetation establishment. Unlike TRMs, these mats are installed over a seeded site, which makes them more effective in trapping sediment during the establishment of vegetation. This could prove important where labor, equipment, or access constraints rule out the use of soil filled TRMs.

3.2.3.2 Design Considerations

Soft armor channels resemble natural systems and are usually preferred where design velocities are suitable. To reduce erosion potential, design the channel to avoid sharp bends and steep grades. In-channel grass hedges at discharge points may be required for waterways on steeper slopes.

The success of a soft armor channel is dependent on the application of erosion runoff control measures in the upstream watershed. The management of water flows in the watershed reduces the peak rates of runoff and the volume of water to be carried by the channel. Typically, degradable erosion control blankets would be used on flatter slope gradients in the upper reaches of the channel that experience low flow velocities, and nondegradable geosynthetic products are used in high flow velocity channel segments.

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.

Perhaps the most critical parameter in an engineering design is flow resistance before, during, and after vegetative establishment. Long-term flow resistance takes into account the potential for some erosion control measures to be washed away before vegetation becomes established and the potential for other measures to lose their flow resistance as they degrade over time.

Design procedures are based on the principles of open-channel hydraulics, permissible tractive force (shear stress), and the application of the Manning equation of flow velocity. Williams and Austin (1995) suggested that tractive force is the most important parameter for stable channel design. However, in situations of high flow velocities and low flow depths, flow velocity is the more important consideration.

These principles are used to design and evaluate the capacity of channels to perform within accepted limits of stability. Channels are presumed stable if the adopted velocity is lower than the maximum permissible velocity. With a given depth of flow (D), the mean velocity is calculated using Manning's equation:

$$V = \frac{1.486\, R^{2/3} S^{1/2}}{n}$$

Where
V = average velocity in the cross section
R = hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P
S = friction slope of the channel, approximated by the average bedslope for uniform flow conditions
n = Manning's roughness coefficient

The tractive force or shear stress is calculated as:

$$t = \Upsilon DS$$

Where
t = tractive force
Υ = unit weight of water
D = maximum depth of flow
S = average bed slope or energy slope

Design criteria based on flow velocity may be limited because maximum velocities vary widely with channel length, shape, and roughness coefficients. It is important to understand that it is the force developed by the flow and not the flow velocity that challenges the performance of erosion control practices (Theisen and Agnew, 1993).

Cross Section Designs

Soft armor channel side slopes generally are constructed 3:1 or flatter to aid in the establishment of vegetation and for maintenance and are generally restricted to slopes of 5 percent or less. Either a uniform or gradually increasing grade is preferred to avoid sedimentation. Design capacity should be sufficient to convey a 10-year frequency 24-hour duration storm event.

An established grass-lined channel resembles natural drainage systems and is usually preferred if design velocities are below 5 feet per second. Cross-section designs include triangular, parabolic, and trapezoidal channels. Triangular channels are generally used for relatively small water flows. Triangular channels are not recommended because of the risk of scour at the lowest points.

Do not construct U-shaped ditches with steep side banks. These types of ditches have up to 30 percent less drainage capacity than other ditch types and are prone to bank collapse. The steep sides increase maintenance and channel sediment production potentials. Parabolic grass channels are often used where larger flows are expected and sufficient space is available. Combinations of grass and temporary erosion control blanket or permanent turf reinforcement mats may be required where high velocities are expected and where some dissipation of energy (velocity) is desired.

Trapezoidal channels are used where runoff volumes are large and slope is low so that velocities are non-erosive to vegetated linings. Since channels that are excavated as trapezoidal tend to become parabolic in time, the parabolic channel design is recommended for most applications. Lined channel cross-section designs are presented in Figure 3-6.

Depth

The design water surface elevation of a channel receiving water from diversions or other tributary channels shall be equal to or less than the design water surface elevation of the diversion or other tributary channel at the point of intersection. The top width of parabolic and v-shaped, grass-lined channels shall not exceed 30 feet, and the bottom width of trapezoidal, grass-lined channels shall not exceed 15 feet unless multiple or divided waterways, riprap center, or other means are provided to control meandering of low flows.

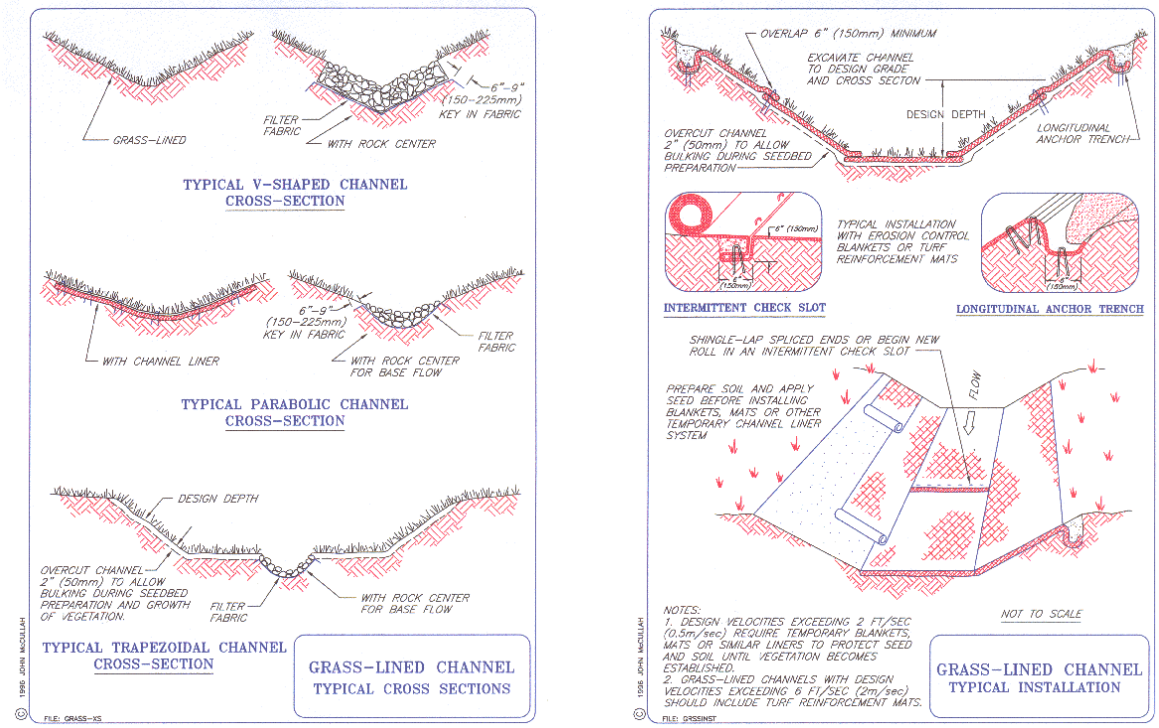


Figure 3-6. Grassed Lined Channel Specifications
(Salix Applied Earthcare)

Design Velocities

The allowable design velocity for soft armor channels is based on soil conditions, type of vegetation, and method of establishment. If design velocity of a channel to be vegetated exceeds 2 ft./sec., geosynthetic mats may be required at the time of seeding to provide stability until the vegetation is fully established. The maximum permissible design velocities and recommended Manning's roughness coefficients for geosynthetic mattings are presented in Tables 3-3 and 3-4.

It may also be necessary to divert water from the channel until vegetation is established or to line the channel with sod. Sediment basins may be needed at outlet discharge points to prevent sedimentation during the grass establishment period.

Table 3-3. Maximum Permissible Design Values for Geosynthetic Mattings

Matting Product	Velocity (ft/sec)		Shear Stress (lbs./ft^2)	
	Short Term (0.5 hours)	Long Term (50 hours)	Short Term (0.5 hours)	Long Term (50 hours)
TRM				
Non-Vegetated	14	8	6	2
Vegetated	20	14	8	5
Non-Vegetated w/Geotextile	12	7	5	2
Vegetated w/Geotextile	20	14	8	5
ECRM				
Non-Vegetated	18	8	7	2
Vegetated	18	10	7	4
PERM				
Non-Vegetated	20	10	8	3
Vegetated	25	15	10	6

Source: Williams and Austin, 1995

Table 3-4. Recommended Manning's Roughness Coefficients for Geosynthetic Mattings[a]

Geosynthetic Matting Type	Flow Depth Ranges (inches)		
	0 - 6	6 - 24	>24
TRM	0.036	0.026	0.03
	0.023	0.020	0.02
ECREM	0.035	0.025	0.021
	0.023	0.020	0.02
PERM	0.038	0.028	0.024
	0.023	0.022	0.021

[a]If vegetation exceeds 40% groundcover; species "n" dominated for expected height.
Source: Williams and Austin, 1995

Outlets

All waterways shall have a stable outlet with adequate capacity to prevent ponding, scouring, or flooding (Energy Dissipator, Section 3.2.7). Disturbed areas are seeded in accordance with a dry or wet soil revegetation protocol based on dominant soil moisture regime.

Soft Armor Vegetation

Soft armor waterways will be seeded in accordance with a dry and/or wet soil revegetation protocol as required. Unless the channel is expected to experience long-term saturation, seed the channel with the dry soil mix.

3.2.3.3 Installation Specifications

The following section provides instructions for installing erosion control mats including erosion control blankets, ECRMs, PERMs, and TRMs.

Degradable Erosion Control Blankets and Nondegradable ECRM and PERM Installation Guidelines (Figure 3-7)

- Prepare the seedbed and seed the site according to design specifications prior to blanket installation. Dig a 12 inch deep and 6 inch wide anchor trench across the lower end of the channel.
- Excavate intermittent check slots, 6 inches deep and 6 inches wide across the channel at 25 to 30 foot intervals along the channel.
- Cut longitudinal channel anchor slots 4 inches deep and 4 inches wide along each side of the installation to bury edges of matting. Whenever possible extend matting 2 to 3 inches above the crest of channel side slopes.
- Beginning at the downstream end and in the center of the channel, place the initial end of the first roll in the anchor trench and secure with fastening devices at 1-foot intervals. Matting initially is upside down in anchor trench.
- In the same manner, position adjacent rolls in anchor trench, overlapping the proceeding roll a minimum of 3 inches.
- Secure initial ends of mats with anchors at 1-foot intervals, backfill, and compact soil.
- Unroll center strip of matting upstream. Stop at next check slot or terminal anchor trench.
- Unroll adjacent mats upstream in similar fashion, maintaining a 3-inch overlap.

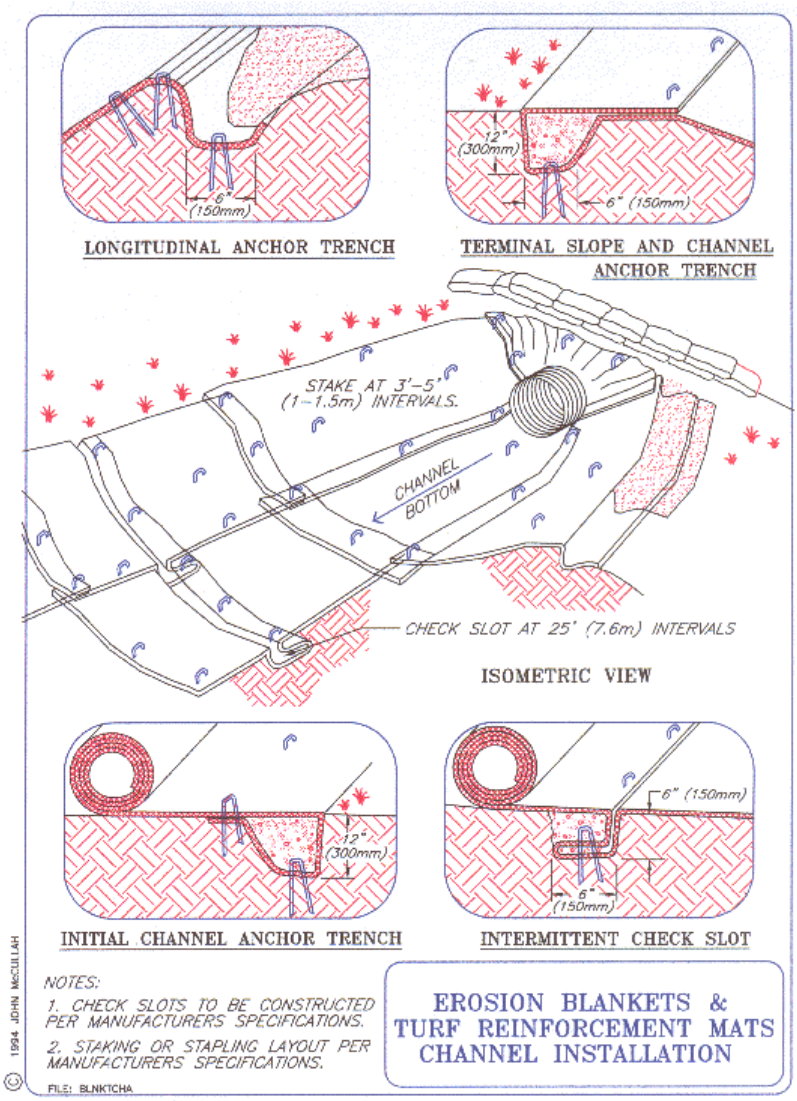


Figure 3-7. Erosion Control Blanket Channel Installation
(Salix Applied Earthcare)

- Fold and secure all rolls of matting snugly into all transverse check slots. Lay the mat in the bottom of the slot and then fold back against itself. Anchor through both layers of mat at 1 inch intervals, then backfill and compact soil. Continue rolling all mat widths upstream to the next check slot or terminal anchor trench (Salix Applied Earthcare, 1999).

Nondegradable TRM Installation

- Prepare the seedbed according to design specifications prior to blanket installation.
- Install and anchor as previously specified for ECRMs and PERMs (Figure 3-7).
- Spread seed directly into the mats by broadcasting and/or hydroseeding.
- Spread 0.5 to 0.75 inches topsoil over the mats with power equipment or hand tools and lightly rake or brush into the mat openings (Salix Applied Earthcare, 1999).

Alternative Method for Noncritical Channel installations

- Place two rows of anchors on 6 inch centers at 25-30 feet intervals in lieu of excavated check slots.
- Shingle-lap spliced ends by a minimum of 1 foot with upstream mat on top to prevent uplifting by water or begin new rolls in a check slot. Anchor overlapped area by placing two rows of anchors 1 foot apart on 1-foot intervals.
- Place edges of outside mats in previously excavated longitudinal slots; anchor using prescribed staple pattern, backfill, and compact soil.
- Anchor, fill, and compact upstream end of mat in a 12 inch by 6 inch terminal trench.
- Secure mat to ground surface using U-shaped wire staples, geotextile pins, or wooden stakes.
- Seed and fill turf reinforcement matting with soil, if specified (Salix Applied Earthcare, 1999).

3.2.4 Grass Hedges (RM-2D)

Grass hedges are narrow, parallel rows of stiff, erect, densely tillered grasses planted across slopes ditches or gullies (Figure 3-8). They are inexpensive, self-sustaining, and compatible with a diversity of other practices. Grass hedges intercept and release stormwater runoff in a manner that:

- Facilitates the development of natural broad-based bioterraces that reduce slope lengths and gradients by adding sediment layers upslope of the hedgerow.
- Reduces flow volumes and velocities by dispersing concentrated flow and promoting water detention and soil infiltration.
- Redirects flows to controlled discharge points or buffer areas.
- Reduces the loss of soil moisture, planted seeds, and soil amendments.
- Traps sediments and soluble contaminants (Farek and Lloyd-Reilley, 2000; Kemper, et al., 1992).

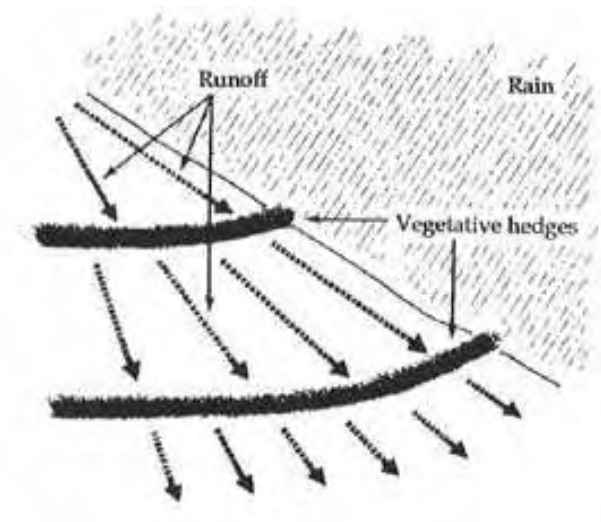


Figure 3-8. Slope Grass Hedges

When runoff reaches a grass hedge, it slows down, spreads out, drops its sediment load, and oozes through the grass hedge with a significant portion of the water soaking into the land along the way. In contrast to a solid diversion berm, water is temporarily impounded and filtered rather than conveyed, which eliminates the need for drainage channel(s). Coarse, stiff, hedge-forming grasses can withstand high water flows that would bend and overtop finer vegetation. Hedges are also less failure prone because water passes over a broad area secured with perennial roots.

Hedges do not filter sediment; rather they trap sediment upslope of the grass hedge by the process of deposition. Over time, the grasses grow up through the sediments deposited upslope of the hedgerow and create permanent bioterraces that may persist on the landscape for centuries. The primary long-term benefit is that grass hedges use natural processes to grow stronger and more stable with time, rather than weaker and more vulnerable as do most other erosion control techniques. The runoff interception-release process facilitated by grass hedges is presented in Figure 3-9.

The two types of grass hedgerows discussed in the following subsections include:

- Slope Hedges
- Channel Hedges

3.2.4.1 Slope Hedges

Slope hedges are located along the contours of slopes to intercept, pond, and release runoff water flows, trap sediments, and decrease downslope water concentration potentials (Figure 3-10). Hedges provide these functions by increasing the path length of flowing water and retarding and spreading runoff for subsequent conveyance to controlled outlets and/or dispersion over the land.

Figure 3-9. Grass Hedge Functional Profile: A) Runoff Interception and Soil Infiltration, (B) Sediment Deposition and Natural Terrace Building, (C) Release of Runoff at Reduced Volume and Velocity, (D) Solid Base of Soil Binding Roots

Figure 3-10. Vegetative Hedges Installed on a Steep Slope
(World Bank, 1993)

For a slope hedges to be effective, they should be spaced on slopes at the proper vertical interval (VI). The VI is the vertical distance between hedges, which is dependent on the slope of the land. The actual distance between the hedges is called the surface run. Based on a VI of 2 meters or approximately 6 feet, hedges on a 5 percent slope would be 130 feet apart and hedges on a 2 percent slope would be 330 feet apart. As shown in Figure 3-11, the surface run between hedges on a 57 percent slope with a VI of 6 feet (2 meters) is about 13 feet (4 meters) (World Bank, 1993).

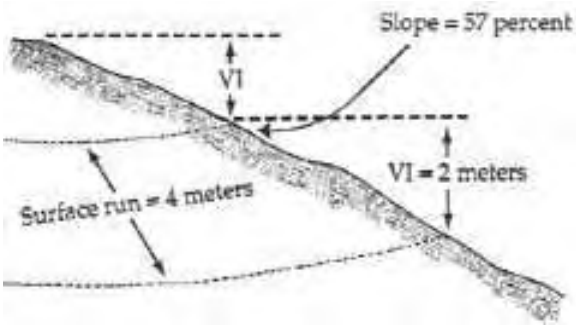


Figure 3-11. Vertical Interval on a Steep Slope
(World Bank, 1993)

Hedge length and width will vary with application, topography, and water flow patterns. It is important that the hedge be designed with curved ends so as not to create flow around the ends of the hedge, which could create erosion problems. The total watershed in a grass hedge should be the smaller of: the size that will provide runoff to pond 1 foot of water upslope of the lowest hedge in the system, or the size that will generate velocities upslope of that hedge greater than allowable for the soil and slope. In a multi hedge system, the last hedge should be located on the foot slope so that the existing velocity does not exceed the critical soil velocity.

Guidelines for installing slope hedgerows are as follows:

- Slope hedges are comprised of 1 or 2 rows of *Alamo* switchgrass or *Pete* eastern gamagrass planted along the slope contour.
- The maximum vertical interval between hedges is 6 feet.

- Gradients along the hedge will be 0.6 percent or less except where the hedge crosses a concentrated flow area. Gradients entering a concentrated flow area may be up to 1.5 percent for 100 feet.
- Hedge length will vary depending on the topography. At a minimum, each row will extend far enough from concentrated flow areas to provide 1.5 feet of elevation from the center of the flow area to the end of the hedgerow.
- After establishment, hedges are fertilized as needed to maintain plant vigor. Establishment failures will be replanted or reseeded immediately; short gaps in seeded hedges may be reestablished more effectively and immediately with transplanted plant material.
- Washouts or rills that develop will be filled and replanted immediately. Short gaps in established hedges should be reestablished with transplanted plant material. Vegetative transplant material should be taken from the lower side of the hedge in non-concentrated flow areas. Transplants should have a minimum of 4 to 5 viable shoots. Soil should be mounded 3 to 4 inches higher than the soil around the transplanted plant to force runoff through the adjoining areas of established hedges. U anchors may also be used to anchor the transplants.
- Mowing of grass hedges may be used as a management practice to encourage the development of a dense stand. Mowing will not be closer than 15 inches. Mowing in concentrated flow areas is discouraged because it will lower the vegetative stiffness index (VSI) by reducing average stem diameter.
- Grass hedges should not be burned. Year-old stems are very stiff and contribute to the effectiveness of the hedge (USDA, No date).

Hedgerow vegetative propagation guidelines include:

- Use a walk-behind trencher to produce a 6-inch by 6 inch planting trench along the contour.
- Recondition the trench soil based on soil testing by adding lime as necessary to a target pH of 5.5 and incorporate mature compost as the primary fertilizer and add VA mycorrhizae as required. If the seedbed is amended with conventional fertilizer, add 0-24-24 at a rate comparable to 100 pounds per acre. Nitrogen should not be applied at planting.
- Plant *Alamo* switchgrass or *Pete* eastern gamagrass bare root clumps 3 to 6 inches apart, backfill the trench, and firm up the soil. Take care not to bend the roots upward during planting. Planting the slips too far apart renders the system almost useless. Although single tillers can be used to create a hedge, this practice is not recommended because it normally takes too long for the hedge to form.
- Plant the slips at the beginning of the wet season to ensure that they get full benefit of the rains. Otherwise, irrigate the plantings until established.
- Special considerations are made for all in-channel plantings and slope hedges subjected to concentrated water flows. Two to three rows are planted as described above and spaced 12 to 16 inches apart (USDA, No date).
- For areas with concentrated runoff, place straw rolls on the downstream side of the rows to prevent plant dislodging and promote water conservation for the seedlings (Section 2.6.5.1).

Grass hedge seeding guidelines are as follows.

- Prior to seeding, prepare a seedbed.
- Recondition the soil within the seeding area based on soil testing by adding lime as necessary to a target pH of 5.5 and incorporate soil amendments as specified above.
- If the seedbed is amended with conventional fertilizer, add 0-24-24 at a rate comparable to 100 pounds per acre. Nitrogen is not applied at planting.
- The minimum vegetative hedge width is 2 feet and the maximum is 5 feet. Plant stratified switchgrass or eastern gamagrass in rows 6 to 8 inches apart. Switchgrass and eastern gamagrass are planted at 10 pounds PLS per acre. Switchgrass is planted to a depth of 0.5 to 0.75 inches, whereas eastern gamagrass is planted to a depth of 1 to 1.5 inches. Planting shallower than that could provide less favorable moisture - seed relations and emergence could be delayed.
- Switchgrass and eastern gamagrass should be planted in the spring when soil temperatures stabilize in the range of 65 to 80°F (April to June) at a depth of 1 inch. Faster germination and seedling emergence will occur when soil temperatures are near the upper limits of the temperature range (80 to 85°F) when soil moisture is not limiting (USDA, No date).

3.2.4.2 Channel Hedges

Channel hedges are placed directly across drainage ditches to intercept relatively high volume and high velocity water flows to prevent ditch scouring and sediment discharge potentials. The channel hedge functions by making the backwaters from one hedge extend to the base of the next hedge upslope. This backwater dissipates energy and causes sediment deposition in the channel. Guidelines for installing channel hedges are as follows.

- Channel hedges are comprised of 2 or more rows of *Alamo* switchgrass or *Pete* eastern gamagrass planted 1 foot apart across the channel and extend far enough to prevent bypass flow around the ends.
- Channel hedge grasses are established as previously described and maintained at a height of at least 15 inches throughout the year.
- The maximum vertical interval between channel hedges is 4 feet.
- Stem density should exceed 50 stems per square foot and contain sufficient density of large anchored stems (living or dead) so that the product of the large-stem density (M, number per square foot) times the large-stem diameter (D, inches, measured two inches above the ground) raised to the fourth power exceeds 0.1 [$(M)x(D^4)>0.1$]. As an example, the product for vegetation with 70 stems per square foot and stems 0.2 inches in diameter would be: $(70(0.2)^4 = (70)(0.0016) = 0.112$ (USDA, No date).
- In concentrated water flow conditions, install a straw roll on the downstream side of the hedge to prevent plant dislodging (Figure 2-35).

3.2.5 Road Cross Drains (RM-2E)

Road cross drains are culverts buried under the road surface that are used to prevent roadside ditch flow concentrations from reaching unmanageable levels (Figure 3-12). The most common type of road culvert is the corrugated metal pipe; however, arch or rectangle conduits may also be used. Inlet

and outlet treatments are available to control flows and prevent plugging. Road culverts are primarily installed to provide periodic ditch drainage and remove water that has collected at a low point in the road. Road culverts may provide better service of drainage needs for steep road grades, wet low points or swags in the roadway, and roads with a life expectance of greater than 20 years. When properly maintained and installed according to specifications, road culverts are not affected by road traffic and provide an economical alternative to surface cross drains.

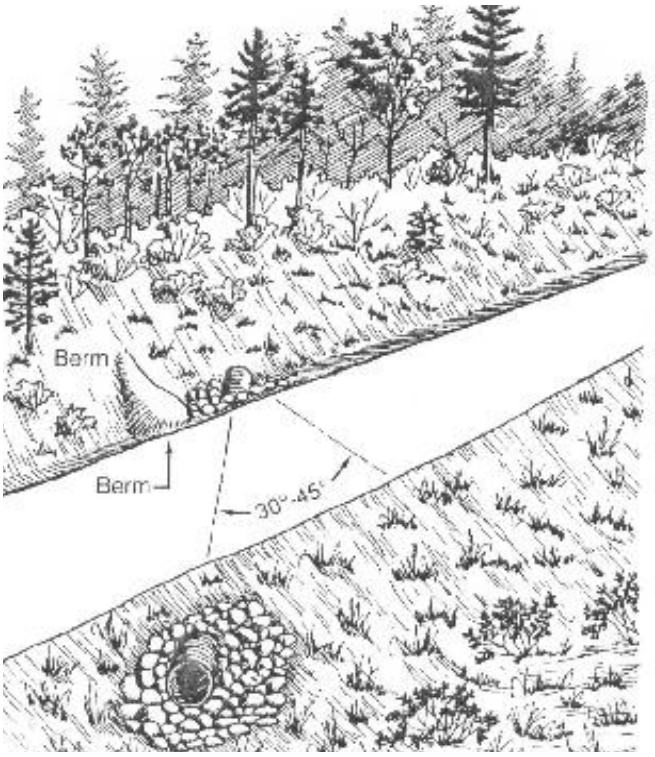


Figure 3-12. Road Cross Drain Culvert

Road cross drain installation guidelines include:

- Cross drain culverts should be at least 12 inches in diameter; increase the size of the culvert in accordance with drainage hydrology. The culvert should be long enough so that the ends of the culvert extend beyond the edge of the road fill.
- Install the cross drain culverts at grades at least 2 percent more than the ditch grade and angled 30 to 45 degrees to improve inlet efficiency (Figure 3-12).
- The bottom of the culvert trench shall be molded to fit the outer circumference of the pipe in such a manner that the depth of the molded bed shall be a minimum of 1/5 times the outside diameter of the pipe below the level of the original bottom of the trench. The trench bottom shall be free of sod, stumps, roots, and rocks.
- The pipe and fittings will be transported and handled in such a manner as to prevent bruising, scaling, or breaking of the galvanized or bituminous coating. After the pipe and fittings have been completely installed and while still exposed, any damage areas where the bituminous coating has been broken sufficiently to expose the base metal shall be remedied by recoating with a material similar and equal to the original coating.
- Install culverts on a compacted granular trench fill material. Material for backfilling shall be similar to the soil material of the trench and free of sod, roots, and lumps or clods. Backfill

under the haunches and around the pipe shall be accomplished by placing and thoroughly tamping layers a maximum of 6 inches thick on alternate sides so as to keep the same elevation on both sides of the pipe at all times. Tamping is performed with hand tools or mechanical equipment. Cover the top of the culvert with at least 12 inches of road fill to prevent crushing. Care must be taken to ensure that the pipe is not displaced during backfilling operations. Equipment or heavy loads will not be allowed to pass over the pipe until enough fill has been placed and tamped above the top of the pipe to prevent damage.

- Install riprap (Section 5.4) at the culvert inlet and an energy dissipator structure at the culvert outlet to prevent erosion. Construct a vegetated berm immediately downstream of the culvert inlet (Figure 3-12).
- Following construction, make a profile and cross-section survey construction check of the installed structure. Check all elevations, distances, and slopes to assure that plans and specifications have been met.
- Disturbed areas shall be revegetated using the appropriate revegetation protocol(s) (USDA, No date).

3.2.6 Turnouts (RM-2F)

A turnout is a transitional excavated depression that intercepts and conveys roadside runoff to a stable discharge outlet. Turnouts serve to convert a concentrated flow of runoff to non-erosive sheet flow. The construction of turnouts is illustrated in Figure 3-13 and described below.

- Install turnouts only where the area directly below the turnout outlet is stabilized by vegetation, has been adequately hardened against erosive volumes of runoff, or where the drainage will not initiate erosion or flow directly into a water body. Ensure that turnouts are constructed with a 30 to 40-degree angle to the roadway and have an outslope of 1 to 2 degrees.
- The width should be a minimum of the width of the road drain from which it is diverting runoff. The length of the transition from ditch to the level spreader should be a minimum of 20 feet.
- All bare ground associated with turnout construction, including the flow line and sidewalls of the turnout, will be revegetated.
- The transition from the road drain to the grade and width of the outlet area (level spreader, stabilized outlet, undisturbed area) should be smooth and blend with the surrounding landscape.

Site-specific modifications may be required based on soils, slope, vegetation, and area of watershed providing runoff to the affected road section. The common spacing for turnouts is shown in Table 3-5.

Table 3-5. Recommended Turnout Spacing

Slope (%)	Spacing (feet)
2	200
5	125
10	80
15	60
20	45

Turnouts are not constructed by pushing a gouge through the woods. Turnout construction is an excavation and surface shaping process where soil material is removed and not simply pushed into a mound at the end of the turnout (Figure 3-14). This type of improper turnout construction frequently increases rather than controls runoff induced soil erosion.

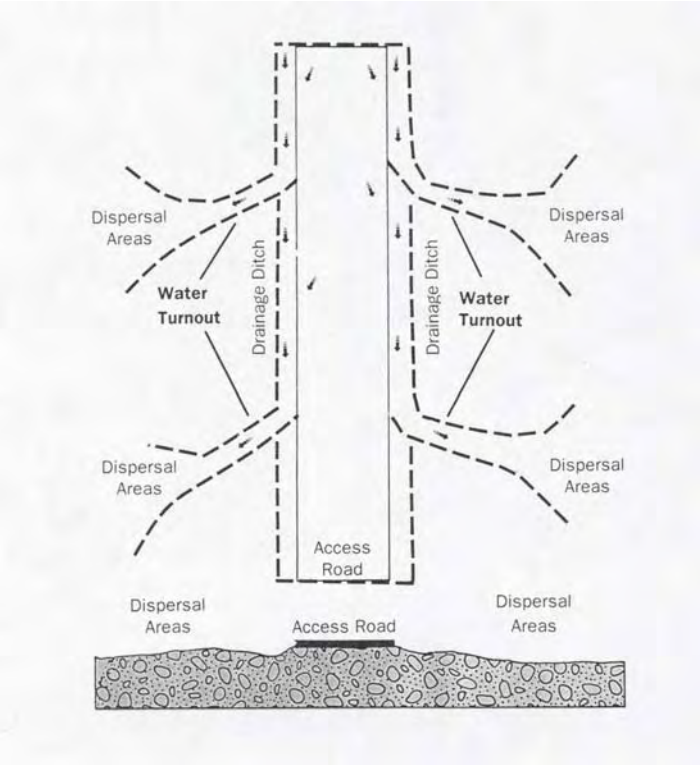


Figure 3-13. Roadside Turnout Configuration
(Florida Department of Agriculture and Consumer Services, 1993)

Figure 3-14. Improper Turnout Construction (Photos by Mike Rainer)

3.2.7 Riprap Energy Dissipator (RM-2G)

An energy dissipator is a riprap structure designed to control erosion at the outlet of a channel or conduit (Figure 3-15). The purpose of a discharge energy dissipator is to prevent erosion at the outlet of a channel or conduit by reducing the velocity of flow and dissipating the energy. Riprap is a layer of stone designed to protect and stabilize areas subject to erosion. Riprap protects the soil surface from erosive forces, slows the velocity of concentrated runoff, and/or improves stability of soil slopes that are subject to seepage or have poor soil structure.

Culvert outlet

Drainage discharge

Figure 3-15. Culvert Outlet Energy Dissipator (Salix Applied Earthcare)

Energy dissipator installation guidelines are discussed below and shown in Figure 3-16.

- 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. The minimum thickness of the riprap should be 1.5 times the maximum stone diameter. Riprap may be field stone or rough quarry stone. It should be hard, angular, highly weather-resistant, and well graded.
- 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. Immediately after construction, stabilize all disturbed areas with vegetation.
- Ensure that the subgrade for the filter and riprap follows the required lines and grades shown in the plan. 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. The riprap and gravel filter must conform to the specified grading limits shown on the plans (Salix Applied Earthcare, 1999).

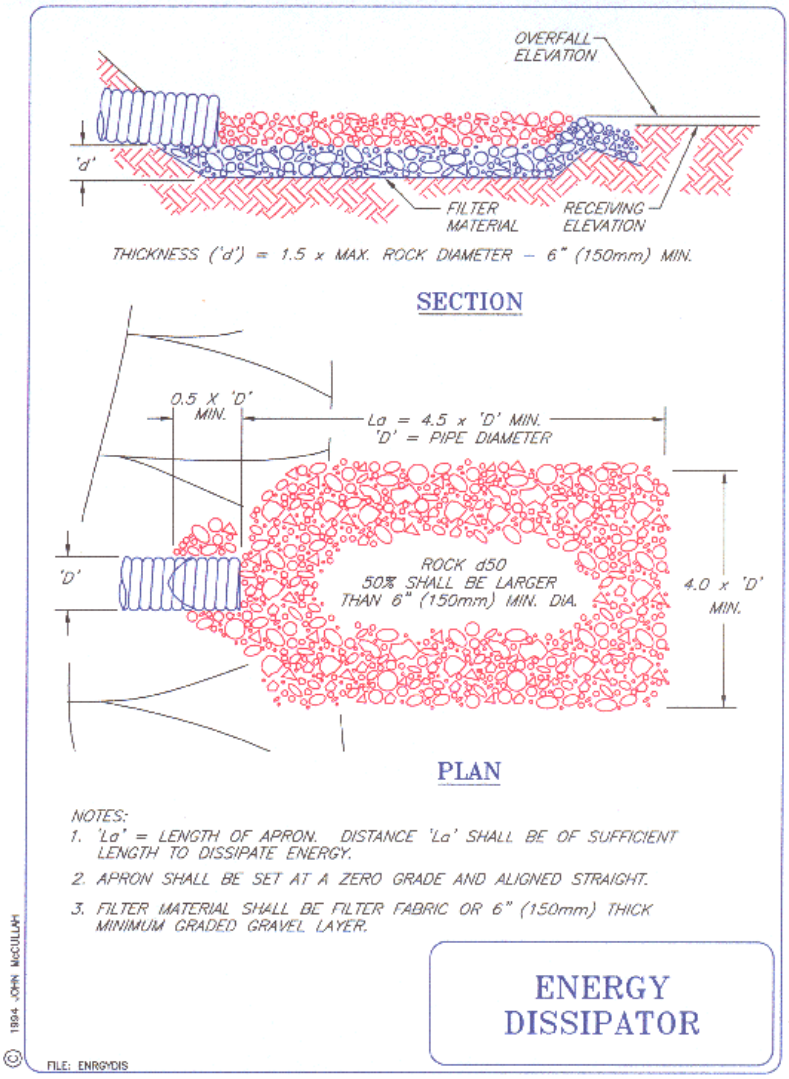


Figure 3-16. Energy Dissipator Specifications (Salix Applied Earthcare)

3.2.8 Temporary Slope Drain (RM-2H)

A temporary slope drain is a flexible or rigid conduit extending from the top to the bottom of a slope that functions to convey concentrated runoff across a slope without eroding the slope (Figure 3-17). This structure is primarily used to discharge runoff during the lag time between grading and permanent stabilization of the slope with vegetative cover or other structural measures.

The structure is typically designed to convey the peak runoff from a 10-year frequency, 24-hour duration storm. The maximum allowable drainage area is 5 acres per slope drain. Temporary slope drains must be sized, installed, and maintained properly because structure failure may result in severe erosion of the slope. Slope drainpipe sizing recommendations are presented in Table 3-6.

Figure 3-17. Roadside Slope Drain

Table 3-6. Slope Drain Pipe Sizing Recommendations

Pipe Diameter (Inches)	**Maximum Drainage Area** (Acres)
12	0.5
18	1.5
21	2.5
24	3.5
30	5.0

The entrance section of the drain should be well entrenched and stable so surface runoff can enter freely. 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. Slope drain construction specifications are presented below and illustrated in Figure 3-18.

- 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.
- Compact the fill material and 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. Install an energy dissipator structure in accordance with the specification presented in Section 3.2.7. Make the compacted dike ridge no less than 1 foot higher than the top of the pipe inlet. Immediately stabilize all disturbed areas following construction.
- Inspect the slope drain and supporting diversions after every significant rainfall and promptly make necessary repairs. When the protected area has been permanently stabilized,

temporary measures may be removed, materials disposed of properly, and all disturbed areas stabilized appropriately (Salix Applied Earthcare, 1999).

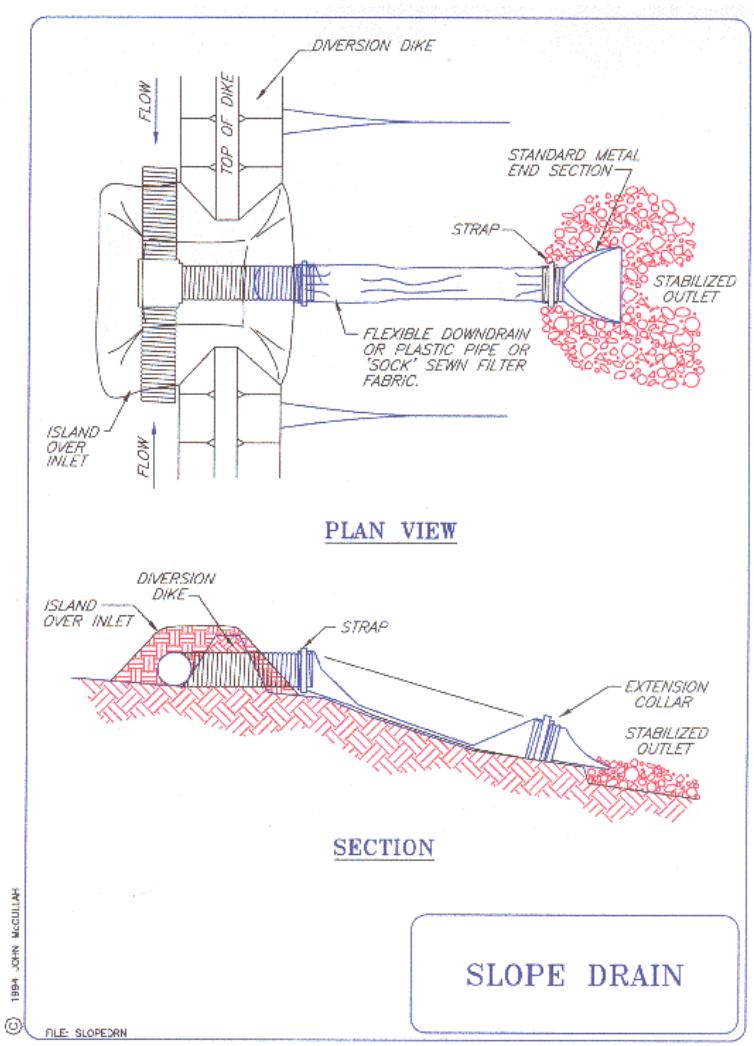


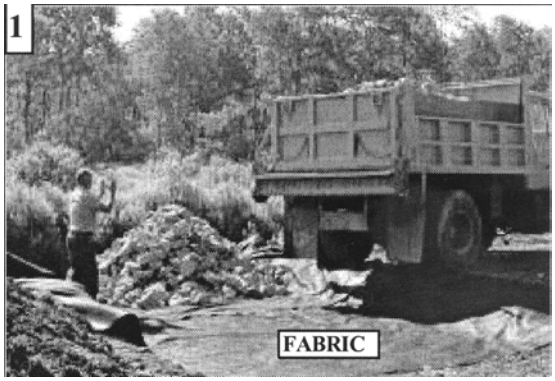
Figure 3-18. Slope Drain Specifications (Salix Applied Earthcare)

3.2.9 Seepage Drain (RM-2I)

A seepage drain is a stone and geofabric structure constructed under the road prism that allows hillslope seepage flow or wetland surface waters to pass under the road. In conditions requiring the use of a seepage drain, the road has created a barrier to natural groundwater or wetland flows that threaten the integrity of the roadway. The saturation of road materials by water causes the rapid deterioration of the road surface, increasing roadway maintenance requirements and unsafe driving conditions.

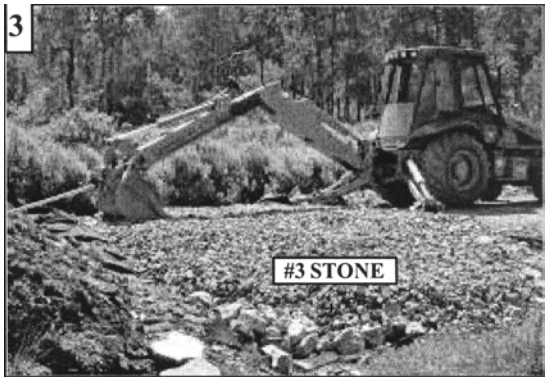
The practice relies on the uneven configuration and support strength of stones and filtering capacity of geofabric to foster the relatively slow movement of water from any direction. The geofabric prevents the clogging of the system by soil materials above and below the structure. The structure is designed to function in gentle flow conditions that characterize groundwater seepage and some depression

wetlands. The practice is used in situations where road cross drains or culverts are impractical. Seepage drain installation guidelines are shown in Figure 3-19 and discussed below.

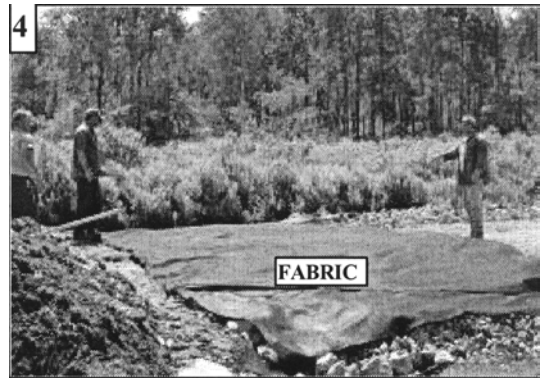


Drain excavation and preparation

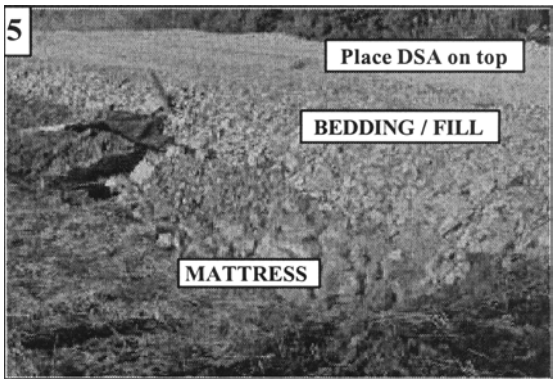
Large stone application



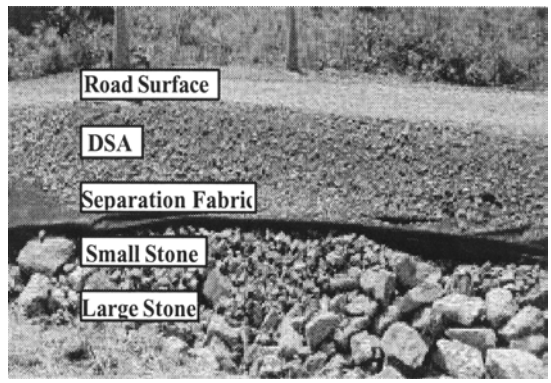
Small stone application



Fabric wrapping



Road surfacing and grading



Completed seepage drain

Figure 3-19. Seepage Drain Installation Procedures
(http://www.mri.psu.edu/centers/cdgrs/Downloads/downloads.html)

- Step 1: Excavate the road to the desired depth and width. The depth of excavation depends on the amount of water to be moved by the structure; generally the depth should be no less than three times the diameter of the largest stone used. The width of the structure depends on the application but should be wide enough to allow slow flow without concentration outlet drainage. Lay geofabric in the excavated area leaving enough fabric on the ends to wrap over the interior stone to create a flattened fabric tube.

- Step 2: Place large R4 stone (3 to 18 inches) on top of the geofabric and spread uniformly.
- Step 3: Spread smaller #3 stone (1 to 2.5 inches) over the large stone in the drain being careful not to intermix the small and large stone. Spread increasingly smaller stone on top to create a layer that will not puncture the fabric.
- Step 4: Wrap the ends of the fabric over the top of the stone making sure the fabric intersections overlap by at least 18 inches. Place an additional piece of fabric on the top of the structure if the wrapped fabric does not completely cover the stone.
- Step 5: Place road fill material over the structure and finish grade to appropriate road specifications (Penn State University, 2001).

4. SEDIMENT CONTROL PRACTICES

This chapter describes stream channel sediment removal and sediment basin, silt fence, straw bale, and compost berm sediment control practices.

4.1 INTRODUCTION

To rely completely on sediment control practices to treat disturbed land amounts to closing the barn doors after all the animals have gone. A practice designed to only settle water and collect sediment infers that erosion and runoff control practices are nonexistent or malfunctioning. If soil stabilization and runoff control practices function in their design capacity in minimizing erosion at the source, sediment control practices primarily function within the realm of temporary or emergency control measures. For example, collecting lost soil resources with silt fences, hay bales, or sediment traps at the stream discharge point provides no long-term benefit to reducing the damage and loss of soil resources at the uphill points of origin. Although providing water quality protection, these types of sediment controls are quickly overwhelmed by sediment loading if erosion and runoff control practices are not jointly installed. The sediment control practices discussed in this section include roadside:

- Sediment Basin (SC-1)
- Silt Fence (SC-2) and Straw Bale (SC-3) Barriers
- Compost Filter Berm (SC-4)

4.2 SEDIMENT BASIN (SC-1)

A sediment basin is an excavated holding pond that is used to capture and detain runoff in a manner that facilitates the removal of sediments and prevents the nonpoint source pollution of waterways (Figure 4-1). The purpose of the sediment basin is to pool surface runoff long enough for sediments to fall out of suspension within the confines of the basin. The basin is designed to function as a temporary measure until permanent vegetative and structural erosion and runoff control measures are completed; the design life of a basin is normally less than 18 months. Installation specifications are presented below and illustrated in Figure 4-2.

- Based on the project design specifications, set out enough well marked stakes for the embankment, riser pipe, and emergency spillway to guide the contractor during construction. Mark the embankment top width and elevation on appropriate stakes.
- Construct the basin by excavating or building an embankment before any clearing or grading work begins. Basin embankment areas and any structural works shall be cleared, grubbed, and stripped of any vegetation and rootmats that would prevent a good bond between the foundation and fill material.
- A cut-off trench (minimum depth of 2 feet) shall be excavated along the centerline of the earth fill embankments. The cut-off trench shall extend up both abutments to the riser crest elevation. All excess water shall be removed from the trench and the foundation areas when fill material is being placed.

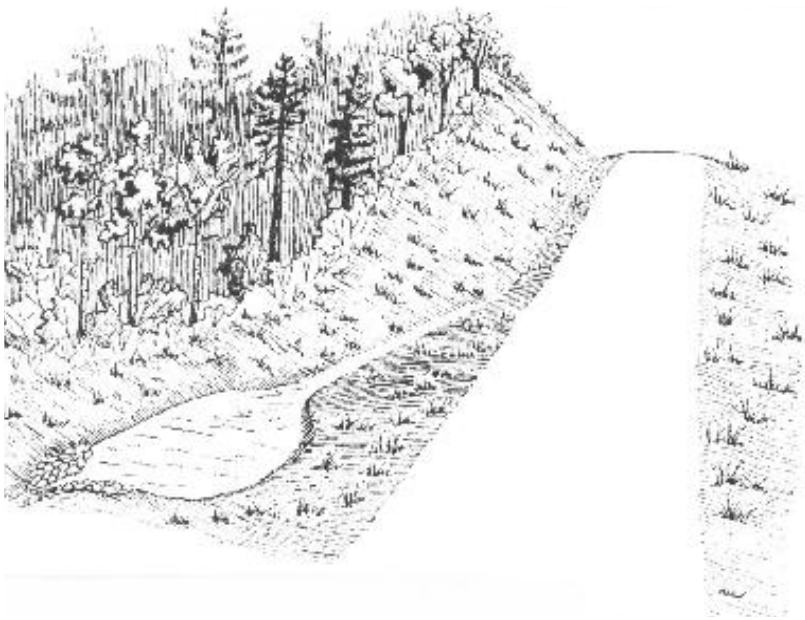


Figure 4-1. Roadside Sediment Basin

- Fill material for the embankment should be clean mineral soil free of roots, woody vegetation, oversized stones, rocks, or other objectionable material and shall contain sufficient moisture so that it can be formed by hand into a ball without crumbling.
- Placing and spreading of the fill material shall begin at the lowest point of the foundation and brought up in approximately horizontal layers not exceeding 8 inches thick. Each layer shall be uniform in thickness and extend over the entire area of fill. Compacting shall be obtained by routing the hauling equipment over the fill so that the entire surface of each layer of the fill is traversed by at least one wheel or tread track of the equipment, or by the use of a compactor. To account for compaction, a minimum of 5 percent shall be added to fill heights. Without compaction or wheel track coverage, 10 percent added fill height is required.
- The distribution and gradation of fill materials shall be such that there will be no lenses, pockets, streaks, or layers of material differing substantially in texture or gradation from the surrounding material. If materials of varying texture and gradation are used, the more impervious material shall be placed in the upstream and center portions of the fill. Undertake construction with fill materials only when the fill moisture content will allow satisfactory compaction and bonding.
- Construction is considered satisfactory when the excavation elevation is within $\pm$ 0.2 foot of design grade. Excavation slopes may be flatter than designed but not steeper.
- The pipe and riser shall be placed on a firm, smooth soil foundation. The connection between the riser and the riser base shall be watertight. Pervious materials such as sand, gravel, or crushed stone shall not be used as backfill around the pipe or antiseep collars.
- The fill material around the pipe spillway shall be placed in 4-inch layers and compacted under the shoulders and around the pipe to at least the same density as the adjacent embankment. A minimum of 2 feet of compacted backfill shall be placed over the pipe spillway before crossing it with construction equipment.
- Steel base plates shall have at least 2½ feet of compacted earth, stone, or gravel over them to prevent flotation.

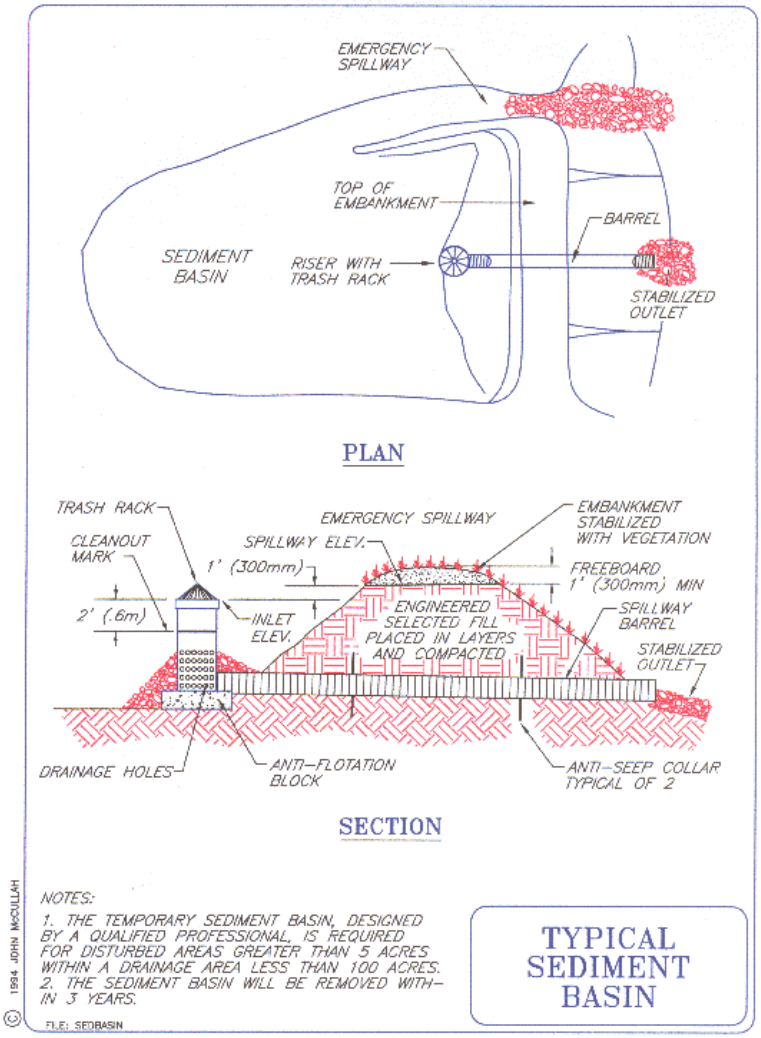


Figure 4-2. Typical Sediment Basin Plan and Section
(Salix Applied Earthcare)

- The emergency spillway shall **not** be installed in fill. Elevations, design width, and entrance and exit channel slopes are critical to the successful operation of the emergency spillway.
- The embankment and emergency spillway shall be stabilized with vegetation immediately following construction, and construction operations shall be carried out in such a manner that erosion and water pollution will be minimized.
- Following basin construction, profile along the centerline of the top of the embankment and cross section the embankment to compare findings to top width and side slope design specifications. Also profile and cross section the emergency spillway and check the crest elevation of the riser pipe spillway. Record field notes concerning the construction materials, adequacy of spillway trash protection devices, and as-built dimensions of the completed sediment basin (USDA, No date).

4.3 SILT FENCE (SC-2) AND STRAW BALE (SC-3) BARRIERS

Silt fence and straw bale barriers are common practices that are almost never installed properly and frequently increase rather than reduce soil erosion and sedimentation. In light of the limitations of these practices, compulsions for misuse, and the existence of other more effective practices, the use of silt fence and straw barriers are not to be used as permanent sediment control measures. The chronic problems associated with these practices are discussed below.

Many erosion control professionals seem to have a love affair with straw bale barriers since they seem to be a frequently implemented erosion and sediment control practice. However, as is evidenced on many roadsides, the use of straw bale barriers is plagued with improper design, installation, and maintenance practices. Their frequent use is linked to the fact that they make for nice visibility, look good on paper, are perceived to be cheap to install, and anyone can install them. The problem is that in the vast majority of circumstances, straw bale barriers do not work and frequently create rather than amend erosion and sediment problems. Specific problems associated with straw bale barriers include:

- Runoff water does not readily seep through the bales as it does through a grass hedge, which may lead to damaging and disastrous runoff concentration and diversion.
- Bales do not effectively filter sediment.
- Bales are frequently improperly installed, causing runoff to flow between, under, and around the bale structures.
- Bale structures are often not inspected and maintained or removed (try to remove a bale from a deep ditch after it has soaked up water for a couple of months).
- Bale debris transported by heavy runoff events can plug culverts and sediment basin outlets.
- Bales are one of the more costly methods for the long-term control of sediment in runoff.

Probably the most common and improper use of straw bales is as in-channel check dams. Their effectiveness in reducing runoff volume and velocity and assisting vegetation establishment is practically nonexistent. Unless bales are installed in a trench, staked, and backfilled, water will flow under the barrier. In-channel installations also normally lack a sufficient number of bales on the channel side slopes to force runoff over the flow line bales. Typically, the result is channel degradation and downstream sediment transport. Occasionally, the temporary use of a straw bale for surface impoundment on a relatively flat surface or use for a few days as temporary diversions or plugs for undesirable runoff conditions may be appropriate. The best use for a straw bale is to break it up and scatter it over the soil as mulch.

Silt fences are another practice that is frequently misused. All too often, silt fences are placed across channels at the points where runoff discharges into streams. Ideally, a silt fence should pond water, allow water to slowly percolate to stream discharge, and allow for the deposition of suspended particles upstream of the fence. However, in practice this rarely occurs. Typically, successive water accumulation and sediment deposition overwhelms the design capabilities of the silt fence and hydrostatic pressure causes the structure to collapse (Figure 4-3). As with straw bales, these systems may also be plagued with water flowing under the structure.

Figure 4-3. Collapsed Silt Fence and Buried Straw Bales within a Roadside Drain (Photo by Mike Rainer)

Silt fence installation guidelines are discussed below and shown in Figure 4-4.

- The height of a silt fence shall not exceed 36 inches. Storage height and ponding height shall never exceed 18 inches.
- The fence line shall follow the contour as closely as possible.
- If possible, the filter fabric shall be cut from a continuous roll to avoid the use of joints. When joints are necessary, filter cloth shall be spliced only at a support post, with a minimum 6-inch overlap and both ends securely fastened to the post.
- Posts shall be spaced a maximum of 10 feet apart and driven securely into the ground (minimum of 12 inches). When extra-strength fabric is used without the wire support fence, post spacing shall not exceed 6 feet.
- Turn the ends of the fence uphill.
- A trench shall be excavated approximately 4 inches wide and 6 inches deep along the line of posts and upslope from the barrier.
- When standard-strength filter fabric is used, a wire mesh support fence shall be fastened securely to the upslope side of the posts using heavy-duty wire staples at least 1 inch long, tie wires, or hog rings. The wire shall extend into the trench a minimum of 2 inches and shall not extend more than 36 inches above the original ground surface.
- The standard-strength filter fabric shall be stapled or wired to the fence, and 6 inches of the fabric shall extend into the trench. The fabric shall not extend more than 36 inches above the original ground surface. Filter fabric shall not be stapled to existing trees.
- When extra-strength filter fabric and closer post spacing are used, the wire mesh support fence may be eliminated. In such a case, the filter fabric is stapled or wired directly to the posts.

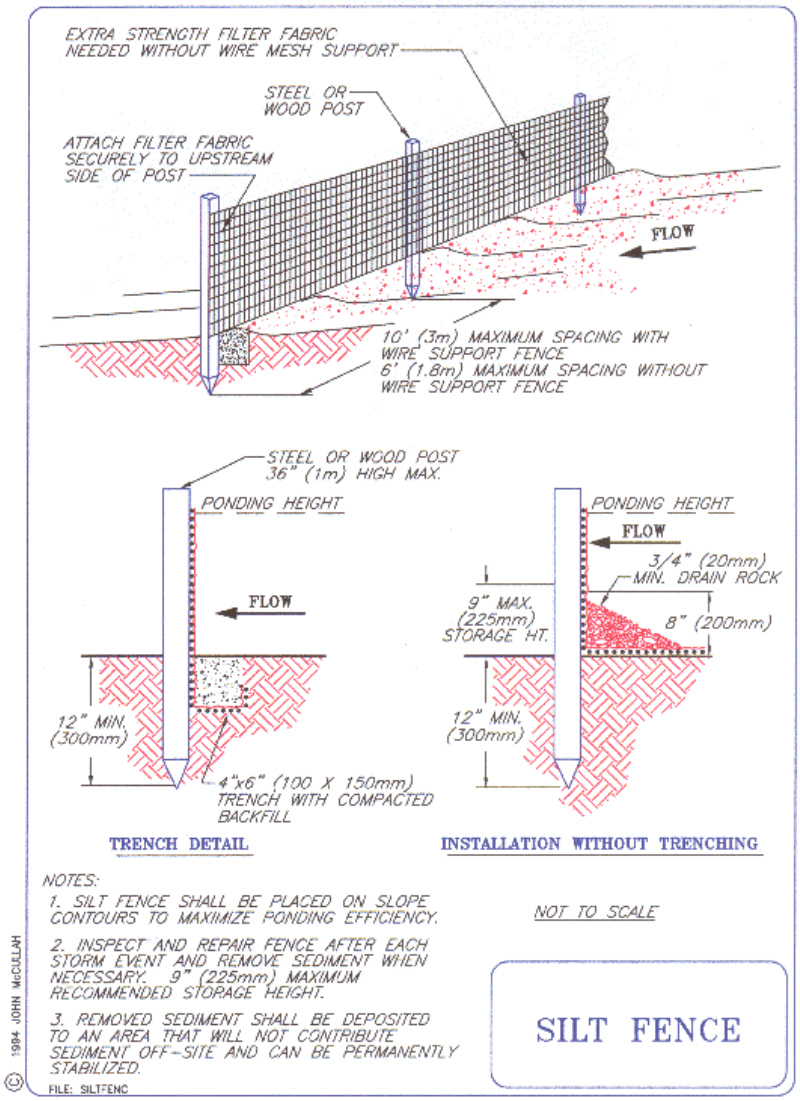


Figure 4-4. Silt Fence Installation (Salix Applied Earthcare)

- The trench shall be backfilled and the soil compacted over the toe of the filter fabric.
- 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.
- 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.
- Silt fences and filter barriers shall be inspected weekly after each significant storm (1 inch in 24 hours). Any required repairs shall be made immediately.
- Sediment should be removed when it reaches 1/3 the height of the fence or 9 inches maximum.
- The removed sediment shall conform to the existing grade and be vegetated or otherwise stabilized (Salix Applied Earthcare, 1999).

Straw bale *barrier* installation guidelines are discussed below and shown in Figure 4-5.

- Construct the rock spillway from graded drain rock (1½ inch minimum that is sized according to expected flows). Filter fabric may be used to cover the bales and be enveloped in the rock spillway to increase the life of the barrier beyond one year.
- Construct the rock spillway to a height of 2/3 that of the straw bales, with a maximum height of 2 feet.
- Place bales in a single row, lengthwise, oriented perpendicular to the flow, with the ends of adjacent bales tightly abutting one another.
- Embed each bale a minimum of 4 inches in the soil. Use straw, rocks, or filter fabric to fill gaps between the bales and tamp the backfill material to prevent erosion under or around the bales.
- If the bales are wire bound, orient them so the bindings are around the sides rather than along the top and bottom. Wire bindings in contact with soil tend to disintegrate, which may cause the bales to fall apart.
- Securely anchor the bales in place with two wooden stakes or rebar driven through the bales. Drive the first stake of each bale toward the previously laid bale to force the bales together. Drive the stakes at least 18 inches into the ground.

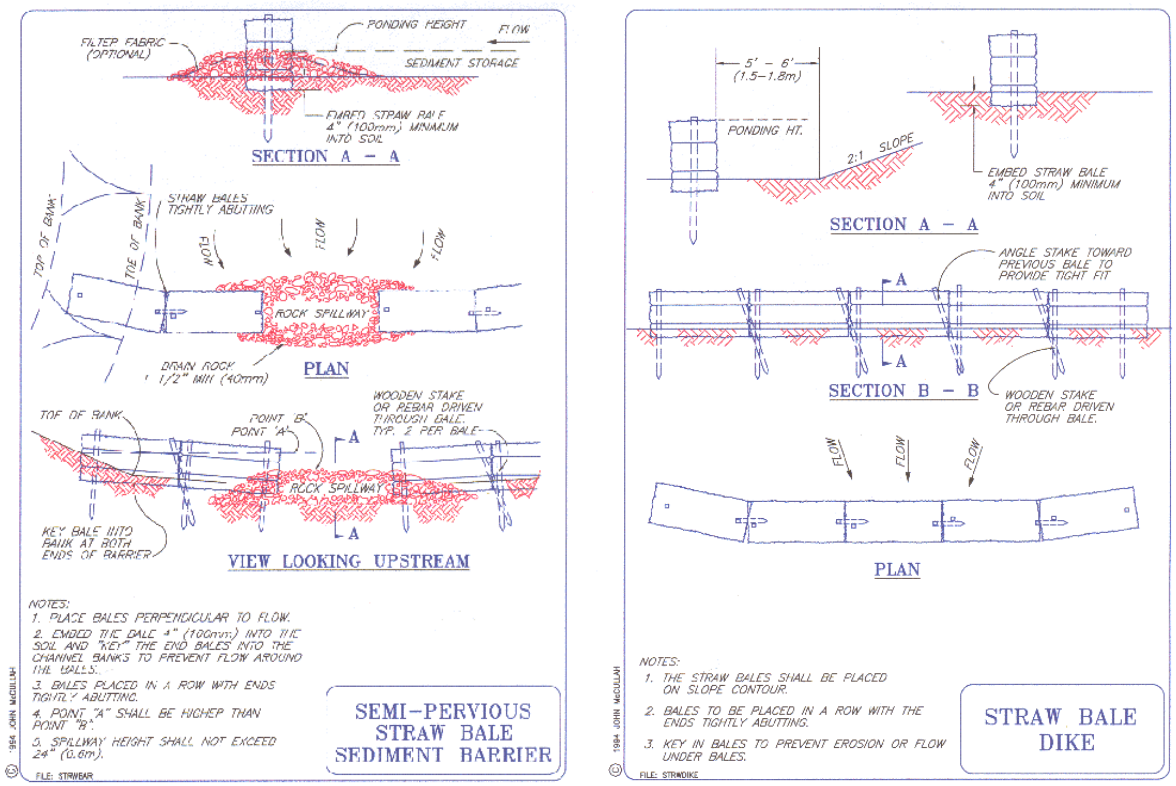


Figure 4-5. Straw Bale Installation (Salix Applied Earthcare)

- Extend the barrier, across the swale, such that the bottoms of the end bales are higher than the top of the rock spillway. This ensures that sediment-laden runoff either flows through or over the barrier and not around it.

- Place rock and/or filter fabric immediately downstream of the road spillway to dissipate water energy and reduce erosion potentials.
- Inspect the barrier periodically and after each major storm event (1 inch in 24 hours). Make repairs or bale replacements promptly.
- Remove captured sediment when the barrier is 60 percent full.
- Remove the straw bales and stakes when the upslope areas have been permanently stabilized and dispose of bale bindings (Salix Applied Earthcare, 1999).

Straw bale *dike* installation guidelines are discussed below and shown in Figure 4-5.

- Place the bales on the slope contour at the toe of the slope. If the dike is constructed at the toe of a slope, place it 5 to 6 feet away from the slope if possible.
- Place the bales in a row not greater than one bale high with the ends tightly butted.
- Embed each bale a minimum of 4 inches into the soil. 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.
- If the bales are wire bound, orient each bale so the bindings are around the sides rather than along the top and bottom.
- Securely anchor the bales in place with two wooden stakes or rebar driven through the bales. Drive the first stake of each bale toward the previously laid bale to force the bales together. Drive the stakes at least 18 inches into the ground.
- The bales do not need to be anchored if they are used on a relatively flat ground and the dike is regularly inspected. Remove sediment behind the barrier when it reaches a depth of 6 inches.
- Inspect the dike weekly and after each significant storm (1 inch in 24 hours).
- Remove the bales when the upslope areas have been permanently stabilized (Salix Applied Earthcare, 1999).

4.4 COMPOST FILTER BERM (SC-4)

Compost filter berms (CFB) are sediment-trapping windrows of processed organic compost constructed across slopes, drains, or gullies (Figure 4-6). CFBs are temporary or permanent water permeable structures that function to intersect and release runoff in a manner similar to grass hedges (Section 3.2.4). As sediment-laden runoff reaches the windrow, it slows down, spreads out, drops its sediment load, and slowly oozes through the berm (Figures 4-7 to 4-11).

CFB have also exhibited the capacity to filter runoff as it permeates through the compost media. Compost produced from vegetation can greatly reduce total phosphorus and some heavy metals in stormwater runoff. The stable, insoluble, high molecular weight biopolymer humic compounds in compost act as polyelectrolytes that effectively adsorb nutrients, heavy metals, and other contaminants from runoff as it slowly moves through the berm. Depending on concentration, some materials filtered by the compost may also undergo bioremediation in which microorganisms metabolize contaminants into stable, harmless constituents such as carbon dioxide, water, and salt (USEPA, 1997).

Figure 4-6. Installation of a Compost Filter Berm Across a Roadside Drainway
(http://www.dot.state.tx.us/des/landscape/compost/berm_examples.htm)

Figure 4-7. Roadside Drainway Compost Filter Berm Depicted in Figure 4-8 Following a Greater Than 2 inch Rainfall Event
(http://www.dot.state.tx.us/des/landscape/compost/berm_examples.htm)

Figure 4-8. Water Permeable Compost Filter Berm Sediment Retention
(http://www.dot.state.tx.us/des/landscape/compost/berm_examples.htm)

Figure 4-9. Vegetated Road Drainway Compost Filter Berm and Ditch Soft Armoring
(http://www.dot.state.tx.us/des/landscape/compost/berm_examples.htm)

Figure 4-10. Compost Filter Berm Installed Across a Relatively Level Slope
(www.landsourceorganix.com)

Figure 4-11. Compost Filter Berm Installed Across a Steep Slope
(www.landsourceorganix.com)

This is in sharp contrast to impermeable hard structures such as concrete berms and silt fence and hay bale barriers that often cause extensive upstream ponding, diminished vegetative cover, and/or increased erosion (Figures 4-12 and 4-13). Under heavy rainfall conditions, ponded water that breaches these structures can result in extensive soil erosion and structure failure (Figure 4-3). As discussed in the previous section, silt fences and hay bales must be installed to rigid labor-intensive specifications; otherwise their effectiveness is significantly reduced. Generally CFBs are more

effective than silt fences and hay bales in controlling total suspended solids (TSS) in stormwater runoff.

Figure 4-12. Comparison of Adjacent Roadside Drain Compost Filter Berm and Silt Fence Conditions
(http://www.dot.state.tx.us/des/landscape/compost/berm_examples.htm)

Figure 4-13. Impermeable Roadside Ditch Concrete Berm (Photo by Mike Rainer)

In many situations, CFBs are to be considered a preferred alternative to silt fence and hay bale barriers. Comparative studies of silt fences and CFBs conducted by W&H Pacific and CH2M-Hill (1993) found that CFBs were more effective in controlling stormwater runoff sediment and TSS than silt fencing. Silt fences reduced stormwater runoff total solids by 39 percent, whereas coarse grade mixed yard debris CFBs decreased total solids by 83 percent. A study by Caine (2001) found that CFBs reduced runoff turbidity by 67 percent and silt fences produced no measurable decrease in turbidity.

CFBs are biodegradable (no disposal required) structures that are easier to construct and maintain compared to expensive, labor-intensive hard structures. In some cases, CFBs cost approximately 30 percent less to install and maintain than silt fences. CFBs can be installed stand-alone or in combination with compost mulch (Section 2.4.4) to further protect the slope. The practice also provides a fertile media for establishing vegetation, which further increases their effectiveness and longevity.

Compost berm planning considerations and construction specifications are as follows.

- Compost materials to be used for CFBs must meet the criteria specified in Table 4-1.
- CFBs are generally used in areas experiencing sheet water flow conditions. High water retention or velocity behind the berm may cause structural failures unless the berm is stabilized with open weave geotextile fabric. The practice may be used on steep slopes up to and exceeding 2:1 (horizontal distance : vertical distance) and other areas where silt fences and hay bales are applicable.

Table 4-1. Compost Filter Berm Media Composition Requirements

Parameters	Units of Measure	Vegetated Berm	Unvegetated Berm
pH	pH units	5.0-8.5	N/A
Soluble Salt Concentration	dS/m (mmhos/cm)	Maximum 5	N/A
Moisture Content	Percent, wet weight basis	30-60	30-60
Organic Matter Content	Percent, wet weight basis	25-65	25-100
Particle Size	Percent passing a selected mesh size, dry weight basis	• 3 inches, 100% passing • 1 inch, 90% to 100% passing • ¾ inch, 70% to 100% passing • ¼ inch, 30% to 75% passing • 98% of the material should not exceed 3 inches in length • No more than 60% passing ¼ inch in high rainfall/flow rate conditions	• 3 inches, 100% passing • 1 inch, 90% to 100% passing • ¾ inch, 70% to 100% passing • ¼ inch, 30% to 75% passing • 98% of the material should not exceed 3 inches in length • No more than 50% passing ¼ inch in high rainfall/flow rate conditions
Stability	Mg CO_2-C/ gram OM/day	<8	N/A
Physical Contaminants	Percent, dry weight basis	>1	>1

Source: American Association of State Highway and Transportation Officials (AASHTO); Designation MP-9; Washington, DC. Online: http://www.rmrc.unh.edu/Research/Rprojects/Project21/specs/AASHTO-MP9.pdf

- Coarse grade leaf compost works best for controlling turbidity, whereas medium and coarse grade yard debris can also be effective at controlling sediment and TSS. Very coarse, woody composts containing less than 30 percent fine particles less than 1 mm in size should be avoided if optimum conditions for TSS reductions are required or if the CFB is to be vegetated.
- Construct a trapezoidal berm along the slope contour or around the perimeter of the treatment area. The size of the CFB should range from 1.5' × 3' to 2' × 4' depending on treatment area conditions such as slope steepness and length. The windrow should always be twice as wide at the base as it is high. When used in series along the full length of slopes, CFBs are spaced 15 to 25 feet apart.
- Construction requirements for 1' × 2.5' and 1.5' × 3' CFBs are presented in Table 4-2.

Table 4-2. Comparison of Compost Filter Berm Construction Requirements

Dimensions	Profile Area (square feet)	Linear Feet/Cubic Yard
1 × 2.5	1.4	18.8
1.5 × 3	4.5	7.6

- Apply the compost uniformly by hand or using equipment such as pneumatic blowers (Figure 4-6) and specialized berm machines. During application, the compost should be directed at the soil surface. Shape but do not compact the berm during installation. When

constructed on slopes, curve the ends of the CFB upslope at least 6 feet to prevent retained water from eroding the ends of the structure.

- If the CFB is to remain as a permanent landscape feature, seed during construction. Seed may be applied during pneumatic blowing or following construction by hydraulic or hand seeding (Section 2.3.2.2). Apply vegetation over and in front and behind the berm for a distance of 5 feet. Use a revegetation protocol appropriate for the site conditions (Section 2.3.1). No fertilize or soil amendments are required for vegetation establishment.
- Once sediment reaches 1/3 to 1/2 of the height of the windrow, additional CFBs may be installed immediately uphill of the existing berm.

5. CROSSING STRUCTURE PRACTICES

This chapter describes culvert and low water crossing structure practices designed to maximize the life of the structure and minimize waterway impact potentials.

5.1 INTRODUCTION

As with roadways and roadside areas, road-stream crossings require attention to maximize the trafficability of the crossing and minimize environmental impact potentials. In this section, special attention is given to installing practices that improve the function and stability of crossing culvert and stream low water crossing structures, to facilitate temporary stream crossings, and to provide a means for replacing culverts and restoring channel gradients under workable conditions. The crossing structure practices discussed in the following subsections include:

- Stream Culverts (CS-1)
- Flood Relief Culverts (CS-2)
- Riprap (CS-3)
- Improved Low Water Crossing (CS-4)
- Stream Diversion (CS-5)
- Portable Bridge (CS-6)

5.2 STREAM CULVERTS (CS-1)

Pipe culvert crossings are one of the most common types of stream crossing structures used on unpaved road systems. These structures are relatively easy to install and can provide long-term service if properly designed and maintained. Culverts should be large enough to convey bankfull stream flow with minimal alteration of the stream's flow characteristics. Culvert stream crossings are generally limited to three pipe culverts per crossing. Normal water levels should rise no higher than half the diameter of the pipe. The elements of proper culvert installation are shown in Figure 5-1.

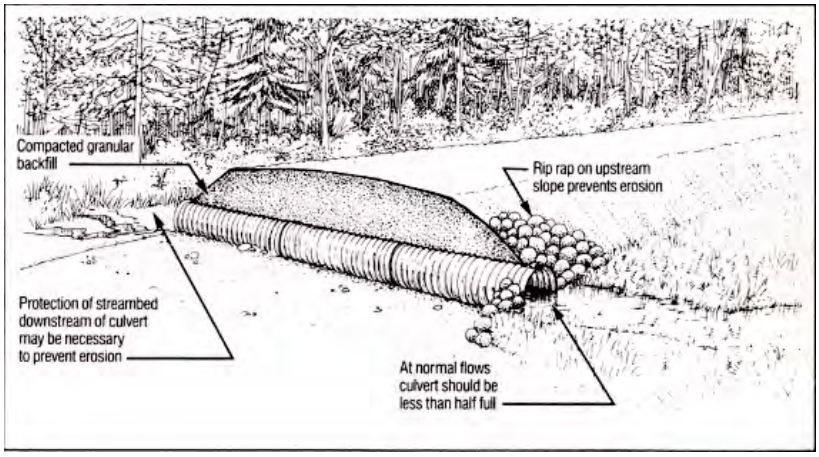


Figure 5-1. Elements of Proper Culvert Installation
(Ontario Ministry of Natural Resources, 1995)

Open bottom culverts that allow the natural stream to flow unencumbered through the crossing is the preferred culvert type; however, if it is not possible to install an open bottom culvert because of streambed geotechnical restrictions, other types of crossing culverts are considered. Since culvert geometry and roughness are different than a stream channel, it is not likely that selected culverts will exactly match the conveyance properties of the stream channel. Culvert installation guidelines are presented below.

- The length of the culvert will be adequate to extend the full width of the crossing including side slopes. Culverts should be long enough to ensure that the inlet and outlet cannot be blocked by road embankment material encroachment.
- Culvert width should be comparable to the reference stream section bankfull width. Where possible, provide for bankfull flow with a single pipe or box culvert. Otherwise, install multiple pipe culverts or multi-cell box structures to minimize bankfull flow disruption.
- For streams where fish passage is a consideration, embed the stream culvert one to two feet below the existing streambed. For multiple culvert installation, the stream will adjust its thalweg and cross section and select one culvert allowing fish passage during low flows.
- Headwalls can be installed to stabilize fill slopes, prevent seepage through backfill, retain backfill, and anchor culverts. Types of headwalls include concrete, cemented rock, gabions, riprap, log crib or abutment, and sandbags. Headwalls are used when the hydraulic capacity needs to be increased. The headwall extensions or wings help mold and direct channel flow into the culvert and protect the inlet from scour.
- If possible, culverts should be installed in a dry or low water environment. For stream channels with severe changes in gradient at the crossing, the channel may need to be diverted around the work site during construction; otherwise the culvert may be improperly set, resulting in further channel degradation. As applicable, schedule work during the dry times of the year.
- Single stream crossing pipes will be placed *on-grade* with the existing stream bottom and at the same slope gradient as the stream such that the inlet and outlet are set as least 8 inches into the streambed. For multiple culvert installations, place the culverts a minimum of 3 feet apart to allow adequate compaction of fill material, and the bottom of only one culvert need be set at 8 inches below the streambed. Avoid drop-offs at the ends of culverts.
- Orient culverts with the natural channel so as not to present an angular deviation from the natural channel form. At the inlet approach, the channel should be narrow or confined and have a natural cross-section and non-meandering thalweg so the stream flow has an overall consistent velocity and high energy to encourage the passage of sediment and woody debris through the structure. Do not widen the culvert inlet basin during maintenance since it tends to promote the accumulation of sediment and wood debris at the inlet.
- Place culverts on stable foundations. If soft, unstable foundation materials are encountered, the area should be excavated below grade and backfilled with uniform gravel material. The excavated area width should be twice the diameter of the culvert and as deep as foundation needs require.
- The load carrying capacity of culverts is dependent on proper backfilling. Properly placed and compacted backfill also prevents washouts and settling; this is particularly important with large culverts. The overall performance and integrity of the structure and its capability to distribute trafficking pressures to the adjourning soil mass relies on the selection, placement, and compaction of backfill material.

- Bank, pit run gravel, and coarse sands make good backfill material. Coarse materials resist erosion more than fine soil materials. Fill material should not be borrowed from the stream channel except as part of a designed channel improvement.
- Place backfill under the haunches of the culvert and tamp, using light tamping equipment. Backfill is placed equally on both sides of the culvert pipe or arch in layers 6 to 8 inches thick and thoroughly compacted. Work fill material by hand or mechanical equipment, tamping rollers, or vibrating compactors until all voids are removed. Most culvert failures are a result of inadequate compaction during backfilling. Compacted layers must extend for at least one diameter on each side of the structure to a minimum depth (Table 5-1).

Table 5-1. Corrugated Steel Pipe Backfill Specifications

Pipe Diameter (mm)	Corrugation Profile (mm × mm)	Wall Thickness (mm)	Minimum Cover (ft)	Pounds/Foot
400	68 × 13	1.6	1.0	12.8
500	68 × 13	1.6	1.0	16.1
600	68 × 13	1.6	1.0	18.8
700	68 × 13	2.0	1.3	27.6
800	68 × 13	2.0	1.3	31.6
900	68 × 13	2.0	1.5	35.6
1,000	68 × 13	2.0	1.6	40.0
1,200	68 × 13	2.8	2.0	65.2
1,400	68 × 13	2.8	2.0	76.0
1,600	68 × 13	3.5	2.0	107.5
1,800	68 × 13	3.5	2.0	120.3
1,600	125 × 25[a]	2.0	2.0	63.8
1,800	125 × 25	2.8	2.0	99.5

[a] The 125 × 25 corrugation can provide greater strength with a lighter gauge material and its weight is considerably less.
To convert millimeters (mm) to inches multiply by 0.03937, and to convert to feet multiply by 0.00328

- If the terrain and trafficking characteristics of the road allow, construct a dip or depression in the approach grade to allow water to overflow the structure if the pipe capacity is exceeded during catastrophic flooding events, minimizing crossing washout potentials (Figure 5-2).

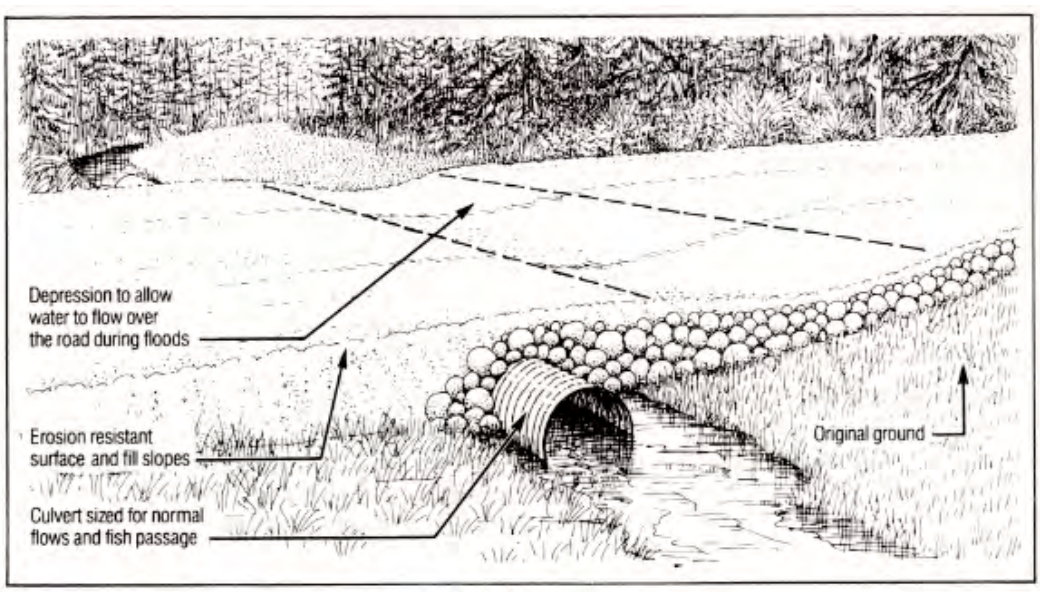


Figure 5-2. Culvert Water Crossing with an Overflow Depression
(Ontario Ministry of Natural Resources, 1995)

- Stabilize all culvert fill slopes to a height of at least one pipe diameter above the top of the culvert and a minimum of one pipe diameter on either side. Revegetate disturbed and exposed fill slope areas on each side of the riprap and the top of the road to the toe of the fill.

Culverted stream crossings are frequently a significant source of road delivered sediment (Reid and Dunne, 1984; Bilby et al., 1989; Megahan et al., 1991). An improperly sized, installed, or maintained culverted stream crossing can cause large sediment inputs, particularly during storm events when the hydraulic capacity of the culvert is exceeded or if the culvert inlet is plugged. If water overtops the culvert structure, catastrophic backfill failure and subsequent stream sedimentation can result.

The principal mechanisms of culvert failure are twofold: 1) excessive stream discharge relative to the hydraulic capacity of the culvert, and 2) culvert plugging by sediment slugs and/or organic debris lodgement during peak flows. There are design techniques for roughly predicting stream discharges; however, other than designer intuition, no specific engineering techniques for assessing culvert-plugging hazards are known. This is crucial, since under certain circumstances culvert plugging can cause catastrophic structure failure even during a moderate storm event. The extreme dynamics and uncertainties of potential flooding events and debris flows may circumvent the best professional engineering designs or result in expensive and impractical stream crossing structure overbuilding.

Designing culvert crossings to withstand severe flooding events such as might occur during a hurricane or other severe storm is an impractical approach because it is equally difficult to predict which culverts will fail. The size and intensity of the storm events have been shown to play a major role in the type and distribution of structure failure.

Large intense storms tend to generate structure failures because of the increased sizes and volumes of culvert plugging materials, whereas in smaller storms that generally transport less upslope material, the proportion of exceedence of hydraulic capacity may be higher and small woody debris failures more frequent. As storm headwaters are ponded at the culvert inlet, the woody debris rafts that may form often plug the inlet, causing an exceedance of the inlet capacity. It is concluded that because of the potential for debris plugging to play such a major role in structure failure, the sole reliance on the use of culvert hydraulic capacity modeling for predicting structure failure may be undependable.

It may therefore be prudent to assume that all culverts may fail and the stream crossing design process may best be served by incorporating techniques that minimize the potential for and consequences of structure failure. Understanding structure weaknesses and failure mechanisms sets the framework for engineering stream crossings that fully support long-term transportation needs while minimizing the potential consequences of structure failure. Techniques for minimizing the potential for and consequences of culvert failure include:

1. *Install Coarse, Thoroughly Compacted Backfill*: Designs should include the maximum allowable amount of coarse fill material to reduce the sedimentation consequences of a crossing failure. Typically, during a culvert failure event, compacted fill will progressively gully out while poorly compacted fills are more likely to fail catastrophically. Therefore, the downstream consequences of compacted fill failure are much less because the stream can transport sediment added in increments versus rapid sediment influx that characterizes the catastrophic failure of uncompacted fill.

2. *Design Backfill at Minimum Cover Levels*: Design the smallest backfill cover possible. Minimum cover reduces the amount of material that could erode into the stream during floods.
3. *Install Road Spillage Depressions*: Depressions allow floodwater that would otherwise overtop and erode backfill material to transition over land in a less erosive manner. Floodwater depressions also prevent channel diversions by ensuring that floodwater does not leave the existing channel (Figure 5-2).
4. *Avoid Disturbance of Streambank Vegetation Along the Approach to the Culvert Inlet*: Native vegetation along the upstream channel margins serves to maintain the integrity and stability of the channel banks, which improves the passage of debris and sediment through the culvert. Widening of the inlet basin during installation or maintenance actually promotes culvert plugging.
5. *Install Arch Culverts on Primary and Secondary Road Culverted Small Stream Crossings:* Unlike conventional round culverts that may increase water velocity and create plunge pools at culvert outlets, the open bottom of the arch culvert allows the stream to maintain natural, unencumbered water flow, which is critical to the maintenance of fish habitat and migration corridors. Matching the culvert diameter to the channel width also minimizes structure failure potentials because the structure installation does not change the cross-section of the channel, which minimizes the potential for structure plugging and failure.
6. *Install Improved Low Water Crossings (LWC) on Small Stream Crossings to the Degree Possible*: Improved stream LWCs present the least sedimentation consequence of flow/structure exceedence and subsequent failure and the least detrimental impact on water quality when crossings by vehicles are infrequent. LWCs are a preferred alternative for low-traffic roads that cross small streams.

The past performance of culverted stream crossings can be readily interpreted by existing physical evidence. Field observations coupled with watershed data provide information for screening potential culvert failure sites and identifying structured sites that need modification or removal. Field indicators include channel versus culvert inlet diameter, inlet basin geometry and morphology, and crushing and plugging of the inlet (USDA Forest Service, 1997).

5.3 FLOOD RELIEF CULVERTS (CS-2)

Sedimentation of floodplains by road fill materials can have long-term impacts on stream geomorphology. Flood relief culverts are installed in the floodplain portion of the crossing to convey floodplain flows and reduce the potential hydrologic load on the main channel culvert and increase culvert outlet energy dissipation during bankfull events (Figure 5-3). As flood flows move downstream, water can continue through the relief culverts. These types of culvert installation are particularly useful for small main culverts that tend to severely constrict stream flows potential resulting in degradation and aggradation of the stream channel downstream and upstream of the crossing respectively. Flood relief culverts may also benefit wildlife by providing a passage corridor through the crossing.

Flood relief culvert installation guidelines are presented below.

- The culvert should be located within the floodplain well beyond the channel banks.
- For streams with relatively wide floodplains, place culvert(s) on both sides of the channel.

- If the floodplain is constricted, place the culvert(s) on the inside of the channel bend to avoid convergence and high velocity flows on the outside of the stream bend.
- Set the upstream culvert invert at the bankfull flow elevation.
- Provide for bankfull flow freeboard that is equal to the maximum bankfull channel depth.
- Protect the culvert outlet and inlet in a manner that takes into account the likelihood of upstream channel lateral migration and/or degradation and scour of the downstream channel over the design life of the culvert.
- Install riprap (Section 5.4) at the culvert outlet to maximize energy dissipation and minimize scour potentials.

Figure 5-3. Restored Stream Channel Flood Relief Culverts
(Photo by Chris Metcalf)

5.4 RIPRAP (CS-3)

Riprap is a layer of stone designed to protect and stabilize soil areas surrounding road-stream crossing culverts subject to erosion (Figure 5-4). The purpose of riprap is to protect the crossing fill soil surface from erosive forces, slow the velocity of concentrated runoff, and/or improve stability of fill soils subject to seepage or poor soil structure. Road-stream crossing riprap installation procedures are discussed below and presented in Figure 5-5.

- Before laying riprap and filler, prepare the subgrade to the required lines and grades shown on the design plans. Compact any fill required in the subgrade to a density approximating that of the surrounding undisturbed material. Overfill depressions with riprap.
- Cut the subgrade sufficiently deep so that the finished grade of the riprap will be at the elevation of the surrounding area. Excavate sufficiently to allow placement of the riprap in a manner such that the finished 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 and space anchor pins every 3 feet along the overlap. Bury the upper and lower ends of the cloth a minimum of 12 inches 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 around the damaged area. If extensive damage is suspected, remove and replace the entire sheet.

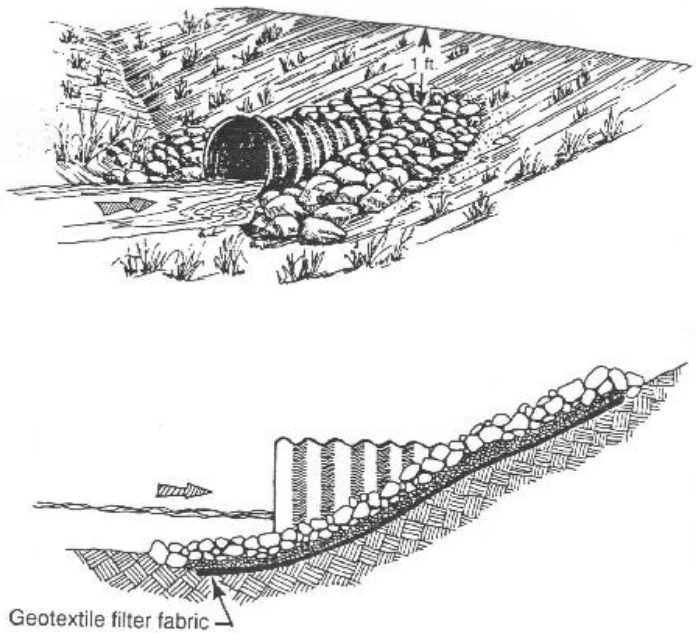


Figure 5-4. Riprap Installed on a Crossing Fill Culvert Inlet

- Where large stones are used or machine placement is difficult, a 4-inch 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 of 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.

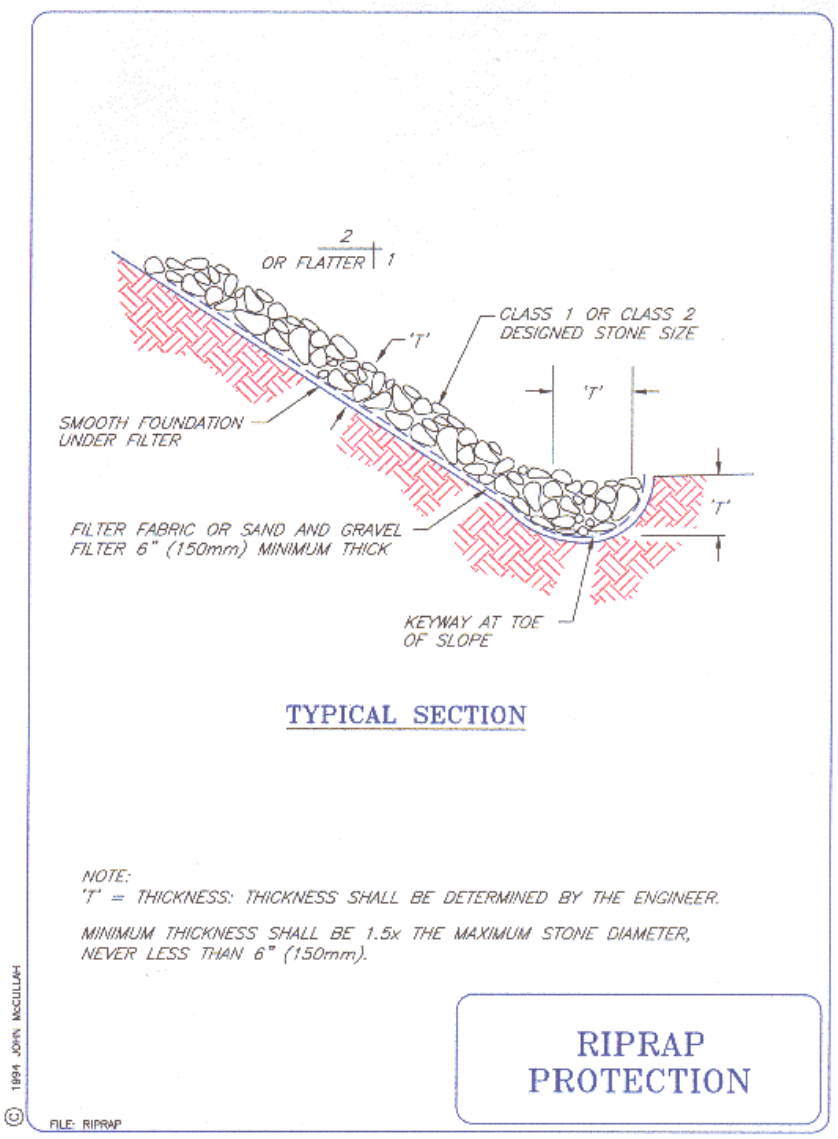


Figure 5-5. Typical Riprap Section (Salix Applied Earthcare)

5.5 IMPROVED LOW WATER CROSSING (CS-4)

Low water crossings (LWCs) or fords are structures that allow vehicles to drive through the watercourse. The purpose of an LWC is to provide a safe, erosion-free, and storm-proof stream crossing that requires little or no maintenance. Problems inherent to culverts and bridges such as size of the opening, provision for debris and sediment passage, and channel or embankment riprap are largely avoided. LWCs can be effective in reducing impacts to drainage systems prone to debris torrents and erratic storms and isolated areas with limited access to maintenance equipment. The use of LWCs is primarily applicable to small, shallow (less than 3 feet deep), low water flow perennial or intermittent streams comprised of coarse gravel, particularly if road use is light or limited to the dry season when little or no water is flowing through the channel.

General improved LWC design considerations include:

- LWCs are installed at right angles to the channel and should not exceed widths of 32 feet.
- Accommodate fish passage over the LWC by maintaining water depths of at least 8 inches or the natural stream depth for the location.
- Construct LWCs during the driest periods of the year.
- The road profile should dip into and out of the stream, creating a concave shape.
- Stabilize 50 feet of each stream bank approach with non-erosive materials and minimize the removal or disturbance on native vegetation.
- In all cases, the natural carrying capacity of the streambed will require amendment of the LWC subgrade with coarse gravel and installation of a geocellular confinement system road base.

The sandy materials that typically comprise streambeds are inherently unstable and unsuited for vehicle load support. The type of LWC structure used at a stream crossing generally depends on the stream flow regime. If the stream is perennial, consider using a geocellular crossing, and if the stream is intermittent or goes dry during the year, consider a gabion crossing structure. Vented concrete fords may also be applicable under certain conditions.

Semi-rigid, honeycomb pattern geocellular systems provide a stable LWC road base for vehicular use. Geocell load support confinement systems are comprised of interconnected polyethylene strips expanded to form the walls of a cellular confinement structure that are packed with granular fill material. Geocell systems act as semi-rigid slabs that distribute loads laterally, reduce subgrade contact pressures, and minimize load deformation and settlement. Load deformation performance is optimized due to the loop strength of individual cells, the passive resistance of infill material in adjacent cells, and the vertical stress transfer to adjoining cells (Figure 5-6).

Figure 5-6. Improved Geocell Low Water Crossing (Photo by Mike Rainer)

Geocell LWC structure installation procedures are as follows.

1. Grade ramp approaches and remove in-situ stream profile materials and replace with coarse gravel/rock subgrade aggregate: Grade a 50-foot approach ramp on each streambank. Excavate the stream profile to the design concave configuration and replace unstable native stream materials with a stable aggregate subgrade of gravel/rock materials (Figure 5-7). Use a track mounted hydraulic excavator with a reach of 25 feet for best results; otherwise, a tracked front-end loader with a 4 in 1 clamshell bucket and a large rubber tired backhoe may be used. Compact the subgrade to the design grade. Following grade and subgrade fill operations, establish the alignment of the structure with offset perimeter stakes that identify line and grade changes. Avoid trafficking of subgraded aggregate with heavy equipment prior to compaction of geocells (Step 5).
2. Install a nonwoven geotextile over subgrade materials: A geotextile layer is required to prevent the mixing of subgrade materials with geocell infill aggregates and also serves as subgrade reinforcement. Geotextile rolls are normally 13 to 20 feet wide. The geotextile sections are overlapped or sewn and anchored according to the manufacturer's specifications. Overlap joints in the direction of fill placement to avoid separation of the geotextile. During windy conditions, temporarily anchor the overlapped joints with staples or placement of a small amount of fill along the joint.
3. Expand geocell confinement system sections into position, set at grade, and anchor. The minimum height geocell for a LWC is eight inches. Hook the edge of geocell sections over temporary stakes and fully expand each section. Do not attempt to assemble all the sections together and drag them into place as a single unit. Position and anchor each geocell section according to the manufacturer's specifications.
4. Place infill material into geocells and uniformly compact: For best performance, load support infill materials should be comprised of AASHTO No. 2 stone with a minimum particle size of 2 inches. Dump the fill directly into the cells with a front-end loader or backhoe and overfill the geocells at least 2 inches above the cell walls. Limit the drop height of fill material to 3 feet. Uniformly compact infill material with a small smooth-drum roller or vibratory plate compactor, avoiding exposure of the cell walls. Uniform compaction greatly increases the load spreading capacity of the structure. If the compaction equipment creates a wave in the infilled geocells, the equipment is too heavy (USDA, No date).
5. Replant disturbed sections of the streambank and road slopes with appropriate soil seed mixes as specified in Revegetation Protocols.

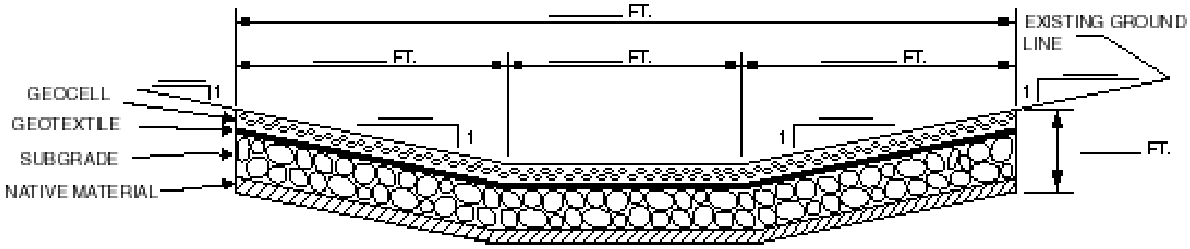


Figure 5-7. LWC Stream Crossing Design Profile

5.6 STREAM DIVERSION (CS-5)

A stream diversion channel is a temporary channel constructed to convey stream flow around the work site while the crossing structure is replaced or permanently removed. The purpose is to minimize erosion potentials and allow work to proceed under less saturated conditions. Synthetic materials are used to line the bottom and sides of the temporary channel and water structure channel plugs serve to divert channel flow. Attempts to replace or remove stream crossing structures and fill materials from a flowing stream could result in the release of extensive amounts of sediment into the stream. Under "dry dock" type conditions, created in the original channel by a stream diversion, stream crossing structures and fill materials can be replaced or removed in a less disruptive, more precise manner. Dry dock conditions also afford the opportunity to reestablish stable channel configurations and gradients.

Upstream sediment deposition and downstream scouring caused by improper stream culvert design and/or installation can result in dramatic variations between upstream and downstream channel elevations of several feet. As an example, the upstream channel morphology (depth, width, and gradient) of the northwest Florida stream in Figure 5-8 was drastically altered by extensive sedimentation from surrounding lands. Unencumbered sediment delivery has resulted in enlargement of the stream channel from approximately 10 feet wide to greater than 100 feet. The difference in elevation between the upstream and downstream channel at the crossing was approximately 3 feet.

Figure 5-8. Extensively Altered Upstream Channel (Photo by Mike Rainer)

Following culvert structural failure, the crossing was reconstructed with three new culverts (Figure 5-9). The culverts were placed in the stream at the existing upstream channel elevation under wet conditions with no attempts made to correct the disparity in channel gradients at the crossing.

As a result, the degraded stream channel conditions remain on both sides of the crossing. The broad, shallow upstream channel exhibits extensive lateral stress and sediment deposition. The downstream culvert outfall is approximately 2.5 feet above the existing channel, which prevents the migration of a federally listed fish species known to occur within the stream and promotes extensive channel scouring during peak flow periods (Figure 5-9).

Figure 5-9. Downstream Outfall (Photo by Mike Rainer)

This exemplifies the type of degraded channel conditions and variations in upstream and downstream gradients in which stream diversion may be useful. Stream channel diversions afford an opportunity to avoid potential aquatic habitat degradation by reestablishing channel stability under favorable dry dock type conditions. In the absence of flowing water, degraded stream channels and crossing structures can be realigned and transition gradients between stream segments established to design specifications.

A properly constructed and lined diversion channel requires a channel plug to prevent stream water from entering the work area. Earthen berms can be constructed to dam the stream water but are prone to erosion and seepage. However, commercial water structures are available to contain, divert, and control water flow. Polypropylene water filled tubes can be positioned across the stream channel to form a stable levee.

The structures are heavy and flexible when filled with water, which allows them to conform to uneven terrain and obtain an effective seal between the ground and the structure (Figures 5-10 and 5-11). Structures generally range from 1 to 10 feet in height, come in standard lengths of 50 to 100 feet, and can be connected in almost limitless configurations.

Stream diversion installation guidelines include:

- Diversion channels are not normally required for removing structures and fill from streams with intermittent to low water flow conditions. Diversions should also be avoided where impacts to sensitive wetlands are imminent. Where in-stream work is unavoidable, the time spent working in the channel shall be minimized. To limit disturbance, overland pumping of the stream may be considered in low flow conditions.
- Prior to construction of the diversion cross-section, survey the existing channel 200 feet upstream and downstream at 50-foot intervals. Cross-section data are to be used to reconfigure the channel profile after fill material is removed and reestablish stream gradients. The dimensions of the diversion channel are also based on survey data.

Figure 5-10. Upstream View of a Stream Diversion (Aquadam®)

Figure 5-11. Downstream View of a Stream Diversion (Aquadam®)

- Excavate the temporary diversion channel to design specifications and install water structure plugs at each end. Consult with water structure manufacturer for installation instructions.
- A silt fence, water structure, or berm shall be placed along the sides of the channel to prevent unfiltered runoff from entering the stream. Berms can be constructed using the soil excavated for the diversion channel.
- Generally, the bottom width of the diversion channel shall be a minimum of 6 feet or equal to the bottom width of the existing streambed, whichever is greater. Side slopes shall be no greater than 2:1. The channel depth and gradient will be dependent on prevalent site conditions but will be sufficient to ensure continuous flow conditions. The diverted stream height should not exceed the stream's 2-year/24-hour frequency storm depth or be allowed to overflow the channel bank. Schedule diversion work for low flow periods. The channel surface shall be constructed at the gradient prescribed in the construction plans.
- Line the channel with the material specified in the construction plans (Figure 5-12). The outer edges of the liner shall be secured at the top of the channel with compacted soil. The type lining used in diversion channels is based on the predicted velocity of bankfull flow (Table 5-2). Geotextile is used as a protective soil cover in channels lined with riprap.

Stabilize the channel with appropriate sized riprap (Section 5.4) if channel velocity exceeds the allowable. Do not construct diversions in sensitive habitat or cultural resource areas.

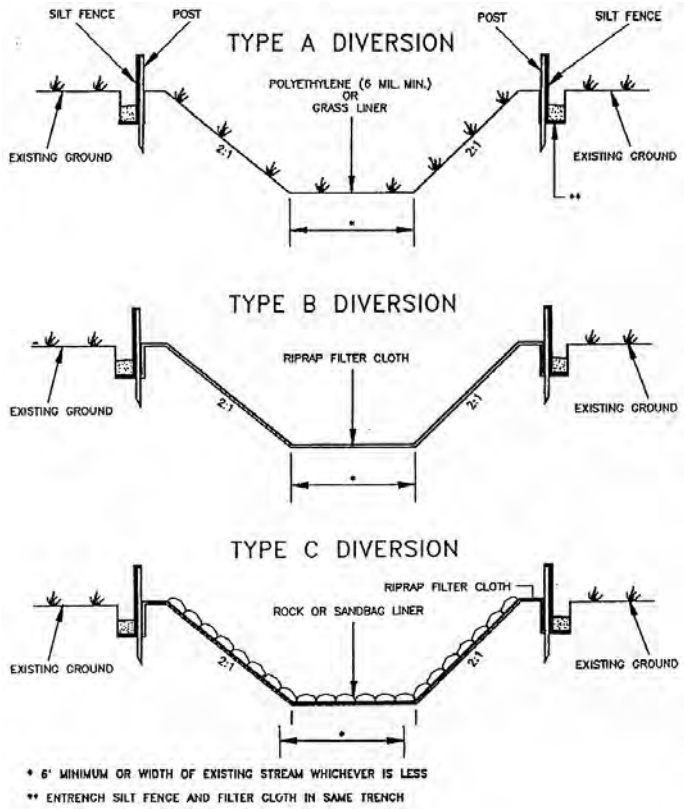


Figure 5-12. Stream Diversion Channel Lining Options

Table 5-2. Stream Diversion Channel Linings

Lining Materials	Acceptable Velocity Range (feet per second)
Geotextile or Polyethylene	0.0 - 2.5
Geotextile Alone	2.5 - 9.0
Class I Riprap and Geotextile	9.0 - 13.0

- Remove the diversion channel plugs once the liner installation is complete, removing the downstream plug first.
- Pump water from the construction area. Construct a dewatering basin if sediment removal is a potential problem. Pumped water reentering the stream is to be as clear or clearer than the receiving stream.
- Once the original steam culvert(s) is removed and the stream channel is restored to natural configurations, the diversion channel is replugged and backfilled. Salvage the liner if it is undamaged.
- Immediately revegetate areas disturbed during the diversion channel construction (USDA, No date).
- In some instances, stream flow from small channels with drainage areas of less than 5 square miles can be piped around the channel plug with a hydraulic pump.

5.7 PORTABLE BRIDGE (CS-6)

A portable bridge is a crossing structure that is installed across a stream to provide temporary access for vehicles and/or equipment (Figure 5-13). Applications may include forestry, natural resource management, utility construction, and natural disaster relief operations. In comparison to culvert and LWC crossings, portable bridge structures cause the least amount of erosion and do not impair the stream migration of aquatic species. Generally portable bridges are less expensive to install, require less maintenance, and are reusable.

Figure 5-13. Temporary Portable Bridge Stream Crossing
(http://www.eng.auburn.edu/users/staylor/timber_bridges.html)

Portable bridges are installed using pre-manufactured deck modules that are to 6 feet wide and 35 feet long. Each module is constructed of glue-laminated timbers treated with a wood preservative. The modules are installed to the design bridge deck width using excavators, loaders, crawler tractors, or similar equipment using preinstalled lifting rings. Crawler tractors may be used to winch the modules across the stream during installation. Installation time is generally less than 2 hours.

Planning guidelines for installing portable bridge structures are discussed below:

- The bridge structure alignment should be at a right angle to the stream to be crossed. Under adverse conditions, limit variation in alignment to 15 degrees off centerline. The centerline for each road approach should align with the crossing structure for a minimum of 50 feet from each streambank.
- Verify that the proposed bridge structure is of sufficient strength to support the intended traffic frequency and loading.
- The structure should be installed to span the entire stream channel.

- The crossing structure should be removed immediately after use. Following removal of the structure, revegetate (Section 2.3.1) and stabilize (Section 2.1.3) the streambank as required to restore the site to pre-construction conditions.
- Install the bridge structure above bankfull elevation to prevent the creation of debris plugs during high stream flow periods.
- The bridge deck modules are lifted and placed side by side over the stream channel. Timber footings are preset on each streambank to prevent the deck ends from settling into the soil. As required, a transverse stiffener beam may be bolted to the lower side of the bridge to distribute traffic loads.
- Anchor bridge modules with a cable or chain secured to a large tree or buried steel rod to prevent channel obstruction if floodwaters float the structure.
- Inspect the structure once a week and following major rainfall events and repair any damage immediately.

6. STREAM RESTORATION PRACTICES

This section presents practices for facilitating the natural restoration of degraded natural stream channels. The purpose of stream restoration practices is to stabilize stream gradients and existing channel banks and create stream habitats. Stream restoration practices discussed in this section include stream sediment removal, channel vanes, stream habitat features, and streambank rootwads. The restoration practices presented in this chapter do not attempt to correct problems associated with incised stream channel dimension or pattern.

6.1 INTRODUCTION

According to Rosgen (2001), the application of hard structure design variables, such as one-dimensional, uniform flow, and single objective management plans to natural streams frequently result in ineffective trapizodal channels. Structures have been used for centuries to stabilize stream channels; however, many hard structures such as gabions, concrete lined channels, spur dikes, rock jetties, reinforced revetment, log cribs, and check dams have proven to be instrumental in causing rather than reducing stream instability. In many cases, these “hard” structures violate the sediment transport and dimension, pattern, and profile attributes of stable stream systems. Hard structures are often installed as a patch for an unstable condition rather than as a practice that promotes overall stream stability and integrity.

Eight interrelated variables of natural stream design include slope, width, depth, velocity, discharge, boundary roughness, size of transported sediment, and sediment concentration. In a stable condition, these variables exist in quasi-equilibrium. Changes in one or more variables will result in subsequent adjustments of other variables to reach a new quasi-equilibrium. Channel practices that are designed and installed in a manner that do not promote quasi-equilibrium will increase channel instabilities. Properly designed, channel practices should:

- Reduce near-bank shear stress and increase or decrease stream power.
- Sustain central channel sheer stress and stream power necessary for bankfull flow and sediment transport.
- Maintain stable channel dimension, pattern, and profile.

Channel structures that reduce near-bank stress will reduce bank erosion by several orders of magnitude. Channel practices are designed and implemented to achieve the following objectives.

- Maintain stable channel width/depth ratios.
- Maintain sufficient shear stress to move large particles.
- Maintain channel capacity.
- Maintain fish passage at all flows.
- Improve fish habitat.
- Be visually compatible with natural channel features.
- Provide safe passage or enhance recreational boating.
- Cost less than traditional “hard” structures.

- Create maintenance-free diversions.
- Reduce crossing structure scour.
- Reduce erosion and sedimentation (Rosgen, 2001).

To properly design and install natural stream recovery practices, it is critical that there be a thorough understanding of the variables of local natural channels that constitute a stable stream or reference reach. The stream channel reference reach constitutes a baseline stable stream used as a blueprint for restoring impacted channels.

The selection and installation of channel structures must coincide with achieving the appropriate variable conditions that produce a stable stream channel. The recovery practices discussed below are designed with flexibility in the use of construction materials native to the site. As an example, in the relatively low sloping, sand-bottom streams of northwest Florida, it may be more appropriate to use woody materials rather than rocks in the construction of channel structures. Woody debris provides a significant component of in-channel habitat native to northwest Florida.

The stream restoration practices discussed in this section include:

- Stream Channel Sediment Removal (SR-1)
- Channel Vanes (SR-2)
- Stream Habitat Features (SR-3)
- Rootwads (SR-4)

6.2 STREAM CHANNEL SEDIMENT REMOVAL (SR-1)

Stream channel sediment removal involves the physical removal of sediments in the vicinity of the crossing structure using excavation or specialized dredging equipment (Figures 6-1 and 6-2). This practice is only employed under conditions where the stream has experienced high sediment inputs from the crossing resulting in creation of sediment bars or plugs in the immediate vicinity of the crossing structure. Natural channel design should also be considered for appropriate channel cross sectional dimensions for a stable stream channel. The purpose of the practice is to restore the natural channel flow of the stream. Stream channel sediment removal guidelines are discussed below.

- Sediment removal activities are limited 100 feet upstream and downstream of the crossing structure.
- Monitor sediment removal operations closely to ensure that stream channel deepening or widening does not occur. Maintain stream channel configurations comparable to stable reaches of the stream.
- As applicable, work shall be performed with a backhoe or excavator where relatively extensive amounts of sediment are to be removed or with hand held, portable suction devices for minor sediment removal activities. Heavy equipment is to be operated from the road crossing or stable areas adjacent to the stream.

Figure 6-1. Excavator Sediment Removal
(Streamside Systems LLC., Findlay, Ohio. Online: http://www/streamsidesystems.com/)

Figure 6-2. Portable Dredge Sediment Removal
(Streamside Systems LLC., Findlay, Ohio. Online: http://www/streamsidesystems.com/)

- Excavated sediment materials are loaded onto trucks and hauled away for disposal. Do not place removed materials on the streambanks or within the floodplain.
- The finished channel shall be free of abrupt changes in alignment and conform to natural contours above and below the excavation. The finished surfaces should be rough and uncompacted, with no ridges or depressions that may act to concentrate or pond water. The transition from finished slopes to undisturbed ground shall be smooth and free of ridges or gaps.
- Avoid damage to streambank and crossing vegetation. Revegetate disturbed areas with the appropriate revegetation protocol (Section 2.4.1).
- Structures such as J-hooks or crossover vanes may need to be constructed in the stream to stabilize and maintain the channel.

6.3 CHANNEL VANES (SR-2)

Channel vanes are in-stream structures constructed to reduce streambank shear stress and to control streambed gradients. The concentration of stream flows away from the streambank and toward the channel center created by vane structures generally increases channel depth and reduces channel bank erosion. These structures also improve aquatic habitats by increasing bank cover and creating deep pool holding areas for refuge cover and spawning habitats. Construction materials include rocks, boulders, and/or logs. Vanes are generally oriented 20 to 30 degrees off the streambank. The 20-degree angle results in a longer vane that protects a greater distance of channel bank. Common types of channel vanes discussed in this section include cross vanes, J-hooks, and W-weirs. Cross vanes and W-weirs are used when both streambanks are eroding due to channel confinement and entrenchment, whereas J-hooks are best applied to protect the outside bends of stream meanders.

6.3.1 Cross Vanes (SR-2A)

Cross vanes are channel grade control structures that direct stream flows away from the banks and reestablish the thalweg in the center of the channel. A basic premise to their design is that as water encounters physical barriers to flow, it crosses such barriers in a direction perpendicular to the structure orientation. Cross vanes can be constructed with rocks, logs, or a combination of the two. The cross vane structure is comprised of two vanes approximately one-third of the channel width and a center structure perpendicular to stream flow; the center structure sets the design grade by holding or raising streambed elevation (Figures 6-3 and 6-4). It is often placed at the head of a riffle feature in small streams or glide in larger streams. The increased stream energy towards the center of the stream and plunge effect of water crossing the vane generally creates a deepened, elongated scour pool downstream of the structure. Geotextiles are used on the upstream side of structure rocks or logs. Structure spacing is based on the relationship of pool spacing and bankfull width as a function of slope. This relationship is represented by the following calculation.

$P_s = 8.2513\ S^{-0.9799}$ Where,
P = the ratio of pool to pool spacing/bankfull width
S = channel slope in percent (Rosgen, 2001).

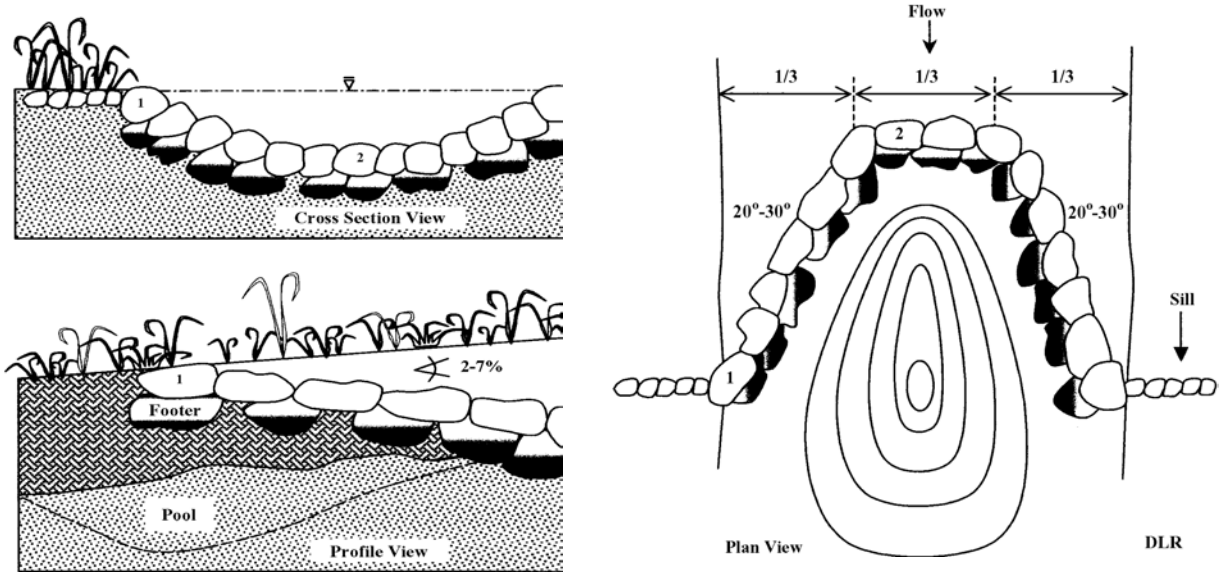


Figure 6-3. Cross Vane Structure (Rosgen, 2001)

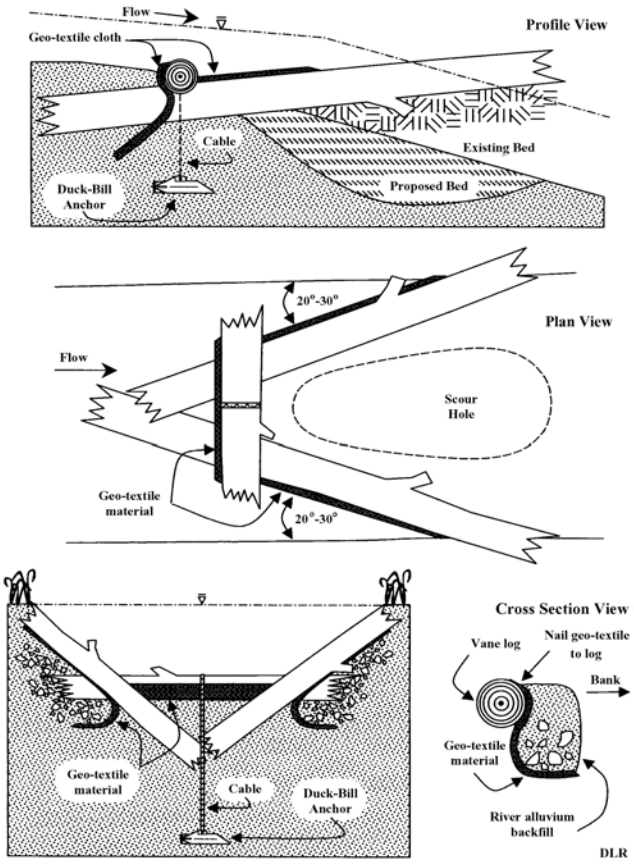


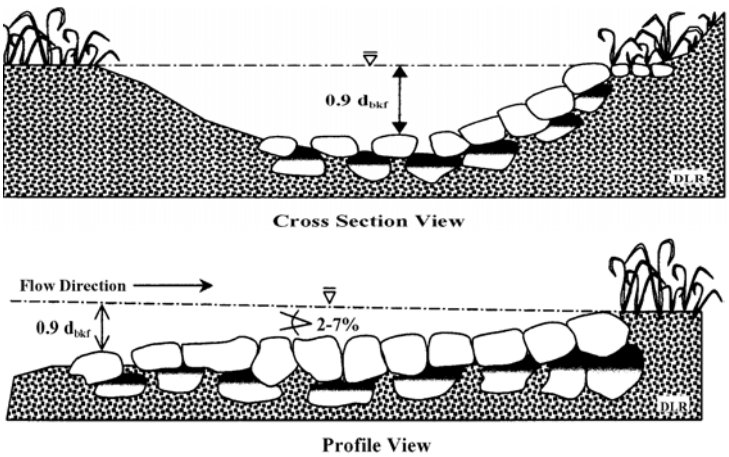
Figure 6-4. Log Cross Vane Structure (Rosgen, 2001)

6.3.2 J-Hooks (SR-2B)

The J-hook is an upstream oriented, gently sloping, bank erosion reducing structure originating at the streambank and terminating in the middle of the channel with a mid-channel J-bend back towards the structure (Figure 6-5). The structure is primarily used to reduce streambank erosion on the outside bend of channel meanders. Properly constructed and spaced, J-hooks effectively reduce the erosive effects of high velocity channel meander down- and up-welling current stress on streambank soils. In many cases, this eliminates the need for lining the bank with “hard” construction features. J-hooks also create and maintain scour pools directly downstream of the structure (Figure 6-6).

Typically, the structure is located downstream of where the stream flow encounters the streambank at acute angles and constructed next to the bank at or slightly below bankfull elevation. With the exception of the last few rocks, J-hook structure rocks are placed so they touch each other with footing rocks placed at the depth of scour. The vane portion occupies one-third of the bankfull width of the channel (Rosgen, 2001).

J-hooks may also be used in combination with logs and rootwads (Section 6.4). Specifications for surface rocks and footers are presented in Figure 6-7 and an example of a J-hook/rootwad combination is presented in Figure 6-8.



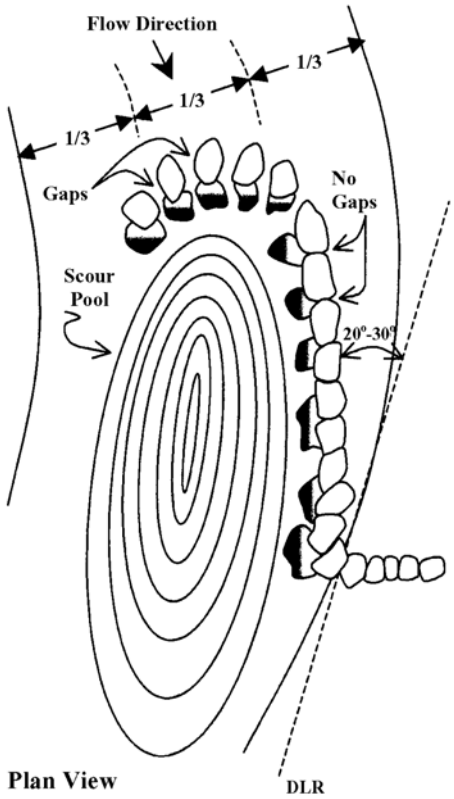


Figure 6-5. J-Hook Structure (Rosgen, 2001)

6.3.3 W-Weirs (SR-2C)

W-weirs are grade control structures similar to cross vanes that are generally used on larger streams because they typically span a large portion of the channel. The downstream facing double cross vane W formation creates two channel thalwegs (Figure 6-9). Two weirs may be constructed on very wide streams or where two bridge center piers require protection. This design is also effective in enhancing fish habitat. As with cross vanes, it is important not to leave spaces between the invert rocks. Otherwise, the top of the footer rocks rather than the structure surface rocks become the grade control elevation invert (Rosgen, 2001).

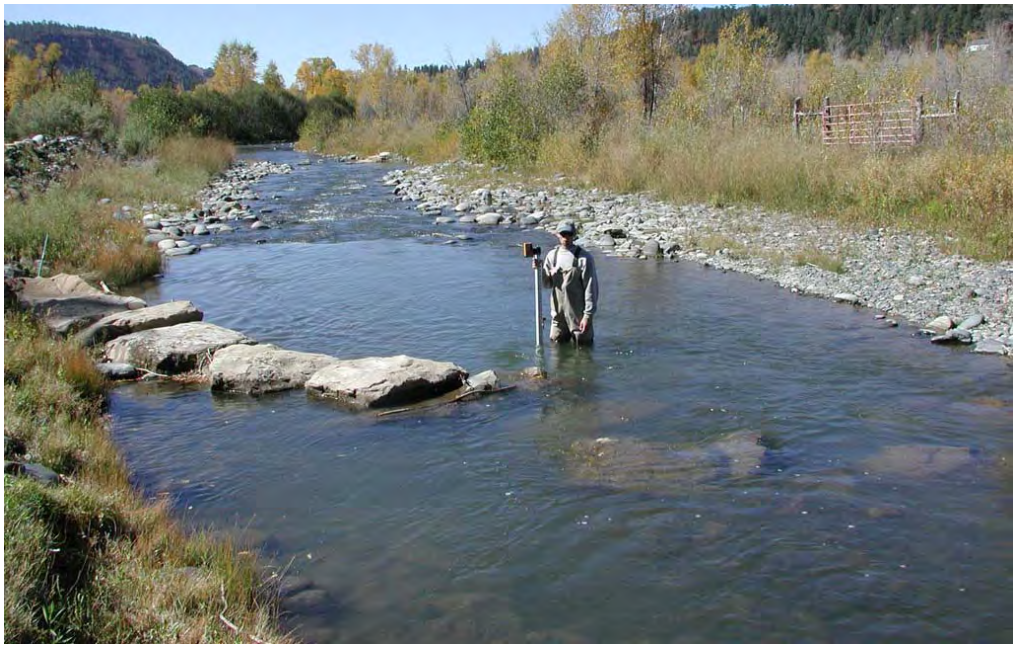


Figure 6-6. 2.5 Foot Pool Depth Below a J-Hook Structure (18 cfs) (Photo by J.D. Kurz)

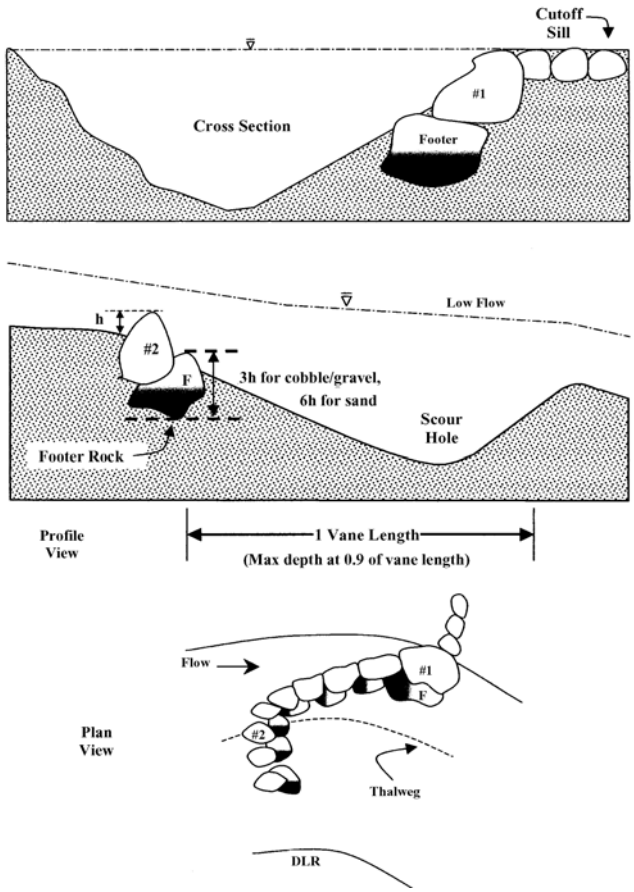


Figure 6-7. J-Hook Structure Surface and Footer Rock Specifications (Rosgen, 2001)

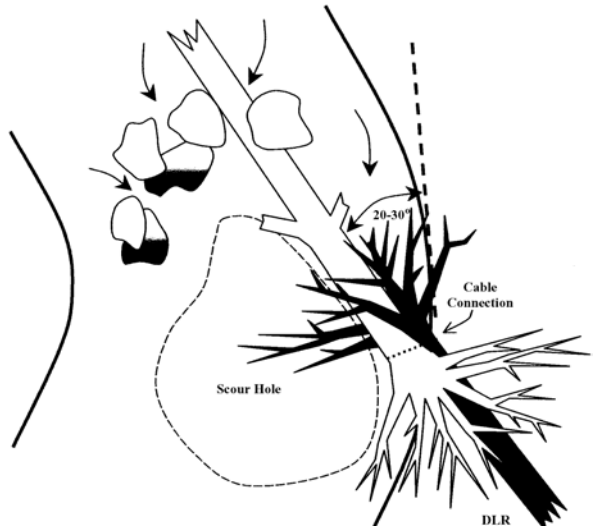


Figure 6-8. J-Hook/Rootwad Combo (Rosgen, 2001)

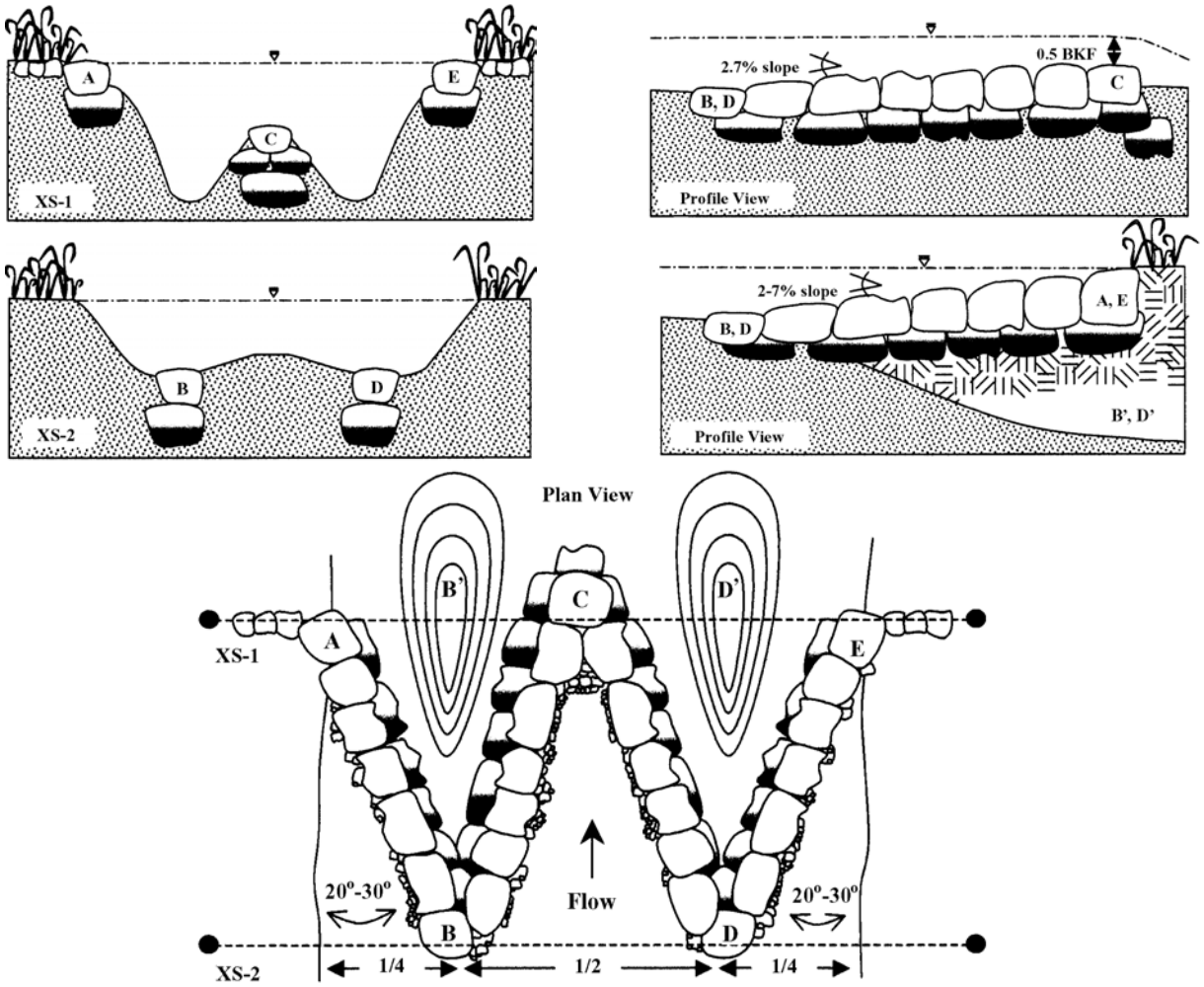


Figure 6-9. W-Weir Structure (Rosgen, 2001)

6.4 STREAM HABITAT FEATURES (SR-3)

Another component of natural stream recovery is enhancing in-stream aquatic habitats. In consideration of habitat quality, stream habitats should be structurally complex and be composed of inorganic and organic features. The overall objective is to create diverse stream habitat environments that enhance the population viability of stream ecosystem organisms. Quality aquatic habitat has adequate food and cover for all seasons, sexes, and ages. Maximizing the dispersion and diversity of habitat types increases the likelihood of providing flora and fauna species habitat requirements.

Vane structures previously discussed greatly enhance habitats, particularly with respect to reestablishing riffle/pool sequences and protecting streambank vegetation that provides a diversity of habitats. Habitat features particularly important to the sandy streams of northwest Florida that are discussed in the following sections include woody debris, overhanging vegetation, floodplain depressions, aquatic plants, deep pools, and streambed coarse substrates.

The beneficial influence of woody debris (WD) on channel morphology and aquatic habitat is well documented (Lassettre, 1999; Oregon State University, 2000; Herrig and Shute, 2001). A study by Angermeier and Karr (1984) of small streams in Illinois identified a direct correlation between the

abundance of in-stream WD and the abundance of stream organisms. When WD was removed from one side of a stream reach and not the other, fish and benthic invertebrates were usually more abundant on the side of the stream with WD than the side without. Most large fish avoided stream reaches without debris; however, some darter fish species were found to prefer stream reaches without debris. Stream reach debris removal was typically followed by rapid decreases in water depth and occurrence of benthic organic litter and increases in channel flow velocities. The significance of fish associations with WD was found to be more related to camouflage and escape cover than food availability. Various invertebrates including chironomids, trichopterans, and ephemeropterans quickly colonized WD that was introduced into streams.

WD may be placed within the stream channel or within the floodplain where it becomes available during flood events. However, WD can only be placed in floodplains in moderation; too much large debris could result in extensive downstream logjams and bank erosion. WD placed in pools or lodged into the streambanks provides habitats for fish and snags that create highly productive leaf/debris plugs (Seehorn, 1992). The types of WD practices discussed in the following subsections include cover logs and tree cover.

6.4.1 Cover Logs (SR-3A)

Cover log (CL) structures are used in portions of stream reaches where water depth is adequate but cover is lacking. CLs can be any shape, length, or size. In many cases, the greatest amount of habitat is created by using large (greater than 16 inches in diameter), crooked, irregular surfaced logs. Limb stubs can be retained on logs to increase spot scouring of the streambed (Figures 6-10 and 6-11).

Stream features where CLs are usually installed include open pools, runs, and/or flats; meanders are often ideal locations for installing streambank CLs. Streambank CLs can be anchored with rebar or attached to abutment logs or large trees in the bank (Figure 6-12). In-stream CLs are usually anchored to the streambed with long rebar. CL structures are also used in combination with rootwads (Section 6.4). Generally in-stream CLs are placed parallel or at a slight angle to flow and streambank CLs are installed at a slight angle to flow (Seehorn, 1992).

Figure 6-10. In-Stream Cover Logs (Seehorn, 1992)

Figure 6-11. Stream Cover Logs
(http://www.krisweb.com/krisweb_kt/restore/sftrestor.htm)

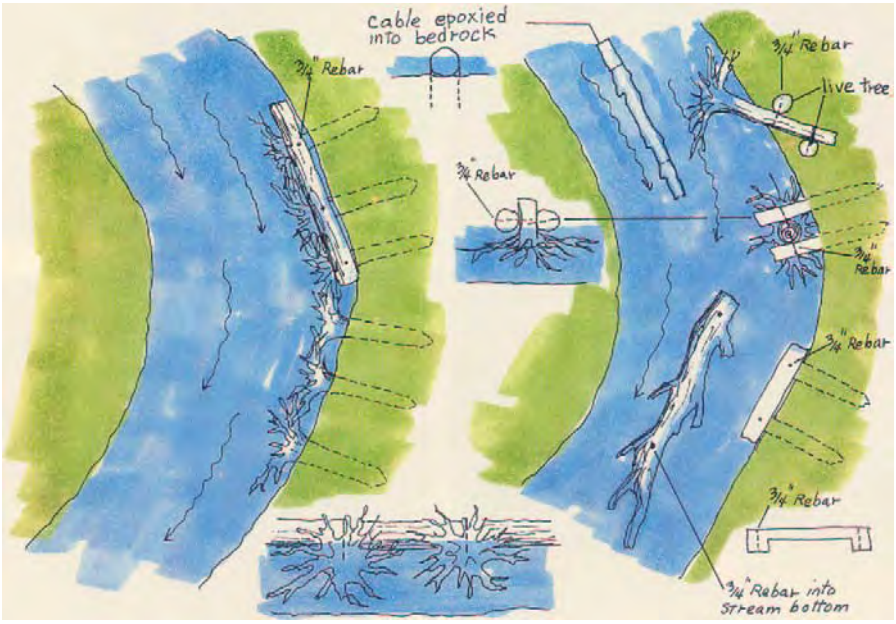


Figure 6-12. Cover Log and Rootwad Structures (Seehorn, 1992)

6.4.2 Tree Cover (SR-3B)

The high surface areas of trees provide excellent habitat cover and facilitate the development of scour pools. In many instances, streamside trees can be cut and felled directly into the stream at a 10 to 20 degree downstream angle to the bank. Felled trees or cut and placed trees/shrubs are secured to the bank by cable, rebar, and/or log anchors (Figure 6-13). Trees or shrubs may be placed in any segment of the stream reach; they are particularly beneficial in shallow wide stream with sand or gravel substrate. In larger streams where cover logs may not be used because of anchoring difficulties, tree cover may be the only reasonable low cost alternative (Seehorn, 1992).

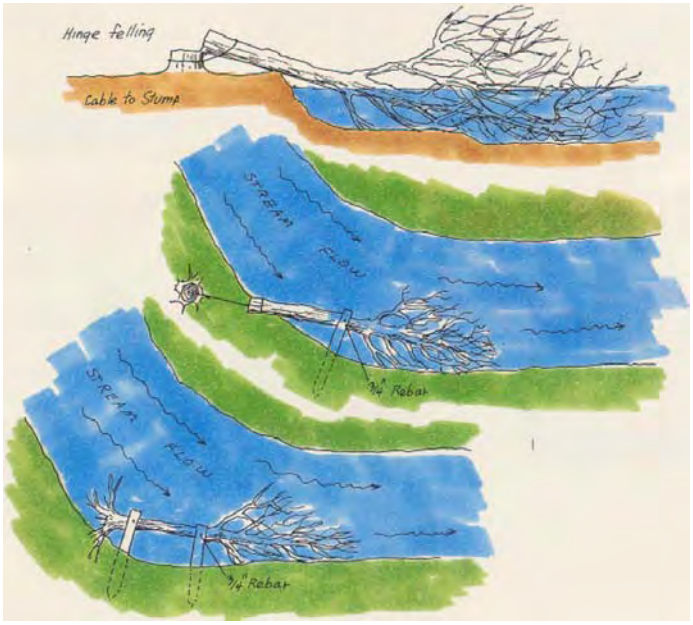


Figure 6-13. Tree Cover Anchoring Methods (Seehorn, 1992)

6.5 ROOTWADS (SR-4)

Rootwads are a natural, relatively short-term (5 to 10 years) streambank stabilization technique. A rootwad is the lower portion of the tree trunks and root balls that are placed along streambanks for bank stabilization, erosion control, and aquatic habitat enhancement. The root network deflects erosive water flows and encourages the reestablishment of streambank vegetation and stable slope profiles. Over time, the root mass of streambank vegetation replaces the slowly decaying rootwad. Generally, trees with deep taproots do not make good rootwads.

Construction specifications for installing rootwads in a streambank are discussed below and illustrated in Figures 6-14 through 6-16.

- Rootwad installation requires a sound length of tree trunk (minimum of 15 feet) for anchoring and an attached flat, dense root mass that exceeds 4 feet in diameter and a footer log 18 to 24 inches in diameter, free of limbs.
- Bury the foot log in a trench parallel to the streambank. Secure the ends of the logs with large rocks and sections of concrete.

Figure 6-14. Rootwad Installation (Photo by Chris Metcalf)

Figure 6-15. Anchored Streambank Rootwads
(http://www.state.nj.us/drbc/wwc/wwrestor.htm)

- Construct a trench or cut a sharp point and push into the streambank so that once installed the rootwad will face upstream at an angle of 20 to 30 degrees from the bank.
- Place the rootwad in the bank at an elevation at which the centerline of the tree trunk is at the design water level and most of the root mass is below bankfull elevation. In most situations, it is best to install the rootwad firmly against the streambank.

- Anchor the rootwad in the bank by placing a large boulder or additional smaller rootwads on top of the trunk just behind the root mass. Do not remove soil from the root mass before installing the rootwad. If trenching is done, backfill and compact, then revegetate the areas disturbed by construction.
- Place woody debris and/or transplants adjacent and behind the rootwad. Several rootwads may be placed in sequence along the streambank (Salix Applied Earthcare, 1999).

Figure 6-16. Multiple Streambank Rootwads (Photo by Chris Metcalf)

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7. LITERATURE CITED

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