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Storm Damage Risk Reduction Guide for Low-Volume Roads

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Storm Damage Risk Reduction Guide for Low-Volume Roads

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CHAPTER ONE
INTRODUCTION

1. INTRODUCTION

The Forest Service, an agency of the U.S. Department of Agriculture, manages more than 375,000 miles of road throughout the Nation. Although designed to handle severe storm events, land use changes, infrastructure degrades, and changes to climatic patterns may put those roads at risk of failure. Millions of dollars are spent on road storm damage repair each year, and whole road systems may be inaccessible for long periods of time while appropriate repairs are determined and implemented. Stream crossing and road drainage failures have caused extensive resource damage. **Modification of stream crossings and control of road drainage, whether generated on the road surface or intercepted by the road cut and ditch, are the most important issues for preventing storm damage.** Addressing streamside road locations, slope stability issues, and adequate vegetation erosion control also is important to reduce the risk of storm damage. In order to meet the Clean Water Act requirements, one must be aware of impending impacts and implement practices capable of reducing risks associated with large storm events. This guide provides a framework to assess the potential risks to a low volume road system and the selection and implementation of appropriate treatments to reduce those risks.

The purpose for storm damage risk reduction is watershed protection; additional benefits are reduced road repair costs, reduced road maintenance, and uninterrupted access. Road-related watershed damage during storm events can vary from inconvenient to catastrophic. When deciding on priorities and methods for storm damage risk reduction, strive to meet the intent of the Clean Water Act. Section 101 of the Clean Water Act states “Protect and restore the physical, biological and chemical integrity of the Nations waters.” If there is a choice between protecting the road and the watershed, choose watershed. This may result in moving the road or finding alternate access. Many road decisions in the past have contributed to damage to the roads and watershed today.

Storm damage risk reduction (SDRR), as used in this guide, refers to nonrecurring treatments on existing roads that reduce the potential for resource impacts and damage or failure of a road feature or road system resulting from storm events. SDRR treatments are needed to:

- ❑ Reduce the potential for future damage (risk reduction).
- ❑ Reduce the magnitude of failures and resource damage that occurs when major storms do occur.
- ❑ Add redundant systems to protect roads receiving less frequent maintenance.
- ❑ Improve hydraulic efficiency and resilience of existing road drainage features.

These treatments relate to open and stored roads as defined in Forest Service Handbook (FSH) 7709.59 - Chapter 60, Road Maintenance (U.S. Department of Agriculture, Forest Service 2009). Stored roads do not have active traffic, but may still have many of the same erosion prevention, drainage, and maintenance needs as an open road. However, the selection and implementation of treatments must take into account the differences in road maintenance levels for open and closed roads in relation to the risk of damage over the life of the treatments. Stored roads do not have active traffic! They will receive less frequent maintenance than open roads, but as long as elements of the road drainage system are retained and expected to function (i.e., culverts and ditches), some periodic evaluation or field checking is needed to assure the long-term stability and functionality of the road and to minimize environmental damage.

In selecting maintenance frequencies, it is important to understand how geomorphic and climatic conditions may affect the road, i.e., some roads may be revegetated within 5 years and may be inaccessible. Anticipate plugged culverts in areas where sediment supply is high. Maintenance and/or treatments necessary to protect drainage facilities and runoff patterns remain as critical management functions, even on stored roads. Stored roads must not pose any more risk to resources than open roads. In future years, maintenance—particularly on closed roads—will be minimal, so the most problematic areas must be prioritized to receive needed attention.

Forest road management must be comprehensive and multifaceted. As part of, or prior to, the selection of SDRR treatments, basic questions need to be answered for roads and road systems (roads analysis). Is the road needed? Should the road be decommissioned? Based on site conditions and stability concerns, can the road be stabilized in its current location, or should relocation be considered? SDRR assessments and treatment selection should not substitute for making clear choices regarding road management. Road decommissioning (permanent closure), while a very valuable tool for addressing critical road issues, is outside the scope of this guide. However, decommissioning may be the best choice for a road. Many of the treatments described in this guide have applicability to road decommissioning because the physical processes that affect roads also must be accounted for when prescribing treatments to decommission a road.

SDRR treatments are not in the same category as capital improvements and are not specifically road maintenance. However, there is considerable overlap across the spectrum when it comes to some of the treatments. SDRR treatments are measures applied to existing roads to reduce or eliminate impacts from storm-related effects on site productivity (loss of soil and vegetation on hillslopes) and on downstream aquatic habitat and water quality, as well as minimize road damage.

Storm-related affects include:

Outside of the Road Prism	Within the Road Prism
Hillslope failure (mass wasting).	Cutslope failure or erosion.
Stream channel migration.	Road surface erosion (gully and rill).
Stream sediment and debris loads.	Road surface drain plugging.
Flooding.	Fillslope erosion or mass wasting (sidecast failures).
Formation of gullies downslope of road.	Culvert scour or plugging.
Drainage feature damage.	Ditch scour or blocking.
Upslope surface erosion.	Bridge and ford scour or failure.
Stream capture.	Drainage diversion and cascading failures.

Annual or other frequent measures taken to maintain drainage features and drivability (including safety measures) and minimize water concentration may include measures found in this guide. Road maintenance is defined in FSH 7709.59, and the types and frequency of maintenance are defined by the road maintenance level. SDRR treatments are not prescribed and implemented on an ongoing basis; however, the treatments may be items that require some maintenance over time to continue to function properly. On the other end of the spectrum, SDRR treatments are not specifically capital improvement projects, although the separation can be indistinct in some cases. Capital improvement projects are implemented as funding allows to improve the safety, drivability, or long-term use of the road. They may be projects to move a road from one maintenance class to another. Practitioners should understand what treatments accomplish storm damage reduction objectives and use funding as available to achieve SDRR objectives.

Some of the SDRR measures include:

- ❑ Keep needed road maintenance up to date.
- ❑ Have adequate road surface drainage measures to move water off the road surface rapidly and prevent the accumulation of water.
- ❑ Have culverts in good condition, free of debris, and with diversion prevention measures installed.
- ❑ Keep bridge channels cleared and free of excessive debris.
- ❑ Have slopes well covered with deep-rooted vegetation or other erosion control methods.
- ❑ Pull back marginally unstable or failing sliver fillslopes.

SDRR treatments may be necessary to protect the investment in a road or protect critical natural resources while road decisions are being made, or while funding is being sought for capital improvement work. In these instances, SDRR treatments are interim rather than final treatments. In other instances, SDRR treatments will constitute the final treatments for a road and will contribute to reducing future maintenance costs. The treatments become a permanent feature of the road and will still require some regular maintenance to function properly over time. On lower use roads, the selection of proper treatments must take into account the need to function with infrequent maintenance. All roads probably can benefit from SDRR treatments. In the context of this guide, SDRR treatments are measures applied to existing roads to correct situations that contribute to a higher risk to resources and of road damage or failure. However, many measures that are considered SDRR should be part of good road design or as road best management practices since they offer ongoing protection for the road, from construction through maintenance and decommissioning. Many SDRR measures cannot practically be added into the road on an emergency response basis, such as when a large storm is forecast (time and resources are not that flexible or necessarily available), so the measures are installed as an upgrading practice through an ongoing SDRR program.

Given the recent unpredictable and often extreme weather events we are experiencing, much emphasis is being given to the issue of global climate change and its impacts on infrastructure, including roads. Most Federal agencies, including the Forest Service; U.S. Department of Transportation, Federal Highway Administration (FHWA); U.S. Department of Commerce, National Oceanic and Atmospheric Administration; and U. S. Department of the Interior, U.S. Geologic Survey; as well as the National Academy of Sciences, are working to understand, model, and ideally minimize climate change impacts. Also, many international concerns exist and efforts are being undertaken by groups, such as the Organization of American States, the World Road Association, World Bank, the United Nations, and others, to deal with the issue.

An increase in the size and intensity of forest fires also appears to be the result of global climate change. Post-fire storm events typically cause increased runoff and erosion from burned-over watersheds. Watershed managers need to prescribe treatments that account for this increase in runoff in channels and ditchlines, and debris movement that may block stream channels and culverts. Many SDRR treatments are effective for preventing or mitigating damage from post-fire storms.

1.1 SDRR Objectives

A Storm Damage Risk Reduction Guide is needed because there are more forest roads. Through the 1980s, the forest road system expanded rapidly, received regular maintenance, and was used extensively. Roads were constructed for efficiency of use and, typically, used 25-year drainage design standards. Construction standards were less stringent, and construction often included leaving stumps and other organic debris in fills, extensive sidecasting of fill material, and fewer and smaller drainage culverts. Large storms caused considerable road damage and cumulative resource impacts. Repair of storm-damaged facilities replaced failed structures with similar structures.

Over the last two decades, road construction on National Forest System lands has almost ended and road maintenance has been deferred. Except where forest management projects are being implemented and where roads access popular recreation sites (campgrounds, trailheads, ski areas, and so forth).

Road drainage designs typically now use a 50- to 100-year storm event for design purposes. The Northwest Forest Plan Aquatic Conservation Strategy requires new culverts, bridges, and other stream-crossing structures to accommodate at least a 100-year flood, including associated bedload and debris. The lack of maintenance and old, undersized road drainage features leaves roads at high risk of failure or damage during climatic events. Aquatic resources that are already impacted also are at elevated risk to impacts from increased sediment delivery from road failures. Repair costs are escalating, and storm frequency and intensity may be increasing due to climate change. Many road features have met or exceeded their design life. Certain locations are expected to be more susceptible than others or have a higher response potential to change under climate-change scenarios; for example rain-on-snow zones and fire-susceptible forests.

This guide is intended to provide a framework for the selection of appropriate SDRR treatments. There are very important tasks and processes that are necessary to make informed treatment selections that are not covered in detail in this guide, but should be part of comprehensive road management programs. They include road condition inventories, hazard assessments, and strategic plans for treating high-hazard sites.

Treatments outlined in this guide are intended to minimize road damage and the accompanying environmental harm associated with how roads respond to storm events. There are multiple benefits from reducing storm damage, including the following:

- ❑ Maintaining soil on hillslopes.
- ❑ Reducing rapid delivery of storm runoff and debris to streams by decoupling road drainage runoff from the stream network.
- ❑ Reducing catastrophic sediment and debris delivery to streams.
- ❑ Maintaining stream channel structure that absorbs stormflow without damage to aquatic habitat.
- ❑ Reducing the cost, effort, and inconvenience of having to repair damaged roads.

The treatments themselves may actually increase the number of initiation or source points in the short term (i.e., adding culverts or waterbars). Care is required to construct these treatments in locations and at a frequency using techniques that do not increase erosion potential. With proper implementation, SDRR treatments should substantially reduce consequences during large storms.

Successful implementation of SDRR treatments has additional benefits. Many treatments will reduce chronic sediment delivery that results from road runoff during all storms. The reduction of sediment delivery (chronic and catastrophic) to streams will reduce the risk of failure for in-stream projects implemented to improve stream function and fish habitat. Where appropriate, consider fish and other aquatic organism passage needs when implementing SDRR treatments. By nature of the interrelated processes, the reduction of sediment delivery involves changing how water is intercepted and runs off of the road network. A secondary effect of SDRR treatments may be to alter how roads change the magnitude and timing of streamflow peaks; and, alternately reduce impacts from storm runoff in the channels downstream. Road maintenance and storm damage repair costs are expected to decrease after implementation of SDRR treatments.

Risk reduction is a variable target. The goal is to reduce to what level of risk? Different individuals, various managers, and scientists have differing tolerances for risk. Different sites have characteristics that affect the tolerance of risk. It is not possible for this guide to prescribe treatments that eliminate all risk. It will be up to the implementation team, in consultation with their public, to evaluate the risks, the values at risk, and the amount of time and resources to apply to reduce the risk to a desirable level.

This guide is intended for use in the Forest Service regions nationwide, including Alaska. The treatments have been developed and used primarily for the climate and geomorphology of western landscapes, but most of the SDRR treatments apply in all regions. Some storm damage issues specific to cold regions are briefly discussed in section 6.7, but a thorough discussion of this topic is beyond the scope of this guide. In any geographic location, the implementation team should perform assessments to assure that the treatments discussed herein are appropriate for the situation. Include the assessment in the determination of the values at risk, site conditions, failure mechanisms, and climatic conditions that contribute to failure.

A summary of most key SDRR—or stormproofing—principles applicable to forest and low-volume roads are the following:

1. **Identify areas of historic or potential vulnerability**. Certain high-risk sites are well known; others may be more subtle. Chronically undersized culverts will have a history of failure. Geologically unstable materials or slopes, roads on steep slopes with sidecast fills, or roads that cross steep channels subject to debris flows, wet slopes, areas subject to flooding, or areas of high soil erosion near streams (inner gorges) all have increased vulnerability.

2. **Avoid local problematic and high-risk areas**. Consider road closure or relocation to avoid problematic areas and poor road locations. Common problematic areas include steep slopes (over 60 to 70 percent), deep-seated rotational landslides, and areas prone to shallow rapid landslides and debris torrents, avalanche chutes, rock-fall areas, wet areas, saturated soils, highly erodible soils, and so forth.

3. **Use appropriate minimum design standards**. Road standards, particularly road width, should be minimized, while still considering traffic safety and road user needs. Because SDRR treatments involve existing roads, road standards are already in place. Use SDRR treatments, however, to lower the standard as appropriate and result in less earthwork, lower cuts and fills, and less concentration of runoff, all of which reduce risk of damage or failure during storms.

4. **Employ self-maintaining concepts into the selection and implementation of treatments**. Resources for road maintenance often are limited and the road systems are extensive. Implementing those treatments that reduce the amount of road miles that need frequent and costly maintenance will allow limited resources to be applied to more of the road system where it is needed. Examples might include outsloping (on appropriate soil types), additional cross drains, and redundant (back up) or larger drainage structures.

5. **Incorporate relevant, cost-effective technology**. Apply current appropriate technology to improve identification of priorities and for planning, design, and reconstruction practices. This includes the use of geographic information systems, and global positioning systems technology; geosynthetics for filters, separation, and reinforcement; mechanically stabilized earth retaining structures; current riprap sizing criteria for bank stabilization; bioengineered and biotechnical slope stabilization and erosion control measures, and so forth.

6. **Perform scheduled maintenance**. Perform scheduled maintenance at a planned frequency to be prepared for storms. Ensure that culverts have their maximum capacity, ditches drain well, and channels are free of excessive debris and brush that can plug structures.[1] Keep the roadway surface shaped to disperse water rapidly and avoid areas of water concentration. There may be insufficient time to do the routine work as a storm is approaching.

7. **Use simple, positive, frequent roadway surface drainage measures and use restrictions**. Provide good roadway surface drainage so that water is dispersed off the road frequently and water concentration is minimized. Where soil properties are insufficient to support traffic when wet (i.e., volcanic ash), restrict use during wet seasons to prevent rutting and gullying. Outslope roads whenever appropriate and practical and use rolling dip cross drains for surface drainage rather than a system of ditches and culverts that require more maintenance and can plug easily during major storm events. Frequent cross drains, insloping and outsloping, and rolling road grades all need to be in good working order. Failed cross-drain culverts are very common after major storm events.

8. **Properly size, install, and maintain culverts**. Improperly installed, undersized, and plugged pipes are common reasons for culvert failure during storms. Improper alignment or grade relative to channels and

1 Limit clearing debris from stream channels to smaller mobile pieces that pose an immediate risk to a structure. Larger pieces that are integrated into the channel bed or banks or large enough to resist movement during most flows are important for stream function and aquatic habitat. A fisheries biologist or hydrologist should be consulted prior to any extensive debris removal.

ditchlines, excessive woody debris in the channel, excessive channel constriction and headwater elevation, excessively wide inlet areas, and inadequate capacity all contribute to pipe plugging and subsequent failure. Concrete or masonry headwalls greatly improve the resistance of culverts to failure during overtopping. Another cause of culvert failure is a lack of proper maintenance. Maintaining inlet configurations and removing debris that may plug the pipe are essential for proper function during storms.

9. **Use simple fords or vented low-water crossings**. Use simple fords or vented low-water crossings (vented fords) as often as appropriate for small or low-flow stream crossings on low-volume roads, instead of culvert pipes that are more susceptible to plugging and failure. Protect the entire (100 year) wetted perimeter of the structure, and the downstream edge of the structure against scour; provide for aquatic organism passage as needed.

10. **Stabilize cut and fillslopes**. Remove or treat unstable fillslopes as necessary to improve stability. Cut and fillslopes should be well covered (stabilized) with vegetation, to minimize surface instability problems as well as minimize surface erosion. Uncompacted sliver fills and settling or cracking fills are a high priority for stabilization or removal. Fillslopes also may be undercut and oversteepened by a stream or channel. Failing, over-steep slopes from road construction where material enters a stream can cause downstream problems to the watershed and contribute to plugging of structures.

11. **Use deep-rooted vegetation to "anchor" soils**. Promote slope stability by using deep-rooted vegetation for soil bioengineering and biotechnical treatments. Combine deep-rooted plants with a mixture of shallow-rooted grasses for good ground cover and erosion control on slopes, preferably using native species.

12. **Design high-risk bridges and culverts with armored overflows**. High-risk bridges and culvert structures often can be designed with armored overflow areas near the structure in case of overtopping, or they can have a controlled failure point that is easy to repair and minimizes environmental damage. Alternatively, oversizing the structure and allowing for extra freeboard on bridges will maximize capacity and minimize risk of plugging. Do not constrict the natural channel. Consider culverts with a span that is at least bank-full channel width and bridges that span the flood plain.

13. **Eliminate diversion potential**. Design and construct (or upgrade) all stream crossings, especially culvert crossings, to have no diversion potential. Design and construct (or upgrade) stream crossings in steep stream channels that are subject to debris flows to withstand such debris flows without being washed out or resulting in subsequent streamflow diversion. Structure damage from a plugged culvert may be minimal, but road damage from a stream diverted down the road can be extensive.

14. **Use scour prevention measures for structures on questionable foundation materials**. Install bridges, retaining structures, and structural foundations into bedrock or on firm, in-place material with good bearing capacity to minimize

foundation failures. Apply foundation strengthening and scour prevention measures when foundation conditions are known to be marginal or a bridge is scour susceptible.

15. **Be aware of channel morphology and stream channel changes near a bridge, culvert, ford, or road along a creek**. Significant changes in stream gradient, from a steeper reach to a flatter area, can cause channel aggradation (deposition) and subsequent plugging of structures or a stream jumping out of its original channel. This is particularly problematic on alluvial fans where avulsion can damage roads and structures. Also, tight bends in the channel promote concentration of flow to the outside edge, often leading to scour. Woody debris tends to accumulate at bends in a channel. Road work or improvements also might cut off a stream's natural access to its flood plain.

1.2 Scope of the Problem

Flood History

The Western United States is subjected to severe weather that moves on shore from the Pacific Ocean. The severity and nature of the storms is dependent on the season and whether individual storm cells originate in the northern Pacific and Gulf of Alaska, or from the southern Pacific and the Hawaiian Islands. Flooding in the coastal mountains and western Cascades is most common during the fall and early winter months (November through February) when deep low pressure pulls large quantities of moisture from the southern Pacific Ocean. These storms may produce 24-hour rain totals of 5 to 10 inches or more. Flooding may be exacerbated if low-elevation snow is present when these storms arrive. These rain-on-snow storms typically cause the largest floods on record in the Coast Ranges, Olympic Peninsula, and western Cascade watersheds (U.S. Department of Agriculture, Forest Service 1992) and Northern Sierras.

Rain-on-snow events are less frequent on the east side of the Cascades and Sierra, and in the interior of the continent. They do, however, account for a significant number of the peak flows. Rapid spring snowmelt is the more typical flood-generating process to the east of the Cascade mountains and in the Inter-mountain west. Unlike the rain-on-snow floods of the west side that only last for a couple days, snowmelt flooding may last for a week or more. Ice-jam flooding also may occur during very cold winter weather followed by a rapid warmup. In this case, blocks of river ice may form large rafts and dams across rivers, causing widespread flooding before the dams breach. When the ice dams breach, the resulting surge flows may cause additional downstream flooding.

Extreme weather variations and uncommonly intense and frequent storms in the Northeast have caused local to widespread heavy precipitation, power loss, and damage.

Hurricanes have increasingly impacted the Southern Region and along the East Coast. Infamous events, such as Hurricane Hugo in 1989, Katrina and Rita in 2005, Irene in 2011, and Sandy in 2012, did widespread damage in those regions. Increasing droughts and violent thunderstorms in the Southern Rockies and tornadoes in the Midwest and South also have had huge impacts on lives and infrastructure.

Some of the largest magnitude floods recorded in the Northwest occurred in the late 1890s and early 1900s during a wetter, colder climate period at the end of the Little Ice Age. These floods preceded the onset of extensive forest management. Much of the early and middle 1900s were marked by comparably modest floods with an occasional very large flood.

The Christmas storm of 1964 was large in magnitude and geographic extent and reset the thinking of road construction techniques and culvert design in much of the Northwest. Floods across the region in the late 1900s and early 2000s have led to another look at roads and the practice of replacing road features in place and in-kind after floods. Road relocation is now considered a viable option for consideration in planning flood repair.

Toward the end of the 20th century, stream gauge records have shown a marked increase in the frequency of large floods (U.S. Department of Agriculture, Forest Service 1992; U.S. Department of Agriculture, Forest Service 2010). During the last 35 years, more than 1,500 bridges have collapsed nationwide, at least half of which are attributed to flooding and scour. Whether the increase in flood frequency is related to land use, climate change, or a combination, is a subject of continued discussion, but there is mounting evidence of both mechanisms having the potential to increase the magnitude and frequency of severe floods (Casola et al. 2005; U.S. Environmental Protection Agency 2010; National Cooperative Highway Research Program 2014).

"Global Climate Change Impacts in the United States" (Karl et al. 2009) report and "Adopting Infrastructure and Civil Engineering Practice to a Changing Climate (American Society of Civil Engineers 2015) each discuss many of the storm and weather changes that are predicted and that affect land management and roads, including increasing frequency of heavy precipitation events; increasing streamflows in some regions, particularly the East; and earlier snowmelt in the West and Northeast. Other descriptions of weather related to global climate change have included more radical or extreme events, more variability, warmer and moister air, more intense storms and more droughts, unseasonable temperatures, etc. Expect more intense storms, but where and when are difficult to predict. Ultimately the problem of increased risk of damage from storms, both to roads and to the watersheds, comes from a combination of global climate change, land use changes, and an aging infrastructure.

Given the unpredictable and often extreme weather events we are experiencing today, a great amount of emphasis is being given to global climate change and its impacts on infrastructure, including roads. Most Federal agencies, including the U.S. Department of Agriculture Forest Service, U.S. Department of Transportation Federal Highway Administration, U.S. Department of Commerce National Oceanic and Atmospheric Administration, and the U.S. Department of the Interior U.S. Geologic Survey, are working to understand, model, and ideally minimize its impacts. The Intergovernmental Panel on Climate Change (IPCC) has produced a great deal of information on causes and impacts of climate change, including their Working Group publications "Climate Change 2014: Mitigation of Climate Change", Climate Change 2014: Impacts, Adaptation, and Vulnerability", and "Climate Change 2013: The Physical Science Basis". IPCC publications are available through <http://www.ipcc.ch>.

The U.S. Department of Transportation, FHWA, has been actively involved in climate change issues and measures to lessen the impacts of more frequent and severe storms, such as disaster planning, management and evacuation issues during disasters, and emergency and permanent repairs, as well as emergency relief. Useful Web sites for information are available at <http://ops.fhwa.dot.gov/publications/publications.htm#eto> and <http://www.fhwa.dot.gov/programadmin/erelief.cfm>.

More intense storm events following fires further contribute to local flooding, debris slides, and significant sediment movement in channels; resulting in ditch erosion, plugged culverts, and other damage to infrastructure. The Burn Area Emergency Response (BAER) program includes the assessment of risk and a prescription of treatments to minimize post-fire damage from increased runoff and peak flows. Many of the SDRR treatments discussed in this publication are typically prescribed by BAER assessments. Some of the treatments are discussed in the BAER catalogue (BEARCAT, Napper 2006).The Forest Service, Rocky Mountain Research Station publication "Climate Change, Forests, Fire, Water, and Fish: Building Resilient Landscapes, Streams, and Managers" (Luce et al. 2012) further discusses the problems with fires and watershed responses from climate change.

Emergency Relief of Federally Owned Roads (ERFO) History

The ERFO program (see Forest Service Manual 7700, Section 7732.26-Repairs Performed with Emergency Relief Federally Owned Funds, U.S. Department of Agriculture, Forest Service 2014b) administered by the U.S. Department of Transportation, FHWA, provides funding to repair flood-damaged roads on Federal lands. Currently Maintenance Level 3, 4, and 5 roads may qualify, as justified by applicable road management objectives for those roads. Historically, when a culvert was washed out, ERFO would fund a replacement-in-kind, replacing the existing structure with the same structure. No consideration was made for the probability of recurring failure, so sites often became repeat repair projects.

From the 1950s through the 1980s, the road system on national forests expanded exponentially and accessed higher risk terrain in response to a growing domestic and international demand for timber. With the increase in roads came an increase in vulnerability to damage.

The ERFO program covers all Federal land in the United States and all causes of damage. From 1971 to 1990, ERFO paid out more than $1.1 billion on road and bridge repairs[2] across the United States. It is a rare year when there are no ERFO funding requests. On average, there are 14 qualifying events each year with nearly 35 flood-related bridge projects initiated. In 2004, three major storms hit North Carolina in a row, causing widespread devastation and $50 million in damage. Hurricane Irene in the summer of 2011 caused widespread damage in the East and New England States with over a 100 year precipitation event in many areas. The overall cost of this damage is estimated at $20 billion. Hurricane Sandy was a massive storm that caused widespread damage and flooding throughout the Northeast in 2012, with estimated damage amounting to $50 billion. Whether the cause is climate change, an ever-expanding road system on high-risk terrain, or just an aging road system with deferred maintenance, the need for ERFO funding and the escalating ERFO repair costs are staggering.

The major storm patterns from the Pacific Ocean shift up and down the coast. On rare occasions, the entire area from northern California to the Canadian border is affected by major storms triggering ERFO response. For one forest in the northwest Cascades, average annual ERFO road repair funding went from $190,000 per event for the 1970s decade to $411,000 for the 1990s decade (actual costs) (Doyle and Ketcheson 2004). The Forest

[2] *Jennifer Rhodes and Roy Trent; An Evaluation of Highway Flood Damage Statistics. Undated report. Federal Highway Administration, Offices of Research and Development, 6300 Georgetown Pike, McLean, VA 22101.*

Service Pacific Northwest Region averaged more than $6 million a year in ERFO repair between 2002 and 2010. The Pacific Southwest Region spent more than $40 million on the 1997 storm damage program alone.

Useful information on the ERFO program, funding, eligibility, and types of storm damage, the use of damage survey reports, and regulations are found in the FHWA publication "Emergency Relief for Federally Owned Roads: Disaster Assistance Manual" (FHWA 2015). It is available at <http://flh.fhwa.dot.gov/programs/erfo/documents/erfo-2015.pdf>.

One of the challenges of working with the FHWA and obtaining adequate ERFO funding is that ERFO guidelines still are targeted at "replace in kind." Forest Service standards, however, have changed and the road that failed will no longer meet the new standards. The forests often need to acquire additional funds, over the ERFO allocation, to fix storm-damaged facilities to current standards. Obtaining the additional funds is challenging and may not occur in a timeframe that complies with ERFO funding time limits.

It is the intention of the Forest Service, through the use of this SDRR Guide and the travel analysis process, to reduce the reliance of the forests on emergency funding by implementing an effective program of storm damage risk reduction, combined with proactive road maintenance and a vital capital improvement program that will result in minimal storm damage to roads. Where forests decide to decommission rather than repair damaged roads, emergency funds may be used for decommissioning. However keep in mind that currently ERFO funds can only be used on Level III or higher roads.

Vulnerable Road Placement

Forest road systems are often damaged by floods when drainage features are overwhelmed by water and debris. Roads located in riparian corridors and on flood plains also face the erosive power of streamflow at streamside locations and may be completely removed by the river.

Roads crossing alluvial fans or located at the transition from a steeper slope to flatter terrain, are at risk since drainage channels in this area can shift over time. Intense storms leading to debris slides or debris torrents may fill existing channels with debris, causing the channel to shift to a new location.

The southwest regions and parts of the West have been impacted lately by severe droughts, fires, and then debris flows following heavy rains. Roads crossing ephemeral channels and arroyos are at risk of damage from extreme events and the associated debris torrents. Road-stream crossings in these areas should either involve very large structures, such as bridges, or minimum investment structures, such as simple fords. Culvert structures have a high risk of plugging. In the northern and northeast regions, more extreme events or ice and snow can lead to more ice dams, blocked structures, and high snow loads. Inconsistent cold and warm weather can lead to more subgrade damage and freeze-thaw damage on roads, as discussed in section 6.7.

Road design and repair must take into account the probability of flooding and the potential effects on the road. Older roads often were designed for small storm events and may not be adequate to handle more severe floods. Pipes and other drainage features on older roads also are aging and failing. For road-stream crossings placed on unstable terrain or on dynamic landscapes, stream channels may shift during storm events, severely damaging the road and bypassing existing drainage structures.

Hillside road locations are subject to a number of threats:

- ❏ Hillslope failure that blocks ditch drainage and forces the flow down or across the road, resulting in rilling or gullying of the road surface and often mass failure of the fillslope, or a cascading series of failures down slope at culvert crossings.
- ❏ Hillslope failure that buries and plugs ditch-relief or cross-drain culverts causing water to cross the road prism and erode or wash out the fillslope.
- ❏ Cutslope failures and landslides from unstable slopes either burying the road or removing the road prism.
- ❏ Rockfall that damages the road or creates a safety problem.
- ❏ Debris slides or debris avalanches that race down small drainages and overwhelm culverts or bridges, resulting in washed out drainage crossings or plugging and stream diversion.
- ❏ Excessive ditch erosion due to the accumulation of water from long distances between ditch-relief culverts or due to the bypassing of runoff past a plugged relief culvert.
- ❏ Ditch plugging or loss of ditch capacity due to dry ravel of cutslope materials, forcing runoff out of the ditch and down or across the road.
- ❏ Saturation of the road fill from subsurface moisture either from upslope or from water ponding in flat ditch grades or sags that causes mass failure of the road fill.
- ❏ Settling of road-fill materials forming open cracks at the surface that collect surface runoff, resulting in mass failure of the road fill.
- ❏ Excessive erosion and possible rilling of the road tread on steep grades, resulting from inadequate surfacing, channeling of water in rutted or compacted tire tracks (loss of inslope or road crown) or down tire ruts in mud or snowpack.
- ❏ Reduced ditch capacity over time due to vegetation encroachment into ditch and roadside zones, forcing water onto the road.

Road systems that place several roads on a single hillside (road stacking) or a set of switchbacks have an increased risk of loss during storms because of the domino, or cascading failure, effect of a road failure high on the slope. Water from upper road segments often concentrates and accelerates as it flows down the road or downslope and the water, eroded soil, and debris can damage roads in succession lower on the slope, causing multiple failure areas down the road.

Roads on valley floors or flood plains are subject to some similar and some different threats that merit special considerations depending on their specific locations:

- ❏ Roads on alluvial fans are subject to debris avalanche deposits plugging drainage culverts, shifting drainage channels, and/or burying the road prism in debris.
- ❏ Stream channels on alluvial fans migrate and can cause erosion of the road prism and breaching of the road.
- ❏ Rivers migrate across their flood plains forming a channel migration zone (CMZ) [3]. Roads located within the CMZ of the river are subject to washing away during floods.
- ❏ Roads on high terraces or upslope from flood plains may fail as streams undercut the toe of the old terrace or slope.

[3] *Channel migration zone is defined as an area adjacent to an unconfined stream where channel migration is likely during high-flow events. The presence of side channels or oxbows, stream-associated wetlands, and low terraces are indicators of these zones. (Southwest Oregon State Forests Management Plan 2001. Glossary. Other definitions and mapping guidance in A Framework for Delineating Channel Migration Zones. Rapp and Abbe 2003. Washington State Department of Ecology Pub. 03-06-027).*

- ❏ Road crossings, bridges and culverts, and associated approaches may be lost due to migrating river channels.
- ❏ Roads within flood plains are subject to inundation during floods, which may result in the compromising of road surfacing and drainage systems and erosion of road prisms. Roads in narrow canyons are at risk of inundation or being washed away by high water or bank scour.
- ❏ River corridors, flood plains, and CMZs are often characterized by a history of diking and riprapping in an effort to protect roads from river migration and erosion. Nonriprapped sections of road are at greater risk because dikes and riprap merely translate stream energy to banks downstream.
- ❏ Roads adjacent to aggrading stream channels resulting from land-use induced sediment delivery are threatened by increased channel instability and migration.

Figure 1 shows the inundation of the Feather River Canyon in northern California in the floods of 1986 and 1997, each roughly a 100-year event (statistically). The highway is located in a narrow river canyon that is vulnerable to flooding. Each flood resulted in road closure for months and millions of dollars in damage repairs.

Figure 1—The Feather River Canyon, Plumas County, CA, where floods have resulted in major road damage and long periods of road closure (a). Signs (b) show water levels reached in February 1986 (bottom sign) and January 1997 (top sign).

Examples of Storm Damage

Figures 2 through 10 show examples of forest road storm damage.

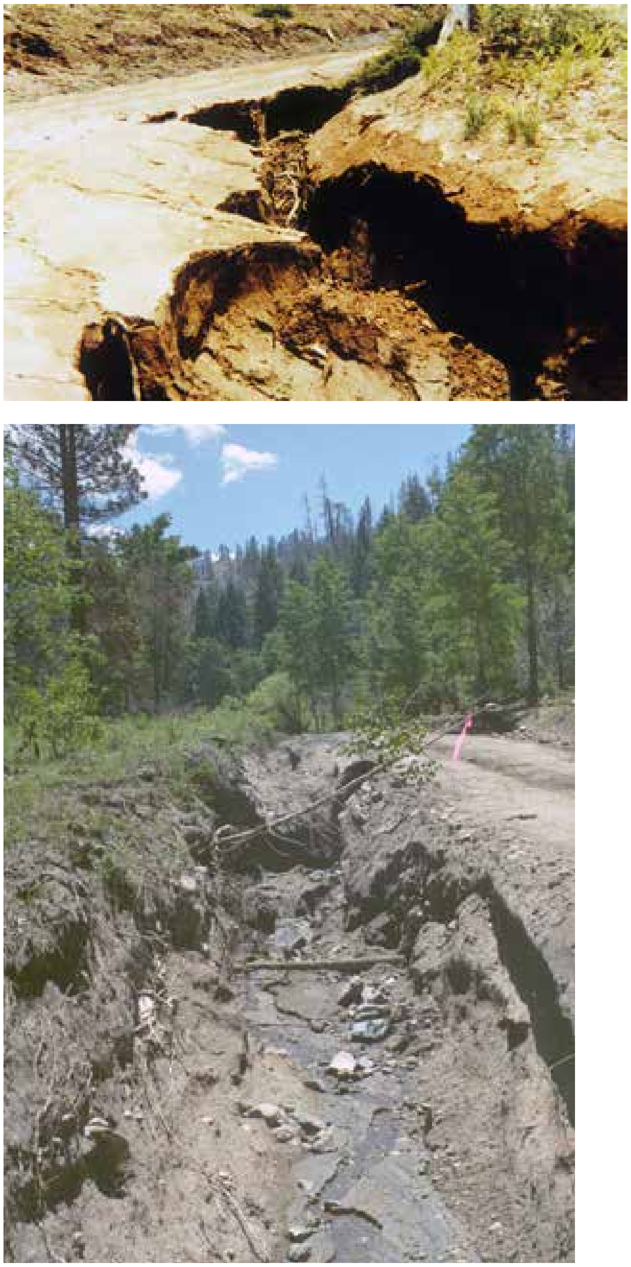


Figure 2—Severe gully erosion damaging forest roads during storm events.

Figure 3—Bridge scour occurring at the abutment of bridges during major storms in northern California because of channel constriction (a) and natural stream meander (b).

Figure 4—A bridge abutment washed away by a debris torrent and channel widening during a storm event in the Pacific Northwest. (Courtesy of Mark Leverton.)

Figure 5—This road washed out because of placement on a flood plain and channel widening during a storm event.

Figure 6—Damage to a low-water ford caused by scour of the bedding material under concrete planks.

Figure 7—Culvert plugging (a) and a total culvert washout (b) during major storm events.

Figure 8—Examples of road closure caused by cutslope and fill failures during storms.

Figure 9—Streambank erosion during a major flood and loss of riprap streambank stabilization material. Surrounding land management contributes to the susceptibility of a road to damage. In this instance, grazing practices and poor riparian conditions (compacted soils devoid of deep-rooted vegetation) contributed to severe streambank erosion. Poor installation and undersized riprap contributed to the problem.

Figure 10—Road-stream encroachment and flooding along the South Fork, Salmon River, Idaho, due to a rain-on-snow event. (Courtesy of Tom Black.)

Definition of Risk Reduction Treatments

As discussed above, storm damage risk reduction is neither road maintenance nor capital improvement. Prescribed SDRR treatments fall into a category between the two; but may involve some combination of both types of treatments. The primary purpose of these treatments is to reduce the risk of damage to the road and to the environment from the stresses experienced during storm events. Understanding the hazards and controlling water is paramount. Erosion and sediment delivery from roads to streams and the consequence of the sediment and related debris in the streams are primary concerns. Therefore, these treatments are ones that control surface runoff within the road prism, increase mass-stability factors for road cuts and fills, and make the road features more resilient to forces from outside the road prism, such as upslope mass wasting and debris, rain-on-snow runoff, and other severe climatic events. Treatments often will involve increasing the size and decreasing the spacing of drainage features, fortifying stream crossings, and stabilizing slopes.

Open Roads

Maintenance level 3-5 roads are open and maintained for travel by prudent drivers for standard passenger cars. Maintenance level 2 roads are open for use by high-clearance vehicles. The selection of treatments for open roads is constrained by the need to provide for the passage of vehicles. Depending on the maintenance level, this may mean consideration for passenger cars, vehicles pulling trailers (horse, camp, utility, snowmobile, and so forth), log trucks, or equipment on lowboys. Treatments that would restrict or prevent the passage of these types of vehicles would not be selected for maintenance level 3-5 roads.

Rolling dips (broad-based dips) may require varying design criteria depending on the steepness of the road and whether the expected use is passenger cars and light trucks versus logging trucks and lowboys. Where high-clearance vehicles are the intended use (maintenance level 2), more aggressive treatments that affect the travel surface may be selected. Drivable waterbars and rolling dips may be more pronounced on maintenance level 2 roads compared with maintenance level 3-5 roads.

Closed Roads (Roads Placed in Storage)

When traffic is not a factor in selecting appropriate SDRR treatments, the types of treatments available expand significantly. However, the expectation of a lower maintenance frequency must be factored into the selection and design of treatments. A closed road, or road in storage, is a road that may be closed to use for a long period of time, say 5 to 20 years, but with the expectation that it will be used again. Therefore, implement SDRR treatment prescriptions for closed roads with that understanding.

On a closed road, road width, surface roughness, and drainage structures all can be viewed differently. The road does not have to be wide enough to carry traffic so unstable fills can be removed. Drainage structures can be removed completely, and large gaps in the road surface are acceptable, even desirable. The amount of road prism left intact on a closed road depends on the amount of time until the next expected use, the physical setting and failure risk posed by the local climate, the age of the road and associated drainage structures, the return interval flow for which the existing drainage structures were designed, and the resource values at risk. In sensitive landscapes and severe climates, a closed road may appear similar to a decommissioned road (permanently closed) due to the level of treatment. The anticipated length of closure, and expected maintenance, may affect the degree of treatment.

Closed roads remain as part of the forest road system and should receive periodic inspection and maintenance to protect the road and forest resources. However, the reality is that there is limited funding or other resources available to inspect and perform maintenance on closed roads. For closed roads, SDRR and closure treatments must be prescribed with the caveat that maintenance will be very limited or not occur at all until the road is reopened.

Treatment selection and design criteria must result in road features that will stand up to years of storms without an impairment of function. As with all SDRR treatments, the design is not expected to be for the largest storm events. Designing for the 100-year storm event (plus debris) necessitates some allowance for increased capacity and redundancy in order to absorb some effects by the more common storms without losing capacity or stability.

Relative Treatment Costs

The SDRR treatments described or referenced in this guide span a wide range of implementation costs. Costs for the same treatment vary widely over time and geography, due to specific site conditions and the availability and price of materials. Various economic factors will determine actual costs once proposals go to bid. Cost is an important factor in the selection of the appropriate treatment, but cost-effectiveness over time should carry more weight in the decision.

Some treatments may be very expensive, such as bridge-scour countermeasures, but can be cost-effective if it prevents a bridge failure. If a higher cost treatment is warranted, a lower cost, less effective treatment should not be substituted unless it is viewed as an interim treatment to lower an imminent risk. Because of the variables influencing costs, this guide does not include cost items for individual treatments, but rather categorizes treatments as to most common and lower cost, to less common and higher cost.

Table 2 with a summary of the SDRR measures discussed in this guide is found in section 3.

The appendix A5-Glossary presents the definition of a few terms commonly associated with storm damage risk reduction and road management.

CHAPTER TWO
STRATEGIC RISK ASSESSMENT

2. STRATEGIC RISK ASSESSMENT

There are essentially two risk components in the storm damage risk reduction (SDRR) evaluation for selection of appropriate treatments. The two factors of a hazard risk assessment are:

1. **Probability** of occurrence and failure (how big and frequent the storm runoff occurrence is and the probability that it will wash out a bridge, plug a culvert, or cause a landslide).
2. Expected **consequences** (loss of life, safety, cost of damage to infrastructure, environmental costs, etc.).

The probability of a failure is related to the factors that contribute to the potential for a failure to occur. The consequence, should a failure occur, relates to the infrastructure or natural resource impacts resulting from a failure. The values of natural resource(s) or the road component that would incur damage are important in determining the amount of resources to allocate towards preventing a failure and the level of risk that is acceptable.

The selection and application of the most cost-effective SDRR treatment depends on a thorough assessment of the factors that place a particular road or group of roads at risk, and an understanding of the consequences (relative to health and safety, environment, and infrastructure) should a road failure or damage occur. There are a number of physical and climatic factors that need to be considered. This assessment should involve an interdisciplinary team and should be completed early in the storm response process, or it can be completed on a whole road system in a programmatic way. Having the risk assessment completed expedites response to storms and is invaluable for preparing annual road maintenance plans.

This document does not fully address risk assessment. However, it is intended to offer a framework for the concept and needs of a risk assessment, considering the hazards involved and the consequences of failure, along with some tools and references to aid in doing one.

2.1 Hazard Assessment

It is important to understand and recognize the origin of different factors that affect storm intensities and types, and the responses of a landscape to storms. A complex set of these factors determines the risk of storm damage for a given road. Some of these factors are associated with regional- or landscape-scale phenomena, such as climate patterns; some are expressed at a watershed or subwatershed scale; and others are site-specific factors with very local effects.

Landscape-Scale Considerations

The risk of damage from severe storms, and the severity and frequency of those storms, relates to the regional climate and weather patterns. Understanding how a particular area is affected by storms throughout the year is important for road design and the selection and implementation of SDRR treatments.

Climate

Climate patterns control the types of storms that typically occur within a given watershed. The climate overlay of the Western United States is influenced heavily by the Pacific Ocean and the movement of storm cells onshore. In the Northwest, from northern California north to Canada, deep low-pressure systems arriving from the Pacific Ocean can carry large amounts of moisture that push up over the coastal or inland mountain ranges where much of the moisture is released. Much larger quantities of moisture are released on the west and southwest faces of these mountain ranges than east of the crest due to the prevailing storm tracks. The air mass off the ocean in winter is relatively warmer than air masses that travel across the cold land masses. This condition results in more frequent rain-on-snow storms on the west side of mountains as the jet stream alternates from the Gulf of Alaska to warmer waters of the Hawaiian Islands. Storms from Alaska bring cold air and lower elevation snow; storms originating more southerly from the Pacific bring warm rain and wind that melts snow rapidly.

The air mass dries out and cools as it crosses the mountains and, most of the time during winter, encounters a colder air mass on the east side, resulting in mountain and valley snow. The snow accumulates during the winter and melts out in the spring.

The opposite occurs in the summer, when the air mass arriving from the ocean is cooler than the air mass over land. The air mass warms over the land and holds more moisture that may carry across to the east side of the mountains where additional heating causes thunderclouds to form. Unstable atmospheric conditions may lead to large amounts of energy being generated in these clouds that then release large quantities of rain during short, high-intensity downpours. These intense storms can cause flash flooding. The most damaging storms typically are isolated thundershowers or cells that stall over one particular area or watershed for a long period of time. These localized storms are the least predictable. This phenomenon is more prevalent on the east side of the Cascade and Sierra mountains and the hot desert basins of eastern Washington and Oregon.

In the Interior West of the United States, “Chinook Winds” can blow down from Canada and send atypically warm winds into the region from Oregon to Montana, and particularly in the Rocky Mountain Region. These warm winds occurring in the winter can drastically change the temperature and have been known to melt a foot of snow in a day, resulting in local flooding.

Other phenomenon such as an ”Alberta Clipper” can rapidly move cold air from Alberta into the northern Plains and eventually move to the East along the mid-Atlantic Coast. These storms can bring atypically heavy snowfall over the regions. Other events, such as “derechos,” can move very strong winds and severe thunderstorms along a relatively narrow but long path, from the mid-West to New England, or along the East coast.

The “El Niño” and “La Niña” weather pattern extremes have had dramatic effects on U.S. weather patterns as well as the weather worldwide. As ocean temperatures either tend to be warmer than usual (El Niño) or colder than usual (La Niña) in the central and eastern Pacific, resulting weather across the United States becomes quite variable. During El Niño, the west coast may expect a stormy winter while the North may be warmer and the South wetter. A La Niña winter may produce a cold northern winter and drought in the Southern states. A La Niña year may also result in fewer Pacific hurricanes but more Atlantic hurricanes. El Niño patterns have become more frequent in recent decades rather than the historic more even fluctuations between the two extremes.

Topographic Influences

In many areas along the west coast, precipitation patterns and intensities vary dramatically due to the physical features of the landscape. Western mountain ranges oriented north to south lift air masses moving west to east and cause higher intensities of precipitation on the western slopes and drier rain shadows on the east side. The west coast mountain ranges are characterized by large volcanic peaks that extend to greater heights than the surrounding mountains. These peaks experience heavy precipitation on the slopes facing the oncoming storms but often cause a split in the airflow around the peak. This results in a localized rain shadow on the lee (east) side of the mountain range; but, if these split-storm cells converge beyond the mountain, a zone of higher precipitation may result (Mass 2008) from the convection caused by the collision. It is important to understand these influences of topography, combined with regional storm patterns, when planning for road drainage needs.

Ecoregions

The ecological hierarchy described in "Description of Ecological Subregions: Sections of the Conterminous United States" report (McNab et al. 2005) and the U.S. Environmental Protection Agency (EPA) Level III and IV information characterize climatic differences (precipitation amounts and patterns and temperature), vegetation, and large-scale terrain features throughout the United States. Characteristics of these various terrains can guide managers into areas where there may be concerns for road stability issues. This hierarchy is refined and available locally with land-type association and land type or soil maps. Interpretations resulting from these mapping efforts are invaluable in determining risks associated with roads. The EPA information on ecoregions is available at <http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm#Level IV>.

Watershed-Scale Considerations

The geomorphology and condition of a watershed influences the runoff response to storm events. Geomorphology partially dictates how a watershed responds to climatic inputs (Leopold et al. 1995) and the condition of the watershed affects how the watershed absorbs those inputs (Swanson 1980). The combination of geomorphology and watershed condition determines the response of a watershed to storm events and the level of hazard to be addressed.

Shape and Orientation

Watersheds in all climate regions may display an asymmetry of hillslope profiles on opposite sides of the valley (Leopold et al. 1995). In the middle latitudes of the United States, this expression may be dramatic. South-facing slopes tend to be drier (less snow and more rapid snowmelt and more intense sun exposure) and have greater diurnal temperature swings; whereas, north-facing slopes are wetter (hold snow longer and have less intense sun) with more uniform moisture. Drier slopes generally have shallower soils and are longer with fewer stream channel crenulations.[4] Wetter slopes may be steeper and shorter with a higher density of stream crenulations and deeper soils. While these characteristics are generalized and may be affected by storm patterns and how the underlying geologic structure controls subsurface water, understanding what these landform expressions mean for water movement is important to managing road drainage and stability.

[4] *A crenulation is an indentation in a contour line on a topographic map that represents a course for flowing water.*

At river-basin scales, the orientation of the watershed can influence the response of the watershed to storms. Watersheds that are aligned with the storm track progressing from the mouth to the headwaters will experience higher storm intensities across the higher slopes in the watershed. Watersheds that are perpendicular to the typical storm track may experience greater storm intensities on slopes facing the oncoming storm and lower intensities on the lee slopes. This can alter the runoff timing from one side of the watershed to the other and reduce the peak flows in the lower watershed. Roads located on the slopes receiving higher intensity precipitation may require additional drainage facilities. This leeward effect on precipitation intensity also can result if the watershed is oriented such that a storm travels from headwaters to the mouth.

At the watershed scale, storm duration and intensity may most influence the size of runoff from storms. Localized variability in intensity may be similar to that discussed for larger basins, but overall, it is how rapidly the storm passes over the watershed and the relative precipitation intensity that determines the amount of water falling on the watershed. **Rainfall intensity, more than total rainfall, dictates the design of smaller drainage structures and road surface drainage measures.**

Geomorphology

The geomorphology of a watershed controls how that watershed responds to severe storms and what stresses a road may encounter during storm events. This includes the orientation of the watershed and the hillslope characteristics, which result from the underlying geology and structure, as well as the climate history. Particularly valuable information can be obtained from geology, land-type association (LTA), and soil maps.

Geologic mapping identifies the underlying rock structure that influences slope stability (the strike and dip of the bedrock in relation to that of the hillslopes) and the specific rock types and their distribution across the watershed. Soil and LTA maps show the distribution of distinct combinations of soil types, slope characteristics (slope steepness, orientation, shape), and vegetation. From this information, the stability of slopes and the type of runoff expected from the watershed can be determined (i.e., flashy runoff from shallow, unconsolidated materials). Soils with finer soil texture and more clay-forming minerals may be most prone to instability. Understanding if the topography is convergent, which concentrates surface and groundwater, or divergent, which distributes water, is important for planning on the volume of stormwater a road may need to handle.

Stream Pattern

The climate and geology of a particular area determine the development of stream channels draining a watershed. Similarly, the stream network has a dramatic effect on the topography within a watershed. Mountainous terrain, in wetter climates, tends to have a higher density of stream channels that are deeply incised into the hillsides. Roads across these hillslopes must deal with a higher number of stream channels, steeper slopes, and deeper stream crossings. Drier climates, in general, have fewer stream channels and less deeply incised stream channels. Roads in these watersheds encounter fewer stream channels and typically have shallower crossings.

The geology has a broad effect on the pattern of the main stream channel in a watershed. Geologic structure may dictate the direction of channel development, such as where a channel may follow a straight line along a fault, or a dominate joint set, or a more erodible rock layer. The location of these channels may be more set than channels that are not controlled by geologic structure. Stream channels in watersheds with recent past or current glacial activity may move dramatically across the glaciated valley floor. Large amounts of glacially derived sediment tax the stream's ability to transport the sediment, resulting in active and continual channel shifts. Roads that cross or are located near these streams are at a higher risk of damage from the shifting channel.

Where available, LTA, topographic, and geologic maps provide invaluable information regarding stream patterns that are useful for evaluating channel influences on roads and appropriate SDRR treatments.

Site-Scale Considerations

Roads can cross a large variety of conditions within a watershed and even across a single hillside. Even where the majority of the road crosses a stable landscape, missing the proper interpretation and road drainage needs for one critical site can result in a failure and significant environmental damage. Other factors that determine the risks faced by a road system are related to watershed condition expressed at a given road location. The capacity of a watershed to process runoff and sediment generated during storm events is affected by past and current land use and fire history. If a road location is affected by a recent timber sale or a recent fire, this will modify (and likely increase) the risk of damage.

Geomorphology

The selection of SDRR treatments relies heavily on the expression of hillslope and stream characteristics at the site level. A clear interpretation of the different conditions along a road route is important for selecting and implementing the appropriate treatment.

Slope characteristics are the expression of complex interactions of climate, geology, and soils. Storm runoff patterns and intensity are a reflection of these interactions and the influence of land use on the natural patterns. In general, long, uniform hillslopes with shallow soils tend to shed runoff faster than complex slopes with deep soils; steeper slopes will move water faster than gentler slopes. Deeper soils provide a larger reservoir to store rainfall and snowmelt and will release water slower. Concave hill slope depressions tend to accumulate soil and water, thus having a relatively high incidence of failures or debris slides.

A history of glaciers within a watershed often produces oversteepened slopes and deposits of glacial material that affect water movement and slope stability.

Roads on steep slopes have larger or higher cutslopes; and, depending on the groundwater conditions, will likely intercept more subsurface water than roads on gentle slopes. Thus, roads on steep slopes will need more drainage capacity to handle the intercepted water and lower the risk of failure during storms. Also disconnect the road from the stream system.

Soils and Stability

Local soil characteristics play a major role in determining the stability of a road location. Water movement in the slope above, at, and below the road is influenced by the soil and bedrock features. Shallow bedrock or consolidated glacial till represents a vulnerable failure plane where water cannot move deeper into the hillside and therefore moves laterally across the bedrock interface causing increased pore water pressure in the soil and reducing slope stability. Fine textured soil layers, such as clay, may act in a similar manner, impeding vertical water movement.

Bedrock underlying hillslopes rarely is uniform; it is the result of fracturing, weathering, and erosion over time. Small hollows or depressions in bedrock may have been filled in during the passage of glaciers. These in-filled hollows collect water during storms and may remain relatively stable when undisturbed. But if a road cuts through a hollow, the in-filled material and the road may fail due to the changes in stability from the road cut. Road runoff may also increase the amount of water entering a hollow, resulting in failure.

Soil characteristics affect how water moves through the soil and therefore slope stability of cut and fillslopes. Soil texture and cohesion downslope of road drainage features affect the susceptibility of slope to erosion or mass failure. Soil depth, combined with slope steepness, affects the amount of bedrock into which a road is cut. While a full-benched road may be stable because it is located completely on bedrock, runoff from road drainage features may cause downslope instability due to soil and slope characteristics.

The presence of deep-seated hillslope slumps and earthflows play a major role in road-location stability. Failure planes can concentrate subsurface moisture that can then be captured by roads or cause slope failure. Ground movement can sever roadways and pose safety and access issues. A road cut may destabilize or cut into the toe of an old slide furthering instability.

The soil types across which a road passes affect whether the road needs additional surfacing to support traffic and minimize rutting and roadway erosion. Volcanic ash soils, in particular, have very low shear strength when wet and do not support vehicles, which leads to rutting and gullying. Soils with a high clay content will become slick when wet and, unless otherwise surfaced, will become safety hazards.

Road Location

Historical road location took advantage of easy construction along gently sloping valleys and on flat flood plains, which placed roads in proximity to meandering channels. These roads continue to constitute the primary connecting routes for forest road systems. As roads were used to access resources further upslope, roads were constructed on steeper slopes and crossed more unstable lands. In many instances, stability problems were recognized and design features addressed those issues; however, not all stability issues were recognized or appropriately addressed. Some stability problems come to light only after miles of road are constructed in a watershed. Stability concerns that were dealt with in the original road design may again become issues due to a lack of maintenance.

Road location considerations include:

- ❑ Landform–hillslope, canyon wall, active flood plain, stream terrace, slump scarp or bench, and so forth.
- ❑ Slope position–upper, middle, and lower part of the slope.
- ❑ Slope aspect–orientation as it relates to storm tracks, water accumulation, and snow melt.
- ❑ Slope shape–concave, convex, plane.
- ❑ Slope angle or steepness.
- ❑ Road stacking–are there other roads upslope, including “ghost” roads and skid trails.
- ❑ Presence of unstable or erodible soils/slopes.
- ❑ Site specific morphology at stream crossings.
- ❑ Size and efficiency of upslope watershed area draining to a particular channel crossing.
- ❑ Land use and watershed condition above road and any stream crossings.

Road Standards

Road standards also dictate varying considerations for SDRR treatment selection (see FSH 7709.56, Road Preconstruction Handbook, Chapter 40, Design) (U.S. Department of Agriculture, Forest Service 2014c). As noted in the introduction, SDRR applies to open and closed (stored) roads, but certain treatments also may have applicability to decommissioned roads.

Road standards relate to the drivability and type of vehicles appropriate to the road and have a bearing on the type and frequency of maintenance needed. Knowledge of the road's maintenance history is important since many roads do not receive prescribed maintenance over time due to many reasons. In many instances, maintenance is more dependent on funding than the road management objective or road maintenance level. As important as the maintenance history is, the expected future level of maintenance also has a bearing on the selection of treatment.

Lower standard roads typically have less risk to storm damage than higher standard roads. Factors that contribute to the reduced risk are that lower standard roads:

- ❏ May be single lane, disturbing considerably less area than a wider two-lane road.
- ❏ Have lower design speeds allowing the road to have rolling grades and smaller cuts and fills (less earthwork).
- ❏ May use fords and dips rather than culverts and cross-drain pipes, thus having a lower risk of plugging and failure during a storm.

Nevertheless, lower standard roads may still have high-risk sites for diversion potential and be located on highly unstable slopes or cross steep drainages subject to debris slides. Low-standard roads with low-use levels may have less design requirements, poor construction quality control, and receive less inspection and maintenance than higher standard, high-use roads. Figure 11 shows some of the differences in a low- and relatively high-standard road.

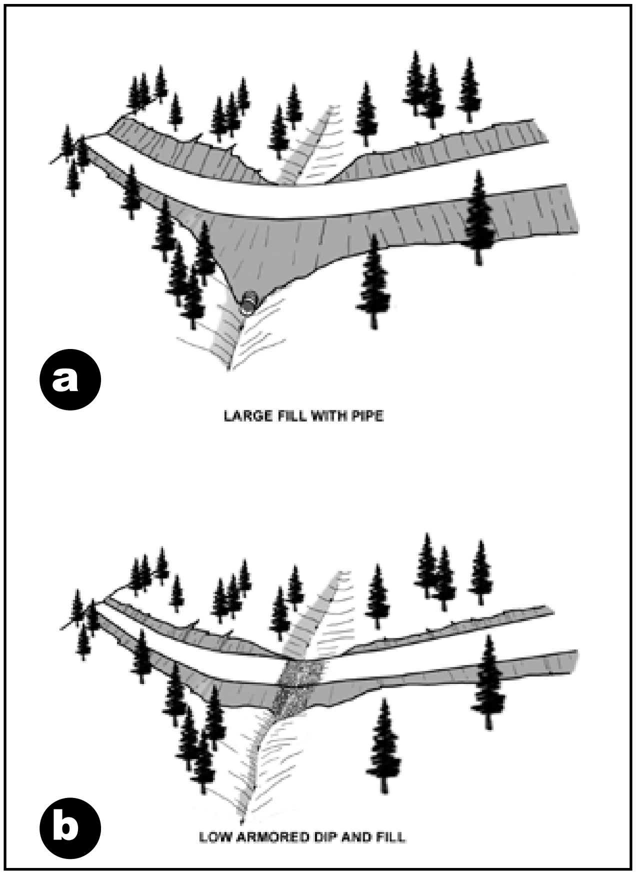


Figure 11—Varying risk of a high-standard road with pipes and larger cuts and fills (a) versus a low-standard road with small cuts and fills and a ford (b).

A specific road may have been originally built to a certain standard. A subsequent administrative decision could change that standard, either higher or lower, yet little physical change may have occurred to the road. Any SDRR treatment will need to be consistent with the current road standard. The full history of the road (when available) and expected future management are important when considering risk and proper treatment. Knowing the original standard to which the road was built, if different from the current standard, has a bearing on how the road may respond to storm stresses.

Construction Practices/Methods
How the road was built often affects long-term performance and susceptibility to damage during storms. This information may be unknown. Often, the age or year of construction is used as an index to identify the most common construction practices at the time. Examples of practices that increase hazard (or reduce long-term stability/performance) include sidecast construction/loose sliver fills and the use of organic retaining walls (burying logs behind stumps to retain loose fill) on slopes that are too steep for the fillslope to catch. Relatively small culverts were typically installed on old roads compared to those used today. When identification of these practices can be integrated into risk assessment or prioritization at a watershed, subwatershed, or site scale, it can help target treatment locations and solutions. When left untreated, these sites will fail and often necessitate expensive solutions, such as retaining walls or difficult road realignment. The failures can cause considerable damage to site productivity and streams downslope.

Failure Potential
The hazard discussion above demonstrates the complex nature of factors that influence the potential for damage or failure during storm events. An assessment of these factors is critical to selecting the proper treatment to lower the risk. A number of procedures have been developed by forests to rank the failure risks of roads. Many potential risk factors exist, but only a short list is presented here.

Factors contributing to failure risks include:
Watershed Factors:
- ❑ Rain-on-snow.
- ❑ Stream density.
- ❑ Debris (wood and sediment) loading on slopes and in drainages.
- ❑ Various land management activities that affect vegetation, soil properties, and runoff.
- ❑ Fires and lack of ground cover.
- ❑ Best management practices implementation.

Slope Factors:
- ❑ Slope angle.
- ❑ Presence of unstable soils; historic mass wasting.
- ❑ Soil texture and stratigraphy: shallow and dry versus deep and wet, presence of fault traces and restrictive layers.
- ❑ Upslope vegetation type and age.
- ❑ Presence of bioperturbation (riverine and mountain beaver).

Road Factors:
- ❑ Road location and grade.
- ❑ Road stacking.
- ❑ Age of road/type of construction (i.e., sidecast).
- ❑ Ability to maintain ditch integrity.
- ❑ Cutslope stability and ravel.
- ❑ Diversion potential: debris plugging culverts, filled ditches, uniform downslope road grade.
- ❑ Road maintenance history.

2.2 Consequence Assessment
The consequence assessment looks at the values at risk—the infrastructure or natural resource impacts that would result should a failure occur.

There are three general categories considered within the SDRR umbrella. First, consider the potential for effects on life and safety. SDRR treatments can contribute to alleviating some of the risk to health and safety by reducing the potential for failure. Road failures pose a threat to persons travelling forest roads. Due to road or bridge washouts, users may be stranded without proper supplies to endure an extended stay. Limited sight distances on low-volume roads may obscure washouts and debris across the road. Upslope road and slope failure may threaten private property downslope.

Second, there is the value of the infrastructure itself. The loss of or damage to road components, campgrounds and other buildings, roads, culverts, and bridges downslope may impair or prevent use until repaired. These require funding and other resources to repair or replace.

Third, there are environmental values at risk. Impairment of site productivity results when hillslopes fail or when upslope debris and soil bury downslope forest areas. The delivery of sediment and road debris to stream channels poses significant risks to fish and can disrupt normal channel processes for extended periods of time, extending over miles of river channel. Some salmonid populations are at risk of extinction due to habitat degradation from sediment impacts. Some stream reaches are designated as water-quality impaired and included on a State's 303d list[5] due to direct or indirect sediment impacts. Riparian plant communities are impacted by streams migrating around debris jams and sediment deposits. Downslope wetlands and other sensitive habitats also may be severely impacted by sediment and debris deposition from upslope failures.

5 States are required by the Clean Water Act to maintain a list of "impaired" waterbodies. The 303(d) list identifies waterbodies where reliable data show water quality is impaired (does not meet State water quality standards) and what pollutants are responsible for the impairment.

Consequences of Failure

If a road fails, consider the following safety concerns.

- ❑ Are there structures downslope; are they inhabited?
- ❑ What is the use level of the road and can access be blocked readily?
- ❑ What would be the expected type and amount of damage to the road and what would be the cost to repair the road?
- ❑ What would be the disposition of the failure material (sediment and debris)?
- ❑ What is the likelihood of a debris jam forming and creating a dam-break flood in the stream? That could extend the potential damage farther downstream.

If the material travels a short distance downslope and comes to rest in the forest or on a river terrace, the harm would be less than if that debris entered a critical environmental site, such as a wetland or a salmon spawning stream reach. An evaluation of the probable fate of the failure material (i.e., sediment and debris delivery potential) is important to determine risk tolerance for the site. For delivery to aquatic sites, knowing the volume and grain size of delivered material is important to assess the potential harm.

Evaluate downslope factors in order to predict the disposition of the failure material:

- ❑ Topography–presence of broken slopes with terraces or benches to catch material versus steep, straight slopes that deliver directly to water or wetlands.
- ❑ Distance downslope to valuable resources–how much material would travel the distance?
- ❑ The resource affected–how resilient is it to impacts?

- ❑ Additional infrastructure downslope–will other road segments, culverts, or other improvements be involved?
- ❑ Potential for road failure to initiate a mass failure, debris torrent and/or dam-break flood.

Understanding both the hazard (potential for failure) and the consequences relating to a failure is paramount to selecting treatments and appropriately setting treatment priorities. Not all hazard sites will be a high priority for treatment, particularly if the consequence is low. All high-consequence sites should be high priority for treatment, but also may be ranked based on the details of the consequences and an assessment of the level of acceptable loss.

2.3 Overall Risk Assessment

Risk assessment is the combination of the potential hazard assessment and the consequence to values at risk. This guide does not provide a detailed process for conducting a risk assessment; however, an accurate and comprehensive risk assessment must be incorporated into all SDRR programs. Table 1, adapted from Exhibit 02 in Forest Service Manual FSM 2500-Watershed and Air Management, Chapter 2520-Water Protection and Management (2520-2014-1 Interim Directive) (U.S. Department of Agriculture, Forest Service 2014a) demonstrates a possible scenario.The first consideration may use a numerical or relative degree rating for the magnitude of the consequence. The second factor considers probability of damage or loss. The factors result in a combined ranking of risk from very high to very low. This risk rating would influence the priority of the work.

Table 1—Risk assessment matrix

Probability of Damage or Loss	Magnitude of Consequences		
	RISK		
	Major	**Moderate**	**Minor**
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

.

Probability of Damage or Loss:

The following descriptions provide a framework to estimate the relative probability that damage or loss would occur (to reduce the subjectivity of these ratings, develop criteria to express these more quantitatively).

Very likely: Nearly certain occurrence (greater than 90 percent).

Likely: Likely occurrence (greater than 50 percent to less than 90 percent).

Possible: Possible occurrence (greater than 10 percent to less than 50 percent).

Unlikely: Unlikely occurrence (less than 10 percent).

Magnitude of Consequences:

Major: Loss of life or injury to humans, major road damage, irreversible damage to critical natural or cultural resources.

Moderate: Possible injury to humans, likely long term, but temporary road closure and lost use of major road or road system, degradation of critical natural or cultural resources resulting in considerable or long-term effects.

Minor: Road damage minor, little effect on natural or cultural resources resulting in minimal, recoverable or localized effects.

Risk and Priority:

A. Very high and High risk: Highest priority for SDRR treatments.

B. Intermediate risk: SDRR treatments needed; may be incorporated into annual maintenance.

C. Low and Very low risk: SDRR treatments may not be necessary.

Proper risk assessment is not only imperative for setting meaningful priorities for SDRR treatments, but useful for making all road management decisions. There are a number of formal and informal risk assessment procedures to help as a guide. The document "Upslope Erosion Inventory and Sediment Control Guidance, Part X of California Salmonid Stream Habitat Restoration Manual" (Weaver et al. 2006) provides considerable information about site assessment.

Depending on the resource values and the complexity of the site, a site evaluation or area assessment may require a data-intensive site review. One such tool is the "Geomorphic Road Analysis and Inventory Package" (GRAIP) (Black et al. 2012) (Cissel et al. 2012b), along with its publications and software. GRAIP is a tool developed by the Forest Service, Utah State University, and the U.S. Environmental Protection Agency to help predict the impacts of roads or a road segment, and prioritize where reconstruction work is needed most. It uses resource data and field road inventory data in an Arc-GIS (geographic information system) platform to predict and quantify sediment production, diversion potential, or slope stability risks. It also is useful to assess hydrologic connectivity of roads to streams. This information can be used to identify, prioritize, and help select SDRR work. A comprehensive field-based inventory of existing and potential road-related sediment sources is inexpensive compared to the widespread application of SDRRs. Information on the GRAIP analysis method is available at <http://www.fs.fed.us/GRAIP/index.shtml>.

Another tool to use in assessing road treatment needs and priorities is NetMap <http://www.netmaptools.org/>.

The publication "Soil and Water Road-Condition Index-Field Guide" (Napper 2008) is still another tool that can help assess the condition of a road and identify problem areas, which may be exacerbated during a major storm event. Those sites often would be good candidates for SDRR treatments. This document is available at <http://www.fs.fed.us/eng/pubs/pdf/08191815.pdf>.

The following section discusses various factors and processes that should be addressed using a two-tiered assessment of hazards and consequences.

CHAPTER THREE

SELECTION OF APPROPRIATE TREATMENT

3. SELECTION OF APPROPRIATE TREATMENT

This guide assumes that an inventory of all potential hazard areas and road conditions is complete or will be completed as part of the process. Selection of the appropriate treatment will depend on the assessment of priorities, the hazards and values at risk, and funds available. This should be an interdisciplinary process. The development of this guide relied on the experience of long-term road managers and other specialists. Each evaluation team should seek out and rely on those with the greatest experience with road management and the resources at risk. However, keeping the process and selection as simple as possible is desirable. Treatment selection also depends to a certain extent on whether the treatment is a repair of existing damage, or preventative, to reduce the risk of future failure. Once a failure has occurred, repair and treatment of the road to reduce future risk may be quite different from a preventative treatment that would reduce the risk of a failure.

Table 2 presents a summary of storm damage risk reduction measures used. The most commonly used treatments are listed first (and discussed in section 5), followed by the less common treatments that typically are more costly or more difficult to implement (discussed in section 6). Note that separate sections do create some redundancy in the document, but it was done to best highlight the most common and cost-effective treatments used by practitioners.

Table 2—Summary of storm damage risk reduction measures

MOST COMMON TREATMENTS	Effectiveness		Cost effectiveness	
	Short Term	Long Term	Low	High
Easy, Low Cost, or Most Cost Effective				
Road Maintenance				
Normal grading, cleaning, and shaping maintenance items.	*			*
Road Surface Drainage				
Add rolling dips.		*		*
Add ditch-relief culverts (cross drains).		*		*
Add waterbars.	*			*
Ditch treatments/armoring/check structures.	*		*	
Add leadoff ditches.	*			*
Cross-drain pipe/dip/ditch-outlet protection/armoring.	*		*	*

Table 2—Summary of storm damage risk reduction measures (continued)

MOST COMMON TREATMENTS	Effectiveness		Cost effectiveness	
	Short Term	Long Term	Low	High
EASY, LOW COST, OR MOST COST EFFECTIVE				
Stream Crossing Structures				
Culvert maintenance.	*			*
Minor channel debris removal and clearing.	*			*
Culvert diversion prevention/armored overflow protection.		*		*
Bridge Protection and Improvement				
Channel maintenance and debris/sediment clearing around footings.	*			*
Erosion Protection				
Physical erosion control measures.	*		*	
Vegetating barren areas/deep-rooted native plants.		*		*
Gully prevention (limiting water concentration).		*		*
Slope Stability Measures				
Sidecast fill; pull-back/sliver-fill failure prevention.		*		*

Table 2—Summary of storm damage risk reduction measures (continued)

LESS COMMON TREATMENTS	Effectiveness		Cost effectiveness	
	Short Term	Long Term	Low	High
MEDIUM-COST TREATMENTS				
Surface Drainage				
Converting inslope to outslope road (only on appropriate soil types).		*		*
Other surface water diversion structures.	*		*	
Cross-drain pipe inlet protection or drop inlets.	*		*	
Stream Crossing Structures				
Increase culvert capacity.		*	*	
Use of trash racks.	*		*	*
Culvert reinstallation/realignment.		*	*	*
Culvert pipe inlet/outlet protection, armoring, adding headwalls.		*	*	*
Convert problem culverts to low-water crossings.		*		*
Local stream channel stabilization measures.	*		*	
Local scour protection.	*			*
Beaver protection.	*		*	
Road-Stream Encroachment				
Add floating log weirs.	*			*
Relocate road away from stream.		*		*
Erosion Protection				
Soil bioengineering and biotechnical methods.		*		*
Gully stabilization.	*		*	
Add roadway surfacing materials.	*		*	
Slope Stabilization Measures				
Modifications to cut-and-fillslopes.		*	*	
Slope-drainage improvements.		*		*
Use deep-rooted vegetation.		*		*
Strengthen existing structures (launched soil nails).		*		*
Deep patch shoulder repair.		*	*	
Road Storage and Closure Issues				
Road closure/storage.		*	*	*

Table 2—Summary of storm damage risk reduction measures (continued)

LESS COMMON TREATMENTS	Effectiveness		Cost effectiveness	
	Short Term	Long Term	Low	High
HIGH-COST TREATMENTS				
Bridge Protection and Improvement				
Increase freeboard on bridges.		*		*
Major bridge-scour protection.		*		*
Slope Stability Measures				
Add retaining structures.		*		*
Change road grade/alignment/width.		*		*

Simple, inexpensive, and cost-effective preventative measures should always be the first priority and are most commonly used. Mitigation measures should be a second priority. More expensive treatments reduce the number of miles of road that can be treated using limited resources. The simpler preventative treatments often are the less expensive ones, but cost effectiveness should be more important than cost alone. Less costly treatments might include work such as:

- ❑ Maintaining or improving roadway surface drainage.
- ❑ Adding cross drains and leadoff ditches.
- ❑ Armoring ditches and drain outlets.
- ❑ Vegetating barren slopes and exposed areas.
- ❑ Preventing gully formation with improved drainage.
- ❑ Adding armored overflow dips, secondary culverts, or diversion prevention dips/drains on high-risk culverts.
- ❑ Clearing minor channel debris at culvert inlets and bridges.
- ❑ Excavating (pulling back) unstable fill material.

Other treatments that involve much more work, major land disturbance, higher cost, or more detailed site evaluation and design detail may be important but more difficult to implement. These treatments likely will be implemented less often. Items with long-term effectiveness in this category include:

- ❑ Reconforming the road surface (from inslope to outslope).
- ❑ Replacing or increasing culvert capacity.
- ❑ Raising a bridge deck for added freeboard.
- ❑ Moving the road away from a stream.
- ❑ Reshaping a slope to a flatter angle.
- ❑ Strengthening retaining structures or adding a deep patch fill repair.
- ❑ Realigning a road section.
- ❑ Stabilizing of unstable cut or fill slopes.
- ❑ Adding biotechnical slope stabilization and erosion control measures.

Short-term or less effective treatments may include:

- ❑ Adding trash racks to culverts.
- ❑ Adding streambank stabilization measures.

Evaluation and prioritization of the many factors involved in treatment selection can be difficult. It is important to assess the risk and the values-at-risk accurately and then tailor the treatment to reduce the risk to an acceptable (agreed upon) level using the most cost-effective treatment. At times, these decisions may be controversial and agreement may be difficult to obtain. Good interdisciplinary communications and thorough study of the situation are critical to this process. Agreeing on effective solutions for high-use roads that also are at high risk of failure can be difficult and controversial when the treatment options are limited by site conditions and funding.

Climate change may add to the uncertainty as to what level of risk is tolerable for some sites. Channel margin areas and rain-on-snow zones may be riskier in the future. Certain species may be more vulnerable to impact due to the effects of climate change on their habitat. Conversely, in some areas climate change might basically be a nonissue.

CHAPTER FOUR
IMPLEMENTATION

4. IMPLEMENTATION

Implementation of storm damage risk reduction (SDRR) measures will vary by forest, depending on funds available to accomplish the work. A lack of specific funding to implement SDRR treatments does not necessarily preclude taking actions to increase a road's resistance to damage. The routine application of best management practices and many actions inherent in preventative maintenance on the road system can go a long way toward reducing storm damage. Preventative maintenance practices are discussed in section 5.1.

Our goal is to reduce road damage as well as the overall resource impacts resulting from a major storm. The objective is to implement SDRR measures as resources and funding allow. However, planning and preparation for storm events before they come is desirable too. This work is valuable considering that predicting storms is difficult. Storms are unique, and some damage will always happen from the largest ones, no matter how much SDRR work is done.

4.1 Planning, Preparation, and Response

Storm events will happen. The question is not if, but rather when, where, and how often or how big. Thus, to minimize the damage and impacts of natural disasters, one must develop a storm damage risk reduction mindset. This mindset should permeate all aspects of road management, from inventory and design through storm response, maintenance, and repair.

Planning before a disaster occurs includes issues, such as having current information about the transportation system and identifying alternative routes to use in case of closures, knowing the weakest links in the system, having local contractors available to do needed work, preparing for temporary repairs, and having a reliable system of communication.

Each forest should develop a process that maximizes the ability to prevent storm damage, minimizes resource impacts and the disruption of the transportation system. Some key elements include:

- ❑ A transportation inventory that includes:
  - All drainage features, ranked as to vulnerability.
  - Culvert and culvert-condition inventory.
  - Road segments or sites of greatest risk or vulnerability.
- ❑ List of priority sites for prestorm inspection and storm patrols (based on historic damage and projected vulnerability), including maps to facilitate planning.
- ❑ Prioritized work lists of:
  - Systematic inspection schedule.
  - Prioritized sites for SDRR treatment.
- ❑ Storm contingency plan:
  - Identification of alternative transportation routes.
  - Available maintenance equipment.
  - Temporary bridges on hand.
  - An organization, such as the incident command system (ICS), in place to deal with disaster coordination.
  - Available maps and a reliable system of communication in place that functions during a disaster.
  - Storm damage patrol organization (ICS) or other identified structure.
  - Preparations for storm damage assistance, such as cooperation with other agencies.
  - Emergency procedures coordinated with regulatory agencies to deal with Clean Water Act and National Environmental Protection Act issues.

A note on storm patrol organizations. The organization should be identified and ready to respond as needed. Map and communication resources should be readily available and operational. Cooperative agreements with other agencies should be in place and communication protocols established.

Storm patrols can be successful in preventing severe damage to sites by relieving blockages at culverts and bridges, but storm patrols also can be dangerous and costly should personnel and equipment get stranded during storms. Knowledge of the magnitude of precipitation that triggers potentially damaging events in different areas can be used to mobilize storm patrols and limit patrols in dangerous conditions. During storms, limited patrols may be used on easily accessible main roads. To remain safe and effective, patrols should occur prior to the major runoff season or in the fall, and after the peak of major storms has passed. Damage from the next storm may be prevented by clearing the latest storm debris and repairing drainage features.

The *"Simplified Guide to the Incident Command System for Transportation Professionals"* contains useful information on the ICS system for overall coordination during disaster conditions, particularly with regard to transportation facilities. It is available at <http://www.ops.fhwa.dot.gov/publications/ics_guide/>.

4.2 Best Management Practices as Mitigation

The regular application of roads best management practices (BMPs) is a powerful tool for SDRR implementation and should be viewed as part of a storm damage risk reduction strategy. BMPs result in the following:

- ❑ Less storm damage.
- ❑ Less environmental damage and water quality degradation.
- ❑ Less impacts from road delays, closures, and repair costs.

Roads need to be built, protected, inspected, and maintained as well as possible with appropriate design standards and mitigation measures. The application of BMPs helps to achieve these goals. BMPs also help guarantee a reasonable level of design quality and environmental protection, which is useful when a major storm hits.

An **environmentally friendly road** is a road that is well located, constructed with minimum ground disturbance, is hydrologically disconnected from the watershed drainage network, is well drained, and is appropriately surfaced to control surface erosion and minimize the loss of surfacing material. Road-drainage structures are suited to the site and have adequate flow capacity, cut and fillslopes are stable, and erosion control measures are effective and minimize sediment delivery to hillslopes and stream channels.

The “Low-Volume Roads Engineering Best Management Practices Field Guide” (Keller and Sherar 2003) presents concepts and lists of best management practices for each key area of low-volume road design (i.e., surface drainage, culverts, slope stabilization, erosion control, etc.). These points complement the BMPs documented in the new approved “National Best Management Practices for Water Quality Management on National Forest System Lands” (USDA FS 2012), particularly in the section on Road Management Activities. Note that the above-referenced “Low-Volume Road Engineering BMP Guide” is cited in the “List of Resources for Road Management Activities” (U.S. Department of Agriculture, Forest Service 2012).

The Forest Service publication “National Best Management Practices for Water Quality Management on National Forest System Lands”, Volume 1 (U.S. Department of Agriculture, Forest Service 2012), provides a general set of best practices for most aspects of forest management, including roads. This guidance should be used in new planning efforts, National Environmental Policy Act analysis, and evaluation of proposed activities, particularly if those projects affect water resources. The national program will contain the National Core BMPs, standardized monitoring protocols, national directives, and the data management structure. The document is available at <http://www.fs.fed.us/biology/resources/pubs/watershed/FS_National_Core_BMPs_April2012.pdf>.

CHAPTER FIVE

COMMON STORM DAMAGE RISK-REDUCTION TREATMENTS

5. COMMON STORM DAMAGE RISK-REDUCTION TREATMENTS

A wide variety of storm damage risk reduction (SDRR) measures exist that can be cost effective and reasonably implemented or incorporated into forest roads to reduce their likelihood of failure and minimize their adverse environmental impacts. Their use depends first on an assessment of the risks involved and then on priorities and funds available to accomplish the work. Treatments are grouped into the following categories:

- ❑ Road maintenance.
- ❑ Road surface drainage improvements.
- ❑ Stream crossing structure protection and improvements.
- ❑ Bridge protection and improvements.
- ❑ Road-stream encroachment.
- ❑ Erosion prevention and erosion control.
- ❑ Slope stabilization measures.
- ❑ Cold region storm issues.
- ❑ Road storage and closure.

In each category there are preventive measures that are relatively simple to implement and are cost effective. The most common, useful, and cost-effective treatments or measures used are consolidated and discussed in this section. Other less common measures that involve structure replacement, road relocation, major rehabilitation, structural improvements, or are more expensive to implement are discussed in section 6.

While these are important treatments for consideration in the right application, some may be less practical, have only a short-term benefit, require excessive maintenance, possibly be quite expensive, or be less cost-effective and therefore implemented less often. Justify their use by analyzing risk, potential damage, and cost effectiveness.

The analysis team, with knowledge about the entire forest road system, must weigh the tradeoffs of high-cost treatments at a few sites and the treatment of a larger number of high-risk sites with lower cost treatments. Leaving more sites untreated in order to treat a few sites with high-cost solutions may leave more resources at risk than treating more sites and cutting back on the higher cost treatments. It cannot be stressed enough that cost effectiveness both by site and across a landscape needs to be carefully considered.

Many SDRR treatments are site-specific so field analysis and good judgment are needed for prescribing and designing on-the-ground treatments. This guide is not intended to be an exhaustive list of potential treatments; there may be other treatments of equal or greater value that are not covered here.

PIARC, the World Roads Association, has presented a general discussion of all natural hazard impacts and reduction options in its publications “Risks Associated with Natural Disasters, Climate Change, Man-made Disasters, and Security Threats” (PIARC, 2013) and “Natural Disaster Reduction for Roads” (PIARC 1999). Additionally, the Forest Service publication “Burn Area Emergency Response Treatments Catalog (BAERCAT)” (Napper 2006) describes a number of useful drainage, channel, and erosion-control treatments to minimize damage from storms after a forest fire and treatments that also apply to general storm damage risk reduction. It is available at <http://www.fs.fed.us/eng/pubs/pdf/BAERCAT/lo_res/lo_res.shtml>.

Road drainage deficiencies typically are the number one priority for SDRR treatments. This includes road surface drainage measures and drainage crossing structure and channel problems that can lead to structural failures. Relatively inexpensive road surface drainage improvement measures are particularly cost-effective and can prevent significant road damage, hillslope erosion, and sediment delivery to streams.

Drainage crossing structures, such as culverts, bridges, and fords, typically are expensive; failure may result in major resource damage, sediment production, and loss of road use for a significant period of time. Risk of failure may be caused by poorly designed structures, lack of flow capacity or freeboard, poor location, foundation scour, or problems with the channel, such as a confined reach or excessively sharp bend. Roads that remain closed while repair decisions are made will not receive maintenance beyond the damage site, perhaps increasing their potential for further damage. Thus, these structures can be a high priority for SDRR measures.

One of the most fundamental actions that one can take is staying current with needed road inspections and road maintenance. This work should be routine or periodic and not just a function of the road crew. All Forest Service employees should actively engage in observing and reporting road drainage problems. Blocked ditches, rutted roads, loss of road crown, damaged culverts, and so forth all contribute to additional damage during major storm events.

Erosion protection measures around structures, in exposed areas, along road shoulders and fillslopes, in quarries, and so forth are critical to prevent erosion and subsequent sedimentation and water-quality degradation. Erosion control measures typically are relatively inexpensive.

While road erosion presents a widespread, chronic source of pollution and may reduce land productivity, a landslide can be an acute catastrophic source of sediment. Landslides can close roads for significant periods of time and can be costly to cleanup or stabilize. The resulting resource damage may be difficult and expensive to cleanup or mitigate. Thus, landslide stabilization or slide prevention can be a specific goal in storm damage reduction on some specific cut slopes and fill slopes. Road closure and storage, decommissioning, or obliteration are other ways to eliminate problematic or potentially damaging roads.

5.1 Road Maintenance

Road inspection and maintenance is a fundamental part of road-system management. Therefore, it should be done both routinely for many items and periodically for recurring issues. This is important for roads to function properly any time of year, and particularly when the large storms occur. Figure 12 shows a road badly in need of road maintenance that is very vulnerable to additional damage from any storm. When a large storm hits, needed inspection and maintenance becomes critical, particularly properly functioning road-surface drainage and stream-crossing culverts. This applies to roads of all maintenance levels. Also, talk to local personnel about priorities and problem areas.

Knowledgeable local individuals often have useful historic information on problem sites. Document the information, and develop a list of priority areas, based upon local experience that should receive maintenance first. Keep in mind, however, that road surface and ditch maintenance will lead to increased sediment production following the maintenance (Luce and Black 2001). Thus, road maintenance should only occur when really needed, particularly when road-surface drainage defects need correction.

Road maintenance items that are particularly important to implement in advance of any large storm (keeping in mind that there may not be much time to react just prior to a storm) are listed below, roughly in order of priority:

- ❑ Remove logs and debris from around the inlet area of culverts.
- ❑ Remove debris from the inlet area of ditch-relief cross-drain culverts to prevent plugging.
- ❑ Clean out debris from trash racks upstream of culverts.
- ❑ Clean ditches to avoid blockage and ponding of water that can saturate the road subgrade and/or fill material.
- ❑ Replace missing riprap armor around the inlet/outlet of culverts.
- ❑ Reshape surface drainage features, such as rolling dips, waterbars, and so forth.
- ❑ Remove unwanted berms that have formed along the outside edge of the road.
- ❑ Grade and shape the roadway surface to maintain a distinct inslope, outslope, or crown shape to move water rapidly off the road surface, keep the roadbed dry, and prevent water concentration.
- ❑ Remove ruts in the road surface that trap and concentrate water.
- ❑ Patch potholes and seal cracks in an asphalt surface to prevent water intrusion and accelerated damage.
- ❑ Compact the graded roadway surface to keep a hard driving surface and prevent the loss of fines.

Figure 12—Ruts and erosion in the road surface because of lack of surface drainage and maintenance. This road in this condition is particularly susceptible to damage from any storm. (Photo courtesy of Vincent Barandino.)

A note on ditch cleaning: During the 1970s and 1980s concerns over sediment production from roads led to changes in road maintenance practices in many areas. Ditch cleaning was identified as a procedure that exposes erodible soils in the ditch and reinitiates cutslope erosion processes, generating chronic sources of road sediment. As a result, less intrusive ditch cleaning became common. Over time, the result of less ditch cleaning was vegetation encroachment and lower hydraulic efficiency within the ditch. Brushing activities cut the stems in the ditch but left stubs that trapped debris, this further reducing ditch efficiency and resulting in plugged ditches. Today a balance should be met between maintaining hydraulic efficiency and keeping a rough or armored surface or vegetative cover to reduce ditch erosion.

Ditches that are hydrologically connected to the stream system are the greatest concern. To maintain hydraulic efficiency of the ditches and also allow for ditch stabilization and stabilization of adjacent cutslopes, ditches need to be oversized so that adequate capacity is maintained in the absence of regular cleaning. Any ditch enlargement needs to be done in such a way that cutslopes are not undercut, creating a new source of erosion and instability. Some sites may not be appropriate for oversized ditches and will require another technique, such as outsloping and/or insloping without a ditch and rolling the grade to manage water.

Additional road maintenance or improvement items that are useful for long-term prevention of damage are:

- ❑ Armor ditches in areas of particularly erodible soils or steep grades.
- ❑ Add frequent ditch relief cross drains or rolling dips.
- ❑ Convert an inslope section of road to an outslope.
- ❑ Install diversion prevention dips at or downslope of stream-crossing culverts that have the potential to divert the stream down the road.
- ❑ Add riprap armor or soil bioengineering protection around the inlet of undersized culverts or bridges.
- ❑ Plant deep-rooted vegetation on oversteep cut and fillslopes or slopes with a history of movement.
- ❑ Install a deep patch slope stabilization repair on chronically settling fills.

Despite the need for maintenance, particularly on open roads, current funding suggests that most roads will not receive the maintenance they need. Closed roads will receive little to no maintenance. Unneeded roads should be decommissioned. For most roads that cannot be closed and will likely receive little maintenance, stormproofing with good drainage measures (as discussed in the following sections) will be important. Roads need to be put into a condition to be as self-maintaining as possible.

5.2 Road Surface Drainage Improvements

A number of commonly used roadway surface drainage improvements that prevent or minimize storm damage are summarized below. With traffic and time, ruts will form down most roads, thus maintenance is needed periodically. In the absence of maintenance, the best road drainage measures to prevent ruts are rolling grades, rolling dips or waterbars, or an inslope or outslope road. The following measures are used to construct and improve roads to prevent the concentration of water, move water rapidly off the road, and facilitate control of water:

- ❑ Close or relocate/reconstruct road segments with excessively steep road grades. The steeper the road grade, the more difficult it is to achieve road surface drainage. With steep grades, even roads with moderate cross slopes keep water on the road surface for a long distance. Road grades less than 10 percent are easiest for control of surface flow. Grades less than 6 percent are helpful on roads receiving infrequent maintenance.
- ❑ Maintain positive surface drainage with an outslope, inslope, or crown roadway section, as seen in figure 13. A cross slope of 4 to 6 percent is typical on an unsealed road. Six percent may be ideal for drainage and requires the least maintenance. Two to three percent may be adequate for a hardened surface on flatter grades, particularly with log haul.
- ❑ Roll grades or undulate the road profile frequently to provide locations to disperse water off the road (figure 14).

- ❑ Use frequently spaced leadoff ditches to prevent the accumulation of excessive water in the roadway ditches.
- ❑ Use roadway cross-drain structures, such as rolling dips (or pipe cross-drain culverts, open-top culvert flumes, or deflectors), to move water across and off the road surface and to move water from the inside ditch across and off the road surface. Space the cross-drain structures frequently enough to remove all surface water without excessive water accumulation. Since these features are intended to cutoff and discharge accumulated ditch water, they must be cut to the bottom of the ditch, which may be relatively deep, and dam the ditch on the downgrade side.
- ❑ Protect cross-drain outlets with rock (riprap), brush, or logging slash to dissipate energy and prevent erosion, or locate the outlet of cross drains on stable, nonerodible soils, rock, or in well vegetated areas. Also use downspouts or downdrains to move water down a fillslope to a stable outlet area. A stable outlet location is important. The ideal spacing listed in tables needs to be adjusted to meet field conditions. Closer cross-drain spacing may eliminate the need for outlet armoring and minimize water concentration.
- ❑ Construct waterbars on infrequently used roads or closed roads to control surface runoff and remove water from the road before it accumulates and causes erosion. Waterbars are road surface features that may not intercept the ditch and may redirect road surface flow into inboard ditches on strongly insloped templates.
- ❑ Repair entrenched roads that are dificult to drain. The road may effectively become a canal. Ideally, raise the road grade above the level of the adjacent terrain with fill material to be able to drain the road surface (see appendix A2 for a drawing of road options in wet, very flat terrain).
- ❑ Use catchwater ditches (intercept ditches) across the natural ground above a cutslope in areas with high-intensity rainfall and overland flow. These ditches will capture overland sheet flow before it pours over the cutslope and erodes or destabilizes the cut. However, be aware that catchwater ditches that are not properly maintained can become counterproductive pools of water above slopes, increasing the probability of slope failure or gully erosion.

Note that many of the measures listed above may not be necessary if you can disperse the flow adequately and/or reduce the concentration or amount of water. If you are getting ditch erosion or need armor at the outlet of a pipe, ditch, or dip, it is a sign of too much concentrated flow. First try to add additional cross drainage or more leadoff ditches to reduce the flow in the problem area.

For all road surface water drainage applications, it is extremely important to know the soil and hillslope conditions where water is discharged from the road onto the slope. Most mass slope failures below roads, as well as many gullies, result from excessive concentration of surface water running off the roads and saturation of marginally stable or unstable hillslopes. Information regarding road surface drainage, road damage prevention, and water quality protection is available in the U.S. Department of Agriculture, Forest Service, National Technology and Development Program publication series “The Water/Road Interaction Technology (WRIT) Series” (U.S. Department of Agriculture, Forest Service 2000). For additional technical information, see the Web site <http://www.stream.fs.fed.us/water-road/>.

Additional information on general road drainage can be found in “Roadway and Roadside Drainage” (Orr 2003).

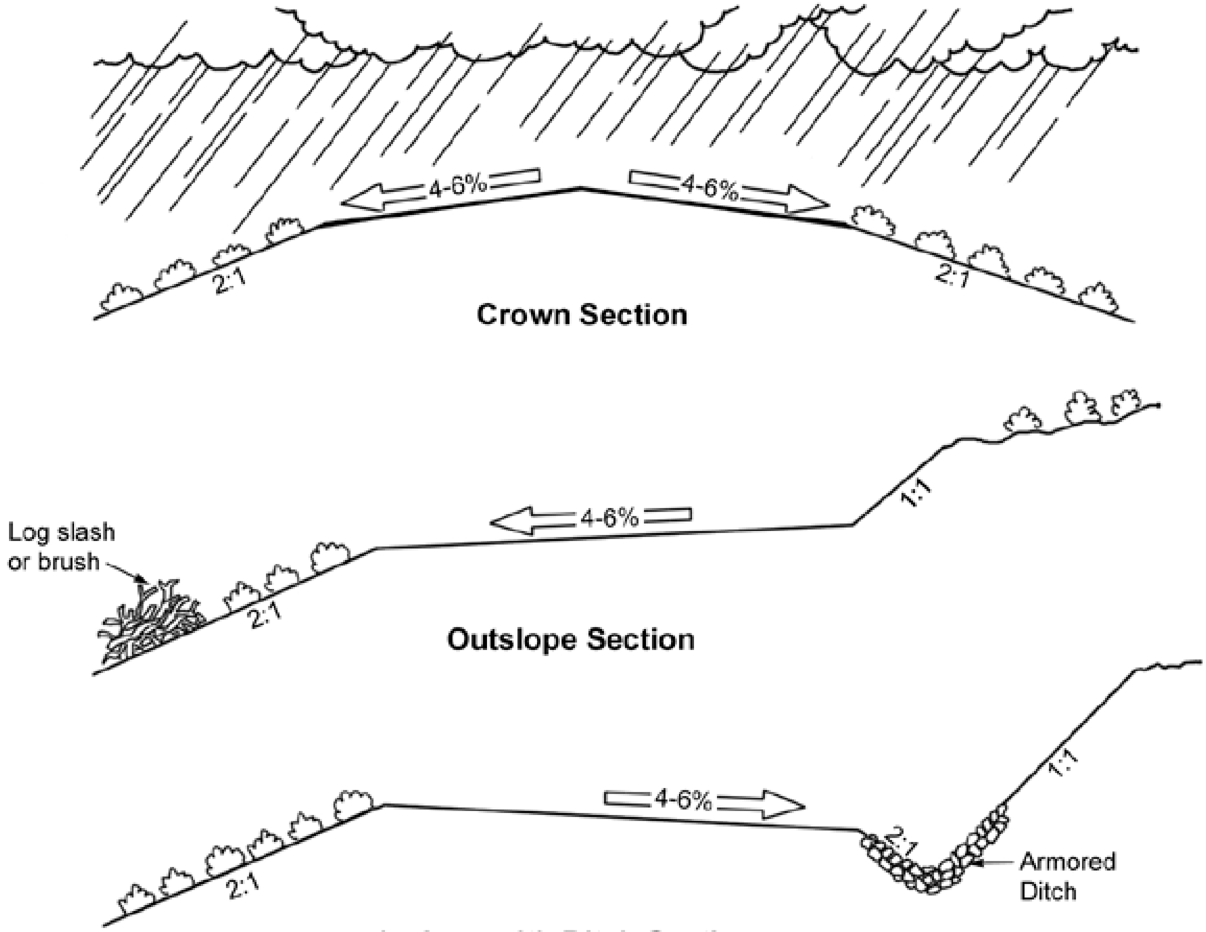


Figure 13—Basic road surface drainage options of an inslope, outslope, or a crown section. The photo shows a crown road with an inside ditch.

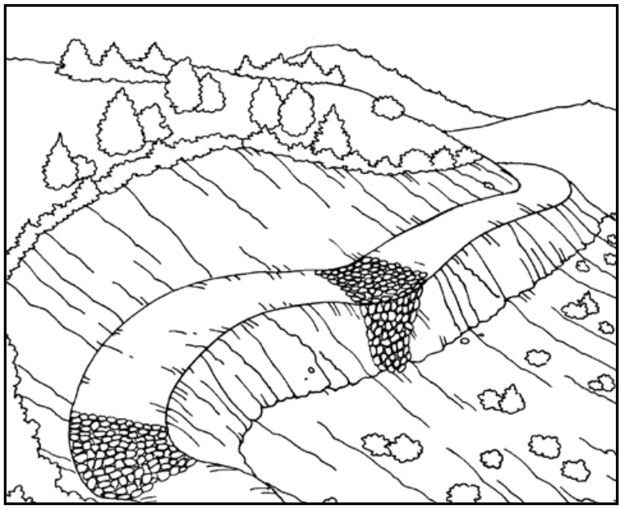


Figure 14—Examples of a rolling grade to minimize concentration of water on the road.

Adding Rolling Dips (Broad-Based Dips)

Rolling dips, or broad-based dips as they are called occasionally, are designed to divert and remove water off the road surface and the roadway ditch while safely allowing for the passage of relatively low-speed traffic. They do not involve culverts that can plug during storm events. Figure 15 shows the concept of a rolling dip on a road while figure 16 shows two different rolling dips. Rolling dips are a cross between a waterbar and a grade break. They have a reverse grade to direct water off the road rather than down the road. Like waterbars, they rely on a mound or high point at the downhill side to reverse or change direction of the waterflow.

Rolling dips are an alternative to conventional ditch relief cross-drain culverts with the added advantage that they drain the roadway surface as well as the ditch. They can eliminate problems with long, sustained grades and ditches. Rolling dips also can be carved into existing roadbeds. Rolling dips usually cost less, require less maintenance, and are less likely to plug and fail during a storm than culvert cross-drain pipes. The outlet area is often armored with rock to prevent erosion or gully formation, as seen in figure 17.

Rolling dips are appropriate on low-volume, low-to-moderate speed roads (15 to 30 miles per hour (25 to 50 kilometers per hour)). They are difficult to drive and are dangerous on high-speed roads. Rolling dips typically are not constructed on road grades over about 8 to 10 percent, particularly for truck traffic. Rolling dips occasionally are constructed on considerably steeper road grades but the excavation becomes significant with construction of a canyon in the road to adequately turn the water off the roadway, making sight distance poor. For that reason they are not commonly used on steep road grades. Use and design depend greatly on the road-design vehicle.

Construct rolling dips nearly perpendicular to the road, or ideally at a slight skew (of 25 degrees maximum), to minimize damage to truck frames driving through them yet effectively change the direction of waterflow. For commercial log-haul roads, install rolling dips perpendicular to the road. For light traffic and infrequently maintained roads or roads in storage, a 20- to 25-degree skew is ideal. The bottom of the dip should have a 2- to 5-percent outslope to ensure positive drainage. The entire structure should be long enough, typically 50 to 200 feet (15 to 60 meters), to comfortably pass vehicles and equipment. If the road has an aggregate surfacing, salvage the existing aggregate before a dip is constructed and respread it once the dip is completed.

Additional armoring material may be needed in the bottom of the dip, where it intercepts the road subgrade, to prevent rutting in soft soils and at the dip outlet. If erosion is occurring at the dip outlet, however, a better solution may be to add more dips, with a closer spacing.

Figure 18 shows the basic form of a rolling dip. The rolling dip needs to be moderately deep to function properly, particularly on the outlet side; have a distinct reverse slope out to properly drain water off the road; and be constructed using a hand level, rod, and tape (or other simple survey instruments) to ensure that the proper grades are established. Armor the mound and dip with gravel or rock, particularly in soft soils, to maintain the shape of the rolling dip during traffic use. Maintenance of dips with a grader is a learned skill, so operators need to understand the form and function of a dip. Otherwise, a dip can be damaged or destroyed during grader maintenance.

In terrain that may receive snow combined with traffic, construct the dips relatively deeply, accentuating the depth of the trough, so that water will exit the road even when tire ruts are formed in the snow. Otherwise, the ruts in the snow can act as canals that channel the water on down the road, through the dip, rather than allowing the water to be diverted off the road.

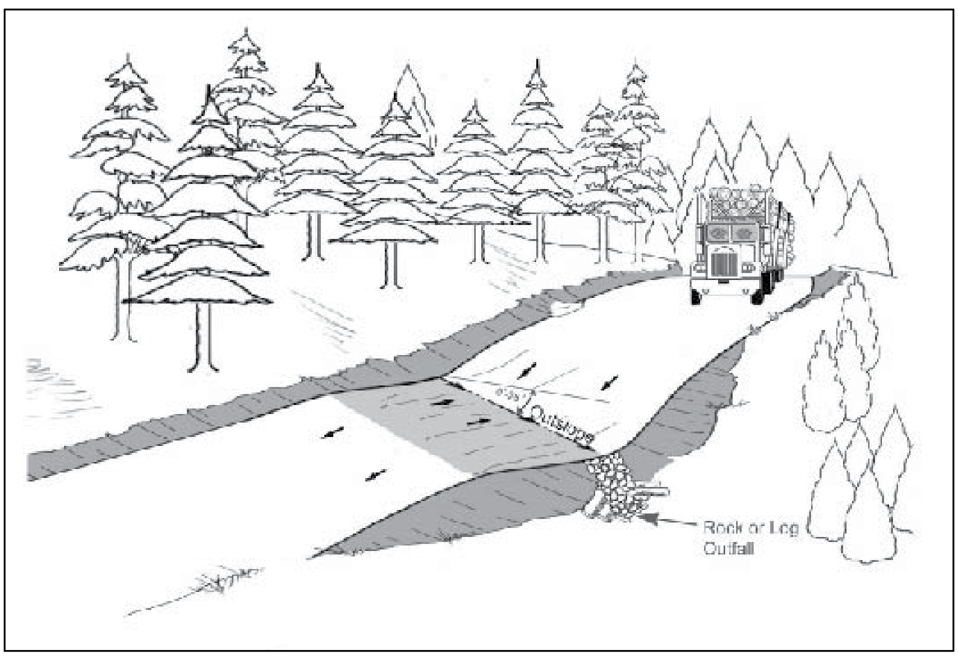


Figure 15—Sketch of a typical rolling dip on a logging road. (Adapted from California Division of Forestry Roads Handbook 1968).

Since different vehicles have different clearance requirements, figure 19 shows dimensions for rolling dips and drivable waterbars (discussed later) designed for passage of a logging truck, a low boy, and a high-clearance vehicle. Additional examples of rolling dips, drawings, and information on their design and use are found in appendix A1. The table is included to aid in the design of rolling dips for a variety of traffic (a design spreadsheet is available electronically for those with access to the Forest Service internal Web site at <http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/drain_dip_spreadsheet>).

Figure 16—The form of rolling dip cross drains on various roads.

Figure 17—An armored and grid-rolled rolling dip on the Umatilla National Forest. Note the armored dip outlet using small riprap. (Coutesy of Caty Clifton, Umatilla National Forest.)

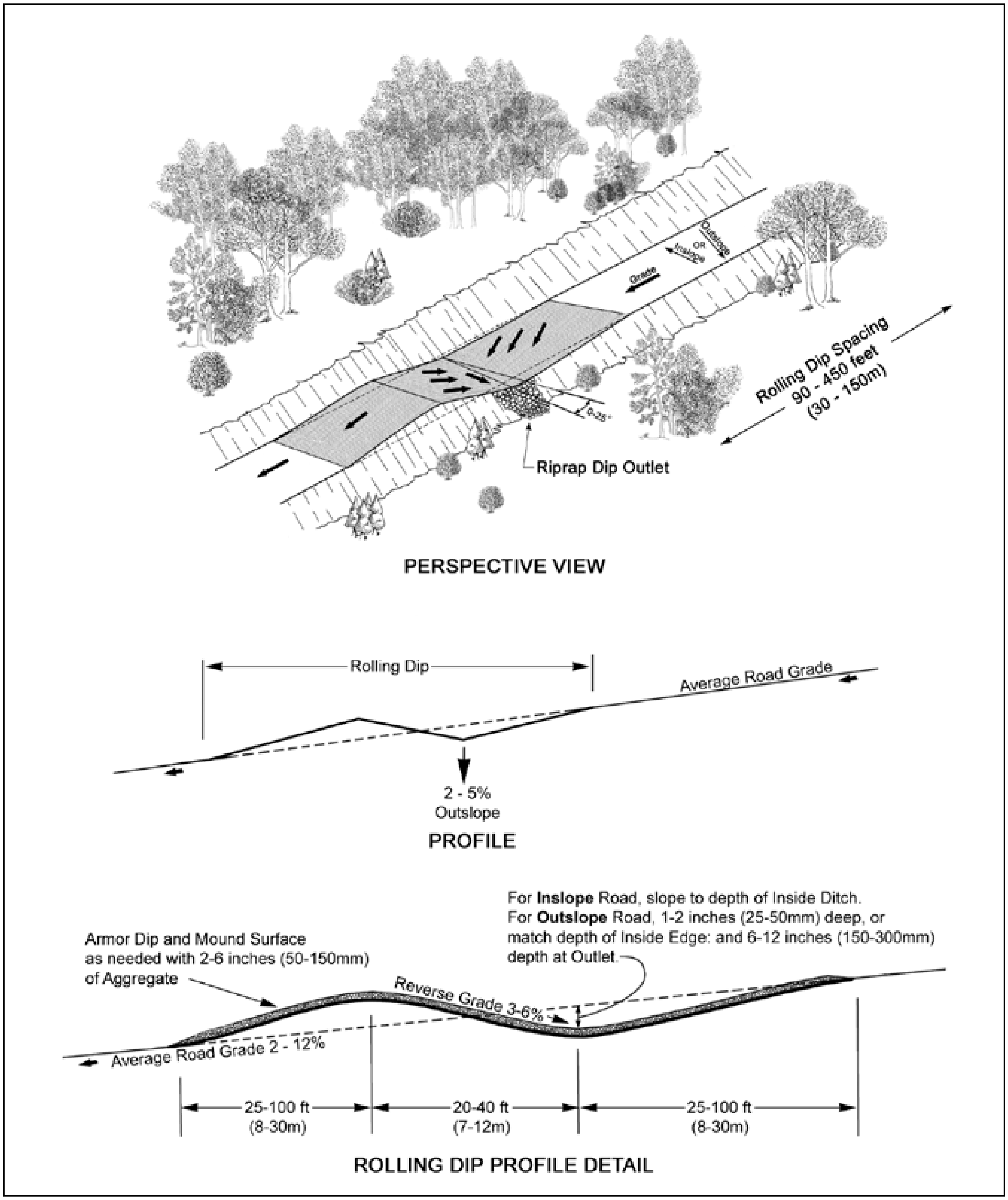


Figure 18—A rolling dip layout and shape, where the dip is used to move surface water off the road, drain any inside ditch, and prevent water concentration.

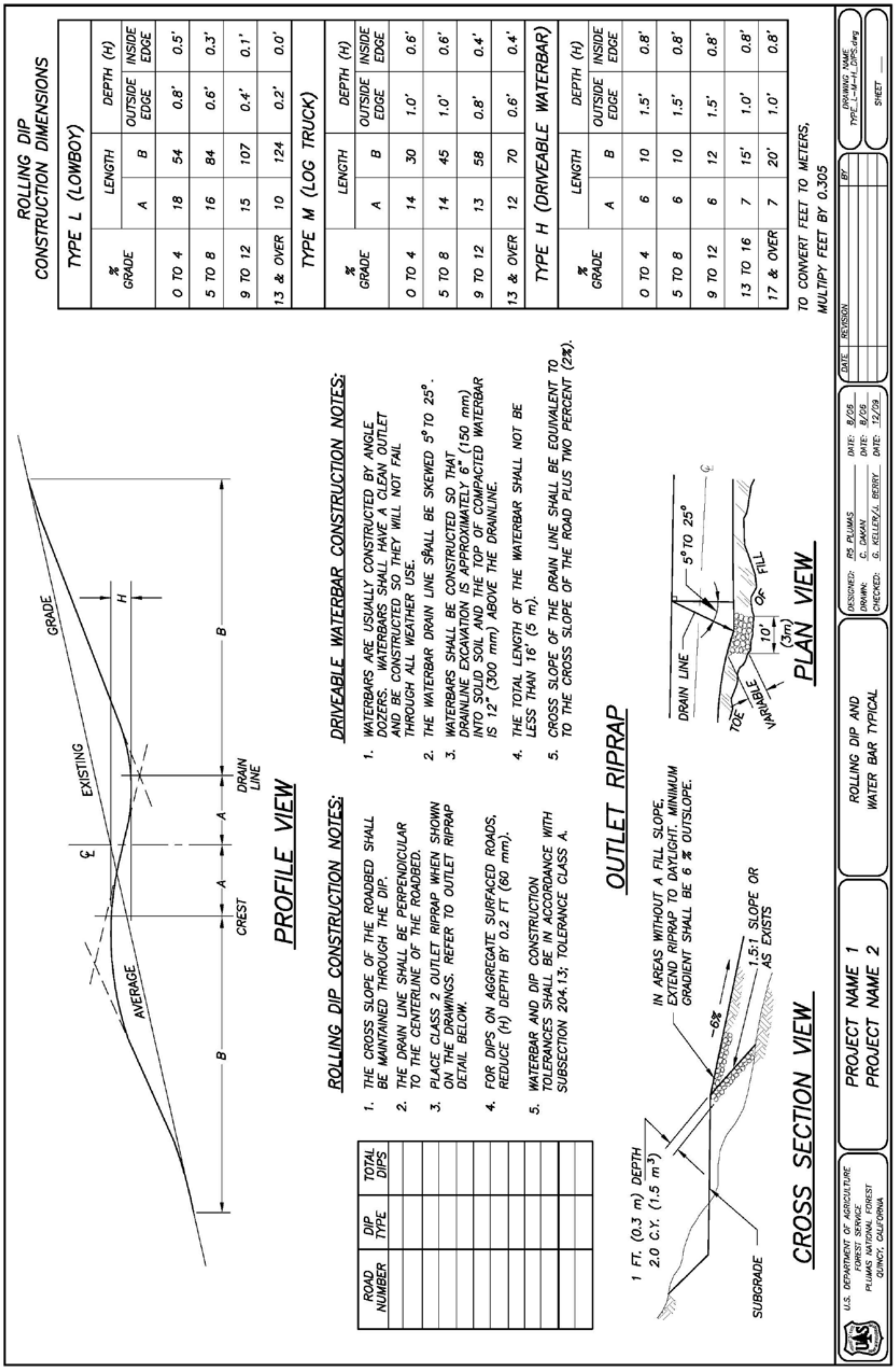


Figure 19—A typical drawing of dips and their dimensions for different design vehicles. (Note: Lengths and depths are shown in feet.)

The recommended range of spacing of rolling dips varies widely. Spacing for maximum distance between rolling dip cross-drain construction on forest roads must be site specific and should be adapted to the local climate and existing soil and slope conditions. As shown in figure 20, many studies have been conducted and recommendations made for locating surface cross drains with a fairly wide range of spacing values. The spacing distances presented in table 3, adapted from Packer and Christensen (1964), are relatively conservative values commonly used in a range of erodible to nonerodible soils to minimize rilling in the road surface. Thus, use local experience and judgment in selecting appropriate spacing values based upon field performance, topographic location on the slope, soil type, road surfacing material, rainfall, traffic, approach grade, and other local conditions. In sensitive areas, such as near riparian zones, spacing might be much closer than in other upland areas. The specific spacing and discharge location should be field adjusted to find locations that will not erode or form a gully. Ideal dip or cross-drain exit locations are in brushy areas, rocky areas, or natural drainage features or ravines.

Cross-Drain Culverts (Ditch-Relief Culverts)

Culvert cross drains (relief culverts) are buried beneath the road surface to discharge ditchwater from the toe of the cut to the outside edge of the road. They are crucial on most inslope and crown roads to prevent excess concentration of water in the ditch. They are the most common type of road drainage ditch relief and are appropriate for high-standard roads where a smooth road surface profile is desired. They also are very common on low-standard roads anywhere a ditch is constructed. However, cross-drain pipes are another expense and the relatively small culvert pipes used for cross drains are susceptible to plugging during storms. Consider rolling dips as an alternative.

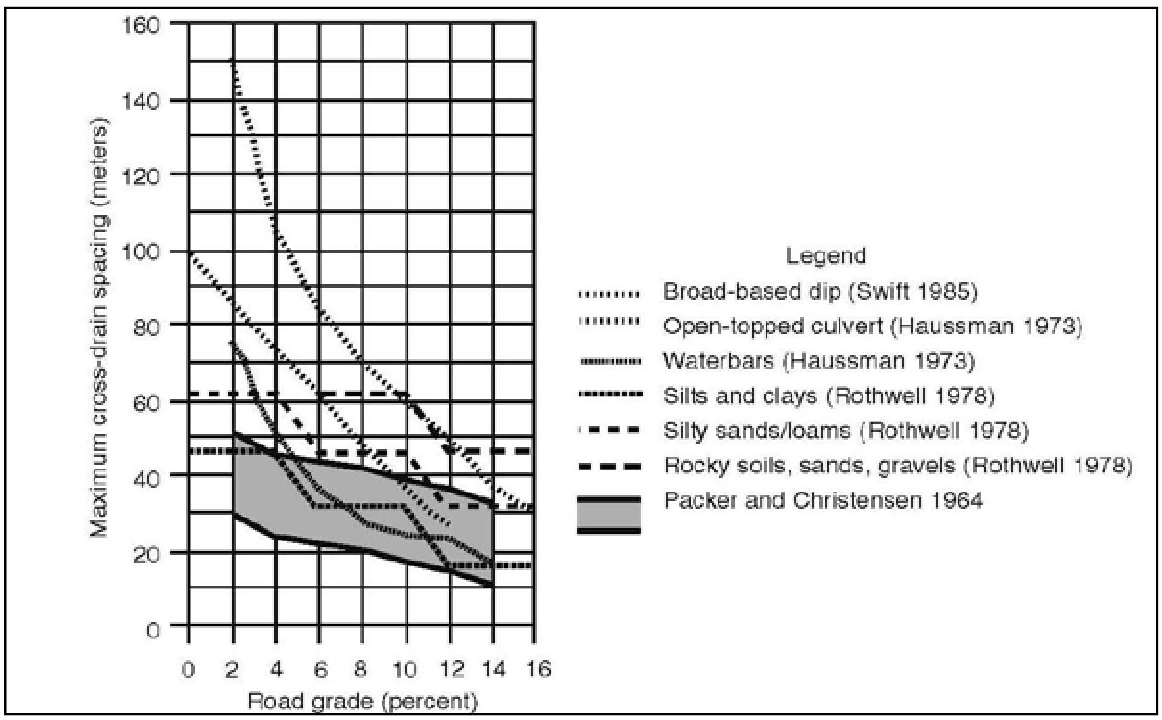


Figure 20—Range of recommended cross-drain spacing (Copstead et al. 1998). Note: Conversion 1 meter = 3.28 feet.

Construct relief culverts with circular or arch pipes or rectangular concrete or wooden boxes. An 18-inch (450-millimeter [mm]) minimum-diameter round culvert is used most often for ditch relief to help prevent failure from debris blockage. Smaller pipes plug easily. If the pipe has plugged, then install a larger pipe, such as a 24-inch (600-mm) culvert. Some State forest practices rules require 18 inches (450 mm) as the minimum size for ditch-relief culverts (Washington State Forest Practices Act). Also, consider additional cross-drain pipes, reducing the spacing between the pipes to reduce the water volume. Calculate pipe size and spacing by using the rational formula with the small road watershed and local rainfall intensity-duration data. Note that pipes installed on a skew slightly affect the effective pipe capacity. However, pipe size and spacing are based more commonly on local experience or on a recommended spacing from tables.

Table 3 lists criteria for spacing of ditch-relief cross drains (and rolling dips) as a function of road grade and soil erodibility (Unified Soil Classification System). Actual spacing can depend on field conditions and on ditch capacity to prevent overflow or limit the water volume to prevent erosion or gully formation at the outlet, or to minimize hydrologic connectivity near a stream crossing. Also, spacing criteria, which was developed in the Central United States, may need to be adjusted for areas with higher rainfall intensity. Downslope stability issues are extremely important when determining spacing and outlet location of a ditch-relief structure.

Table 3—Guidelines for maximum recommended distance between ditch-relief cross drains and rolling-dip cross drains, with spacing in feet, based on soil type. (Adapted from Packer and Christensen 1964, and Copstead, Johansen, and Moll 1998.)

Maximum Recommended Distance Between Ditch-Relief and Rolling-Dip Cross Drains (feet)				
	Low to Non-Erodible Soils		**Moderate to Very Erodible Soils**	
Road Grade (percent)	**Aggregate, Gravels (GW/GP)**	**Silty and Clay-Rich Gravels (GM/GC)**	**Silty Sand (SM), Clayey Sand (SC)**	**SW, SP, ML Sand, Well-to-Poorly Graded, Silt**
2	400	300	170	95
4	340	275	150	85
6	300	230	130	75
8	250	200	110	65
10	200	160	90	55
12+	150	130	75	50

Conversion: 3.28 feet = 1 meter

Note: Soil types are listed by ASTM Unified Soil Classification System. Plastic clay rich soil (CH, CL, MH) types fall between the above range of values for low-to-moderately erodible soils.

Note that rolling dips are very difficult to install on grades over 8 to 10 percent.

The guidelines should be adjusted, according to Packer and Christensen (1964):

1. Reduce the spacing by 15 feet (5 m) if the road is located in the middle one-third of a slope.
2. Reduce the spacing by 35 feet (11 m) if the road is located in the bottom one-third of a slope.
3. Reduce the spacing by 10 feet (3 m) if the road is on an east or west exposure.
4. Reduce the spacing by 20 feet (6 m) if the road is on a south slope.
5. If the resulting spacing after items 1 through 4 falls below 55 feet (17 m), use relief culverts at 55 feet (17 m) spacing and apply aggregate surfacing and erosion protection measures, such as vegetative seeding to ditches, road surface, fills, shoulders, and embankments.

Culvert cross-drain-pipe installation details are shown in figure 21. Install culvert cross-drain pipes with an ideal angle of 15 to 30 degrees skew to the centerline of the road, using a minimum outslope of at least 2 to 3 percent. Both are important to move water efficiently into the pipe and to prevent plugging. Additionally, the outslope should be at least 2 percent steeper than the ditch grade it is draining to reduce deposition at the inlet and prevent debris from plugging the culvert. Usually a berm or ditch-block structure is needed in the ditch immediately beyond the cross drain to ensure that water turns and enters into the pipe. This ditch block should completely fill and span the ditch. Commonly, an excavated inlet basin is used as well. The pipe should exit at ground level to prevent a waterfall and erosion. On very steep ground, the pipe outlet area may need specific reinforcement, such as live stakes

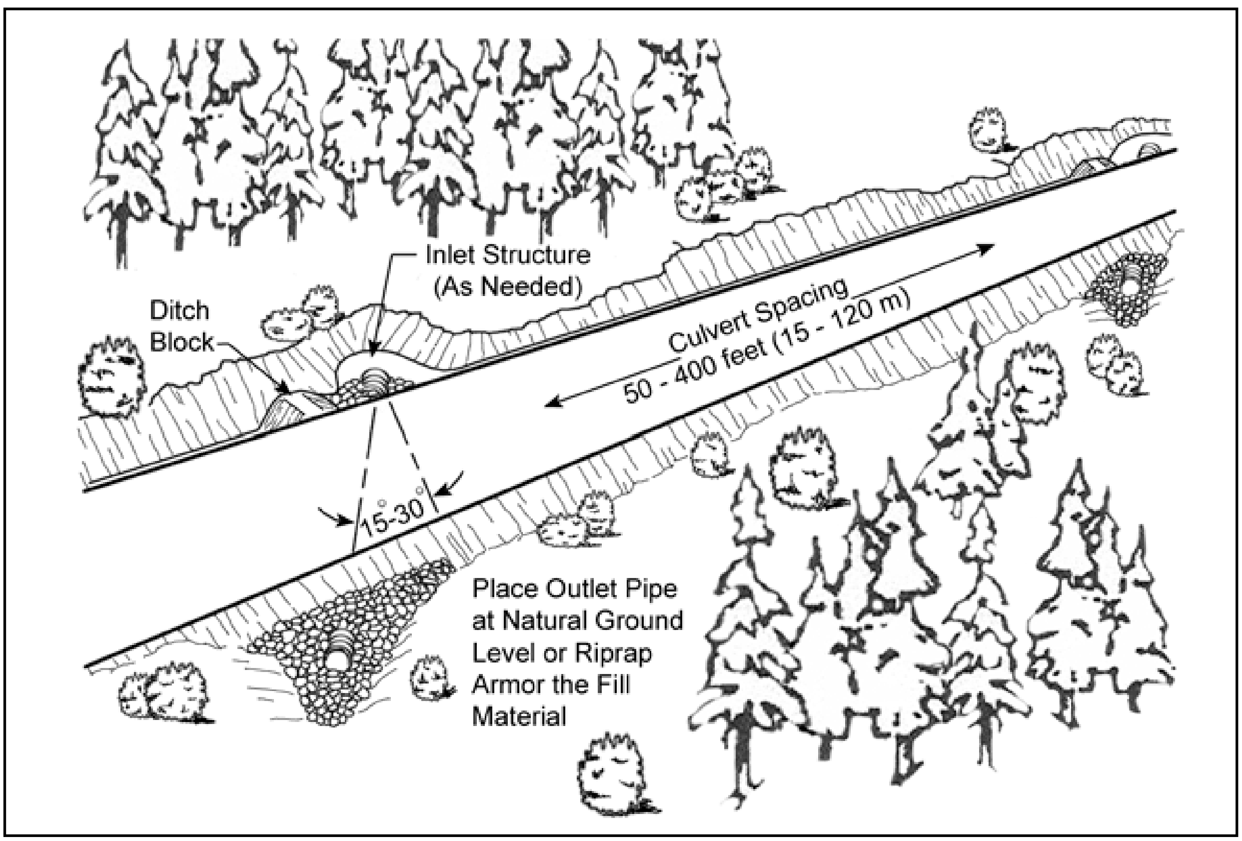


Figure 21—A typical culvert cross-drain installation.

and riprap. Again, if much outlet erosion is occurring, additional cross drains may be the best solution to reduce the quantity of water. In some cases, place rock armor at the outlet for energy dissipation and erosion control, as shown in figure 22.

Figure 22—A cross-drain culvert with an armored outlet and leadoff ditch on fairly flat ground.

Waterbars

Use waterbars to prevent concentrated waterflow from accelerating down a sloping road and to divert water off a road. Waterbars typically are used on roads that are closed or are limited-use roads and trails. It is an excellent method of closing or decommissioning roads and trails where surface water running down the road may cause erosion of exposed mineral soil. Spacing may be close, depending on road grade and soil type, such that erosion does not occur between or within waterbars. Improperly installed or spaced waterbars can allow water to end-run (pass the waterbar) or cause too much water concentration, resulting in additional erosion. Waterbars are installed on grades up to 30 percent or more. On open roads, waterbars are designed as drivable.

Drivable waterbars, as shown in figure 23, have the same function as normal waterbars (to impede waterflow down a road) but are constructed in a manner such that high-clearance vehicles or 4-by-4 vehicles can reasonably drive over them. Drivable waterbars occasionally are used on inactive roads, and 4-wheel-drive roads that receive little use yet occasionally need to pass vehicles. Table 4 shows that the spacing of waterbars is much closer than the spacing of rolling dips or cross drains. Drivable waterbar information also is found in appendix A1.

Nondrivable waterbars are waterbars or mounds that are constructed so radically that they cannot reasonably be driven over by vehicles, including 4-wheel-drive vehicles. They are intended to prevent use (by motorized vehicles) and stop water from accumulating or running down the road. They typically are built into roads in storage, decommissioned roads, or skid trails that are closed. Spacing criteria is the same as used for drivable waterbars.

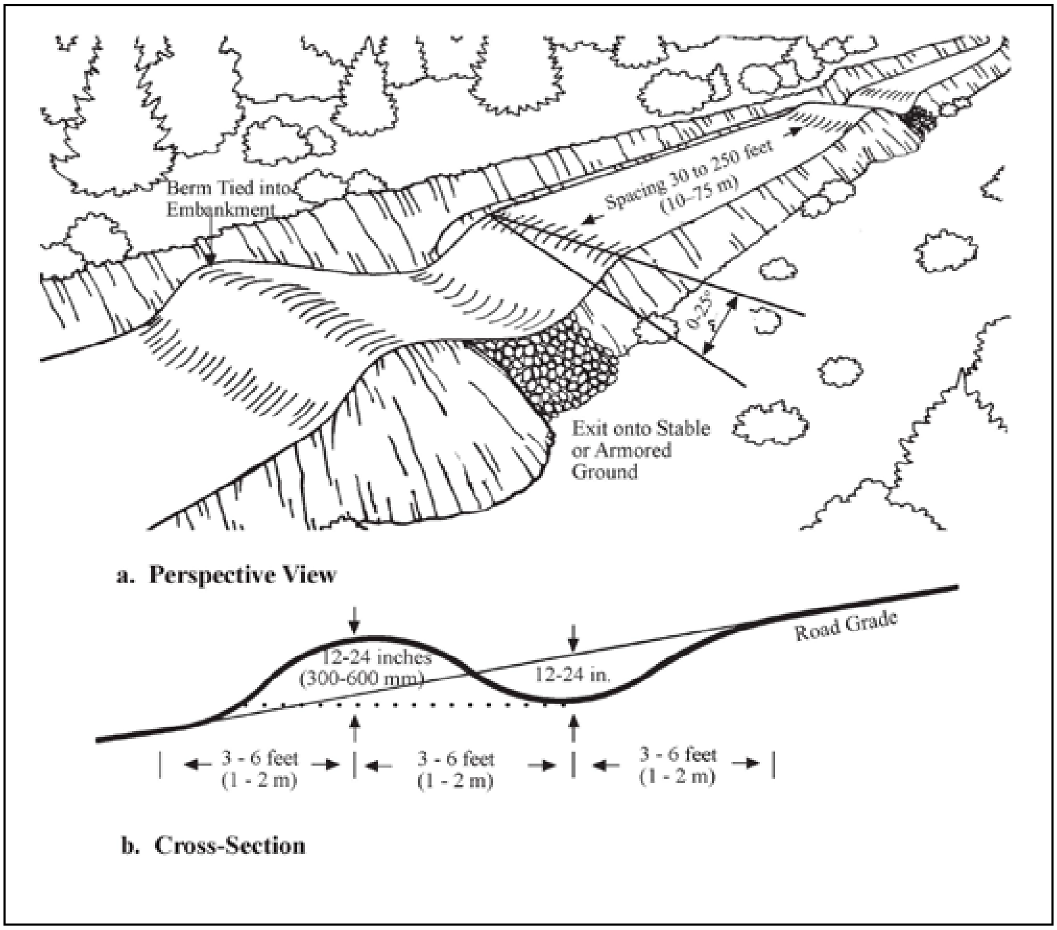


Figure 23—Drivable waterbar construction. (Adapted from Wisconsin Department of Natural Resources Publication FR093 1995.)

Table 4—Recommended waterbar spacing (feet)

Recommended Waterbar Spacing (feet)		
Road/Trail Grade (percent)	**Low-to-Nonerodible Soils (1)**	**Erodible Soils (2)**
0-5	250	130
6-10	200	100
11-15	150	65
16-20	115	50
21-30	100	40
30+	50	30

Note:

(1) Low-erosion soils=Coarse rocky soils, gravel and some clay.

(2) High-erosion soils=Fine, friable soils, silt, fine sands, volcanic ash.

Conversion: 3.28 feet=1 meter Adapted from Packer and Christensen (1964) and Copstead, Johansen, and Moll (1998)

Ditches and Ditch Treatments

Ditches are a key tool to collect, move, and discharge water from the roadway. They should be large enough to carry the anticipated accumulation of water, and possibly be somewhat oversized to function during major storm events, even when no one has cleaned or maintained the ditches. They also can be a source of erosion if too much water is in the ditch or its velocity is too high. Water is removed from the ditch with ditch-relief cross drains, rolling dips, and leadoff ditches. If water cannot be adequately dispersed or removed from the ditch, then armor the ditch with rock or vegetation or reduce the velocity with small check-dam structures. Check dams are problematic and need attention to installation detail. If a ditch is armored or lined, it may have to be oversized initially to accommodate the armor and still have the needed flow capacity, particularly if maintenance is infrequent. With armoring or check dams, ditch maintenance can be difficult.

Leadoff Ditches

Leadoff ditches (or turnout ditches) are another way to discharge water and prevent accumulation of excess water in the roadway ditches (figure 24). They are an inexpensive alternative to culvert cross drains and used at every opportunity where the terrain is suitable. They usually do not use pipes that might plug in a storm.

They are used in flat terrain where there is no cutbank at approaching drainage crossings and at fill areas across a swale or ravine. In very flat terrain, a leadoff ditch may have to be quite long to daylight out into the forest. They work best with an elevated roadway. They also are used at switchbacks where the road quickly changes direction across the slope to divide the waterflow. As with rolling dips or culvert cross drains, they should discharge in nonerosive areas or protected outlets to prevent erosion. Alternatively, if terrain or circumstances do not allow for the use of a leadoff ditch, it may be possible to discharge the ditchwater into a sediment catchment basin. To disconnect the road drainage from the stream, discharge the water into the forest or a vegetated area before the ditch reaches a stream channel, as seen in figures 25 and 26. Figure 26 also shows a number of measures used to prevent sediment from entering streams at a road-stream crossing.

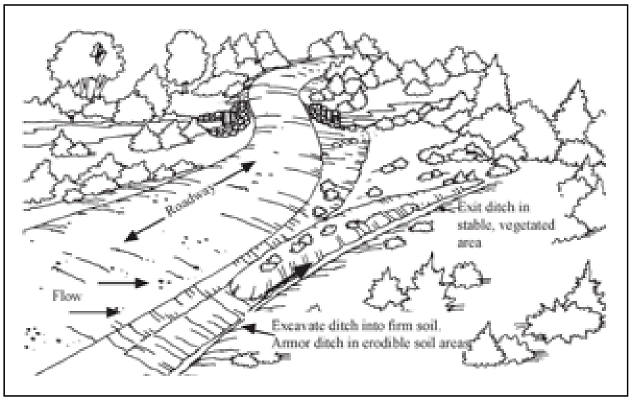
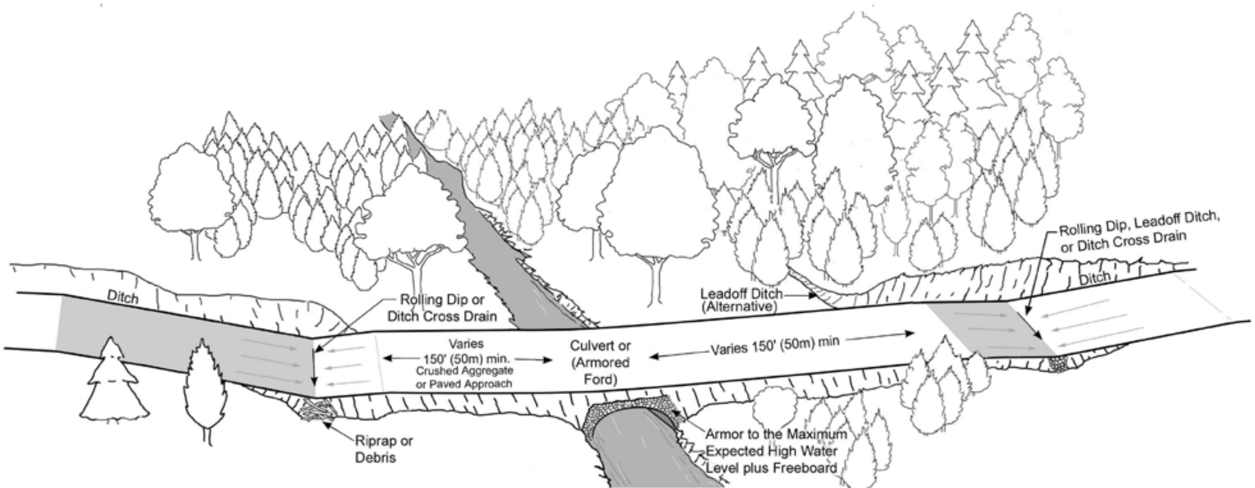


Figure 24—Ditch layout and leadoff before a stream. (Adapted from Wisconsin's Forestry Best Management Practices for Water Quality 1995.)

Figure 25—A leadoff ditch discharging into the forest before reaching a live stream at the bottom of the grade (near the parked vehicles).



Armor or stabilize the stream crossing structure and add surface armoring to the roadbed and approach. Drain water off the road surface before reaching the crossing. Road surface armor should be a minimum of 150 feet (50 m) and should extend to the nearest cross-drain structure. Actual distance depends on road grade, soil type, and rainfall, etc. For fords, set stream channel armoring at the elevation of the natural stream bottom. Armor outlets and fills as needed.

Figure 26—A sketch of a number of sediment protection measures used at a road-stream crossing, including discharging leadoff ditches into a vegetated area before reaching the stream.

Ditch Armoring

Water that runs in the ditch can erode and move large quantities of soil and debris. Avoiding the need for a ditch is ideal, but when a ditch is necessary, frequent ditch-relief cross drainage is ideal to prevent water accumulation and reduce or prevent ditch erosion. However, this is not always possible where the ditch is deep or the road template is strongly insloped. Alternatively, when cross drains are not possible to construct, an eroding ditch can be armored with graded rock to decrease the velocity of water, prevent erosion and downcutting, and to allow the deposition of sediment (figure 27). Small rock riprap typically is used as a lining material. A graded 3- to 6-inch (75- to 150-mm) rock size is ideal. A geotextile may be placed under the rock as a filter to separate the rock from the soil and keep soil from eroding under the rock. For relatively slow velocities, a ditch armored with grass may be adequate.

By decreasing the velocity, silt and debris are deposited in the ditch instead of additional bed material being eroded away. Increasing the roughness of the ditch decreases the velocity of water. Rock-armor ditches are common but need periodic maintenance to remove sediments. They also are labor intensive to construct and can be difficult to clean and maintain.

Figure 27—A rock armored ditch to control the waterflow and prevent downcutting of the ditch.

Check dams (also called ditch dikes) in ditches can be an alternative to solid-lined ditches. They can be made with many types of materials, including sand bags, loose rocks, masonry or concrete, branches, straw bales, logs, gabions, or live vegetation. Of all these materials, loose rock is one of the most commonly used and most effective designs, as seen in figures 28 and 29. **Note, however, that ditch check-dam structures typically are not recommended for stormproofing roads that may be closed or receive infrequent maintenance. If not properly constructed or maintained, they can force flow around the structure and erode or undermine the road shoulder and cutbank.**

The purpose of check dams is to increase roughness and decrease the velocity of water moving down the ditch with grade control. A series of check dams along a ditch reduces the effective gradient of the ditch, transforming a relatively steep gradient to a stair-stepped channel; they also trap sediment. Water successively flows on gentle slopes between structures and then cascades over the stabilized structure. A settling pond or sediment catchment structure also might be added as a ditch approaches a stream crossing if the water cannot be discharged into the forest.

The "California Division of Forestry Roads Handbook" (1968) presents some criteria for spacing of check structures in roadside ditches. Assuming that check structures are about 12 inches (300 mm) high, spacing is every 12 to 100 feet (4-30 m) along the ditch, depending on ditch slope and soil erosion potential, as seen in table 5.

These spacing values are approximate and can be proportionally greater in a deep ditch with 18-inch-high (450 mm) dike structures. Adjust spacing for local soil and rainfall conditions, particularly based upon field performance of the structures and maintenance frequency.

Table 5—Recommended maximum distance between ditch check dams (Adapted from "California Division of Forestry Roads Handbook"1968.)

Recommended Maximum Distance Between Ditch Check Dams, in feet (meters)		
Road Grade (percent)	**Low-to-Nonerodible Soils**	**Erodible Soils**
0-4	100 (30)	50 (15)
4-7	50 (15)	25 (8)
7-10	25 (12)	12 (4)
10-12+	12 (4)	<12 (4)

Rock check structures need maintenance to retain their function and to remove excess sediments; they also are labor intensive to build, but very effective in reducing flow velocity and trapping sediment. Depending on spacing and location, they can be difficult to maintain. They are a dam-like structure, so they have design details that are needed to make them function properly. Key design elements include the following:

- ❑ A V- or U-shaped top to keep the flow in the middle of the ditch and prevent an end run around the structure that can cut into the road. The bottom of the V-notch must be below the elevation of the road surface.
- ❑ The spacing is critical to achieve a nonerodible effective gradient between structures.
- ❑ The structures need to be placed firmly into the bottom of the ditch and into the ditchbank and designed to prevent undercutting. Since water cascades over the structures, there is the potential for erosion at the base of the structures that can undermine the structures and render them useless.

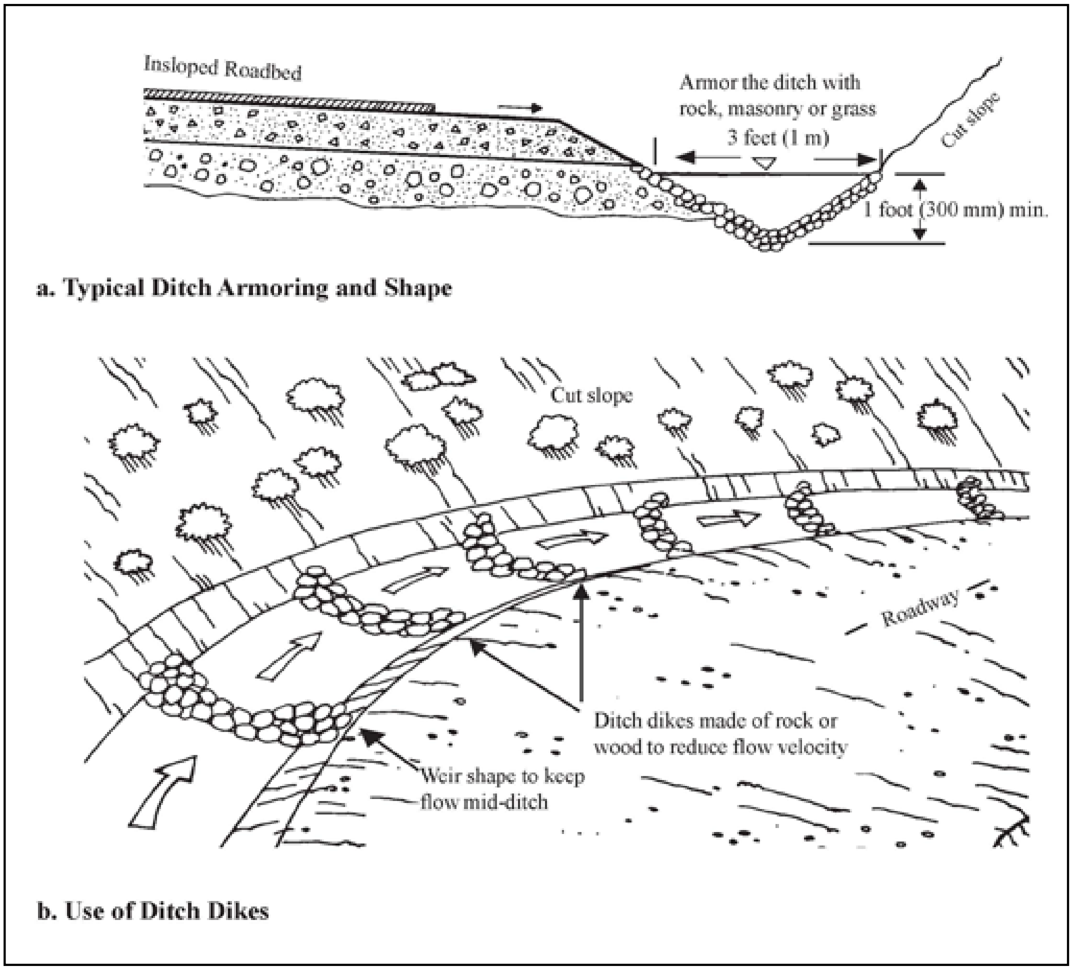


Figure 28—A typical rock-lined ditch and ditch check dams.

Figure 29—Check structures of rock or bagged gravel installed in the ditch to reduce flow velocity and trap sediment.

- ❑ The structure should be lower than the elevation of the road shoulder to prevent water from flowing onto the road (see figure 29).

More detailed information on check-dam design and installation is presented in section 6.5.

Vegetation-lined ditches, typically using noninvasive grasses, offer a natural alternative to other ditch armoring or check structures on gentle slopes or nearly flat ground. Grass-lined ditches often are suitable for ditch slopes up to 5 to 10 percent, depending on soil, grass type, and climate. Vegetated ditches are inexpensive and present an aesthetic natural look, as seen in figure 30. They need periodic maintenance to remove sediments, and this maintenance can be difficult. On flat slopes with a lack of maintenance, the vegetation (as well as other debris) can block the flow and pond water, thus saturating the adjacent road. Ideally, select grasses for good growth properties, hardiness, dense ground cover, deep roots to stabilize the ditch, and some tolerance to periodic inundation. If necessary, reseed the ditch if maintenance damages the grass.

On steeper slopes, grasses may be inadequate and more durable ditch protection is needed, such as turf reinforcing mats, rock riprap, masonry liner, and so forth. Since rock armoring or ditch structures partially block the ditch, a ditch may need to be initially oversized during construction or reconstruction to accommodate the armoring and the anticipated flow, plus some freeboard. If widening or deepening the ditch, do not undercut the adjacent cutslope.

Figure 30—A ditch lined with vegetation (grasses). Note that as the ditch gradient increases the grasses alone may not be enough to prevent higher water velocities from eroding the ditch.

Ditch or Pipe Outlet Armoring

The accelerated velocity of water leaving a roadway ditch or culvert pipe can cause severe erosion or gullying if discharged directly onto erodible soils. Always try to align and discharge culverts and cross-drain dip-drainage structures at the natural ground level away from a live stream and on a stable, nonerodible soil area in a stable area, such as an existing natural (dry) swale or channel, rocky areas, or well-vegetated areas. When necessary, stabilize the pipe, dip, or drain-outlet area, and the energy of the water dissipated by discharging the water onto a few cubic yards (1-2 cubic meters) of a graded rock riprap, as shown in figure 31. Extend the riprap several feet (1-2 meters) beyond the end of the pipe, and ideally, fan out the rock to spread out the flow and prevent erosion (appendix A2). Outlet erosion also is a sign that closer cross-drain spacing is needed.

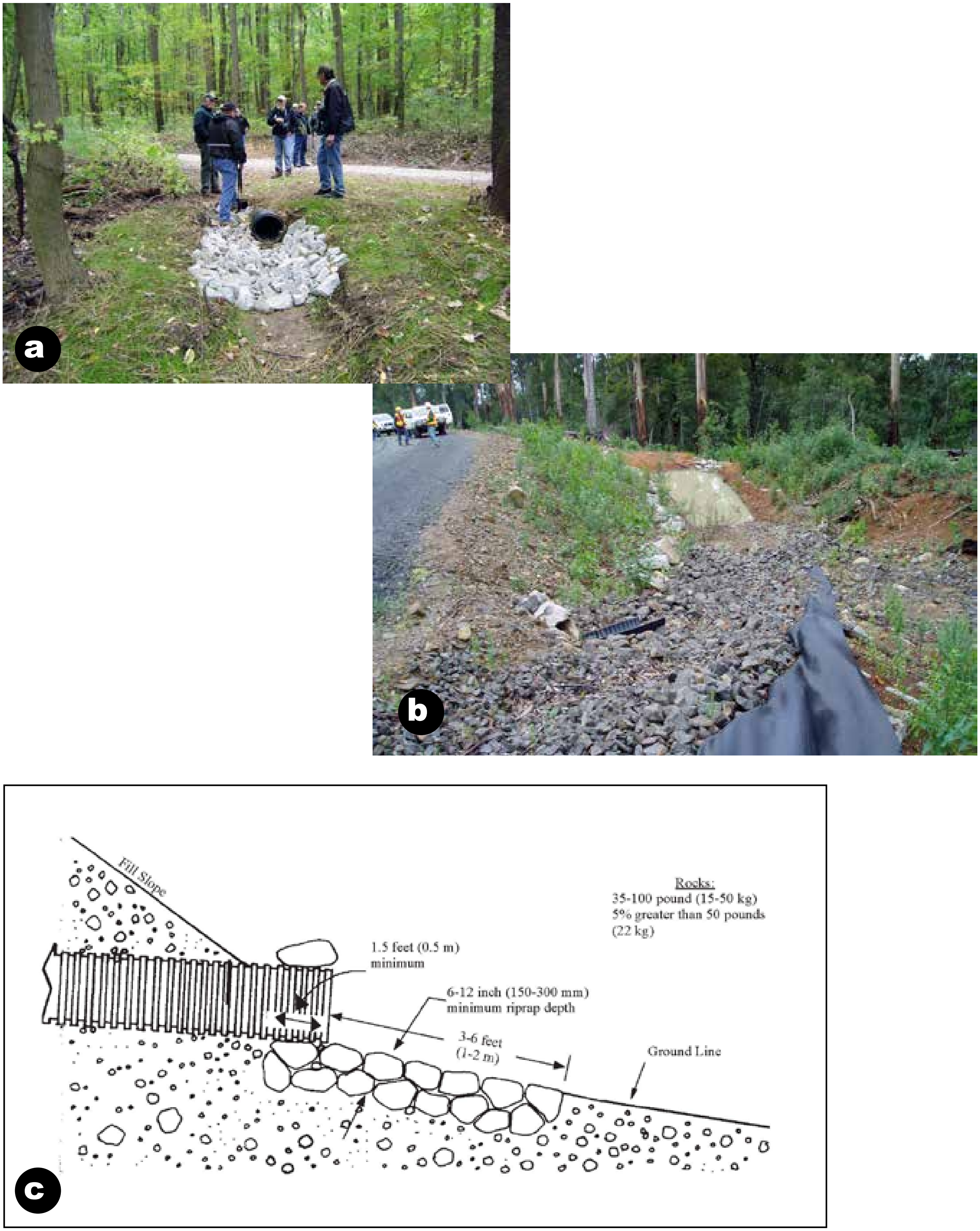


Figure 31—Photos of pipe riprap outlet protection (a) and flow into a sediment catchment basin (b), and a drawing detail of culvert-outlet protection (c).

Other energy dissipation measures include stilling basins or settling ponds, reinforced splash aprons, gabion baskets, dense vegetation, slash and limbs, logs, boulders, or bedrock. When using slash, press the material into good contact with the ground or mix with varying sizes of debris to provide a ground surface protection layer.

A pipe should discharge beyond the toe of any fillslope. Extend the pipe 1.5 to 3 feet (0.5 to 1.0 m) beyond the toe of the fillslope to prevent erosion of the fill material. In high fills, you might need to add a downdrain pipe or armored channel to safely convey the water to the toe of the fill. To minimize the outlet erosion, install a "T" fitting at the bottom on a long, steep downspout to divide the flow. Downdrain pipes are subject to high shear stresses and may be unreliable in areas of heavy snow accumulation. Freezing temperatures, particularly in shade areas or on north-facing slopes, also can cause small pipes to plug with ice.

When ditch-relief discharge cannot avoid unstable slopes, adjust the spacing so that no structure discharges an amount of water that will increase gully formation or the risk of mass wasting. These problems typically are avoided by field observation during maintenance activities or by local experience. In some cases, you may need to perform a hillslope stability analyses to determine the added risk.

5.3 Stream Crossing Structure Protection and Improvements

Culvert and Channel Maintenance

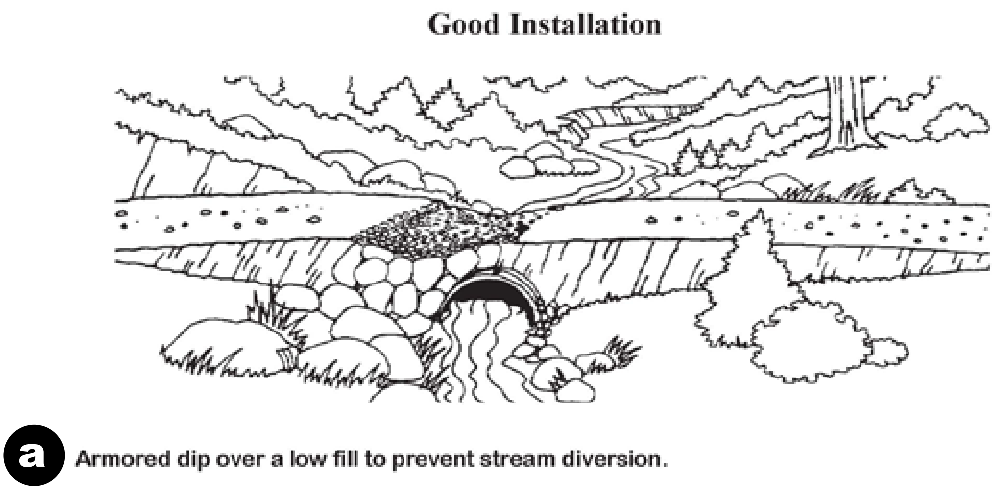
Culvert maintenance and periodic cleaning of the pipe and channel near the inlet to the pipe are critical to the proper pipe function. Lack of maintenance contributes to many culvert failures. Ideally, pipes will receive maintenance before any major storm, though that can really only be guaranteed by performing maintenance routinely and after the last major storm. Common maintenance items include the following:

- ❑ Keep the inlet clear of wood, sediment buildup, rocks, and vegetation.
- ❑ Ensure that headwalls are in good condition.
- ❑ Reline worn culvert barrels or replace the pipe.
- ❑ Replace damaged or missing splash aprons or riprap.
- ❑ Bend back damaged metal blocking the entrance.

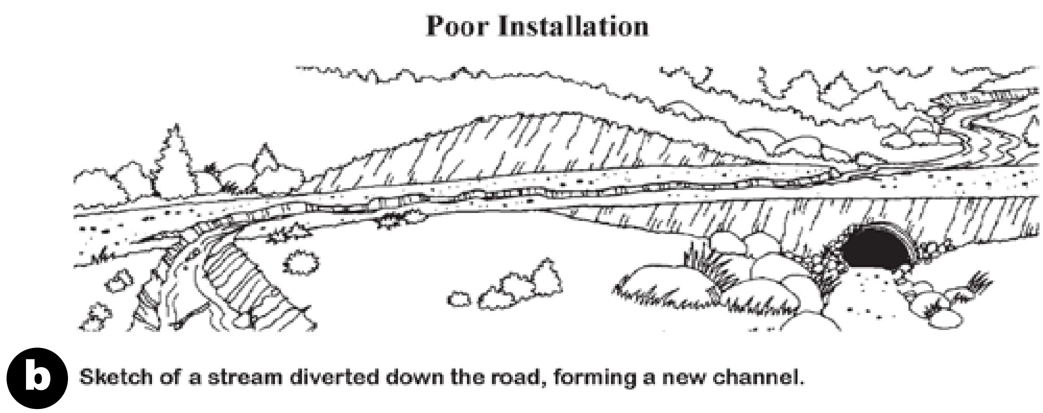
Culvert Diversion Prevention and Overflow Protection

Diversion prevention is one of the most cost-effective and common SDRR treatments for culverts at risk of overtopping and washing down the road. The physical consequences of exceeding the capacity of a stream-crossing structure usually depends on the degree of exceedence, crossing fill volume, fill characteristics, soil characteristics, and the flow path of the overflowing stream discharge. When the structure capacity is exceeded, or if the culvert pipe plugs with debris, the stream backs up behind the fill. If the low point of the crossing is the ditchline, the water will divert down the road rather than flow directly over the road fill and back into the natural channel. At some point, the water will leave the road and erode the fill and the hillside all the way to a channel, as shown in figures 32b and c.

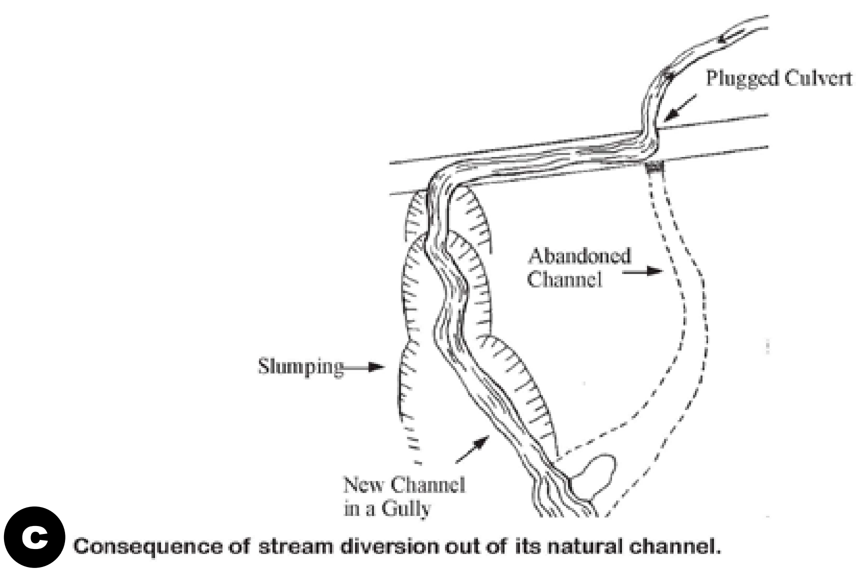
If the low point is over the pipe, or an armored dip is constructed in the roadway near the structure, water will flow across the road and return quickly to the channel (figures 32a and 33). Armoring the dip or low point is important to prevent erosion, downcutting, and additional damage to the road and fill. Figure 34 shows photos of a stream diversion (b) and the subsequent damage to the road (b), where



Armored dip over a low fill to prevent stream diversion.



Sketch of a stream diverted down the road, forming a new channel.



Consequence of stream diversion out of its natural channel.

Figure 32—Existing undersized culvert fitted with an armored overflow dip to pass water without stream diversion or washing out the fill (a). Figures (b) and (c) show a stream diversion where a plugged culvert crossing sends water down the road rather than staying in its natural channel, causing considerable off-site damage. (Adapted from Furniss et al. 1997.)

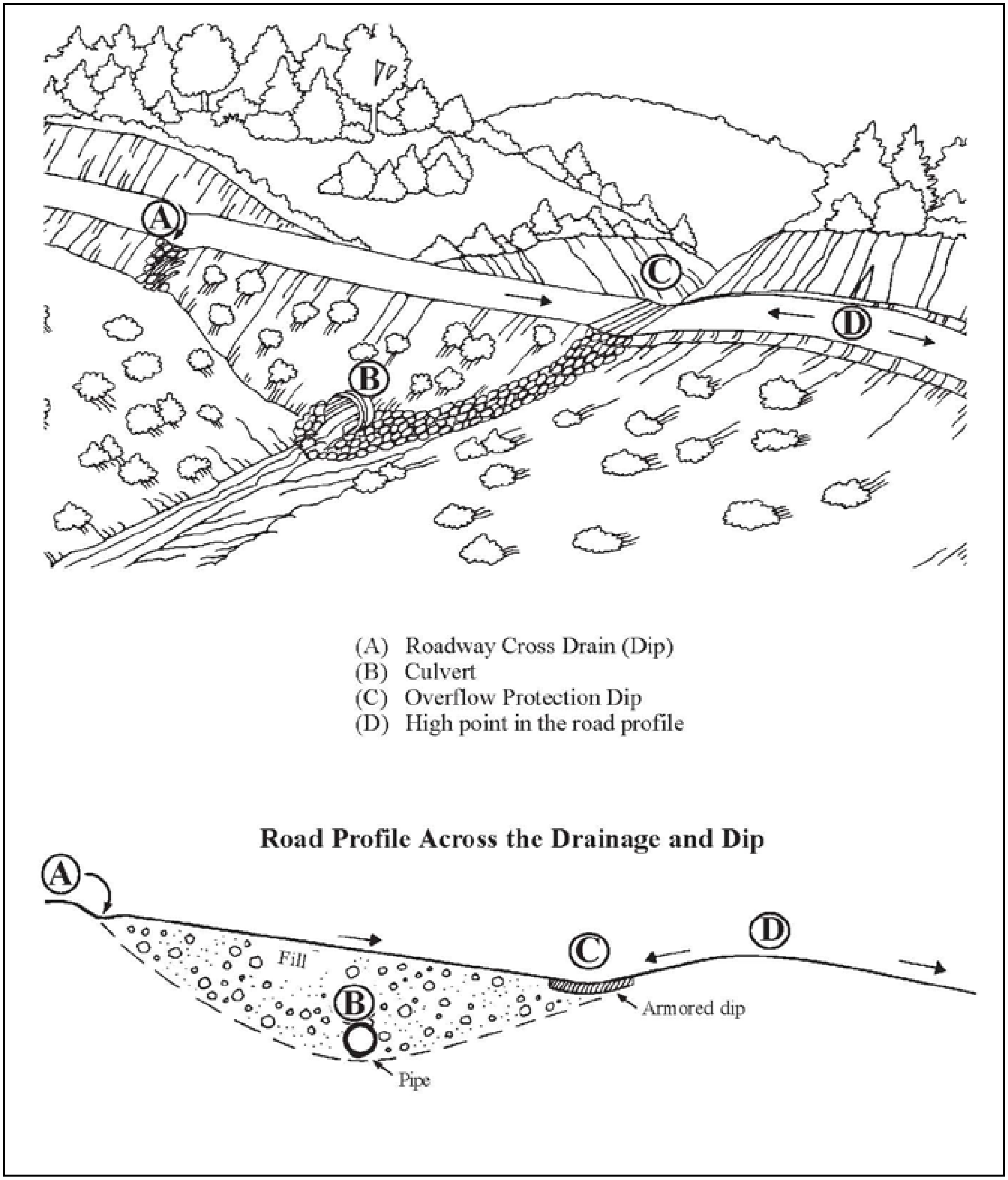


Figure 33—A stream diversion dip built into a stream crossing, showing an ideal location of the dip at the transition from the fill to the native ground. (Adapted from Weaver and Hagans 1994.)

the road was basically washed out for several hundred feet. Diversion potential exists on roads that have a continuous climbing grade across the stream crossing or where the road slopes downward away from a stream crossing in at least one direction.

Figure 34—A plugged pipe that "floated" out of the fill (a), resulting in a stream diversion down the road and past a culvert cross drain with metal drop inlet, (b), causing extensive damage to the road and significant environmental impacts, Plumas National Forest.

Crossings with diversion potential typically pose much greater overall risks than those without diversion potential because the resulting road and hillslope erosion delivers large volumes of sediment to the stream network and can destroy a section of the road, requiring extensive repairs. Figure 35 shows a plugged culvert location, allowing water to run down the road (top photo). On down the road, the creek eventually left the road, causing a major roadway and fill washout (bottom photo). In almost all cases, diversion will create more damage than stream flows that breach the fill but remain in the channel. Research in Redwood Creek, California, showed an average 10 times increase in sediment delivery due to gullying and debris slides triggered by stream diversion as compared to a washout of the stream crossing fill (Weaver, personal communication).

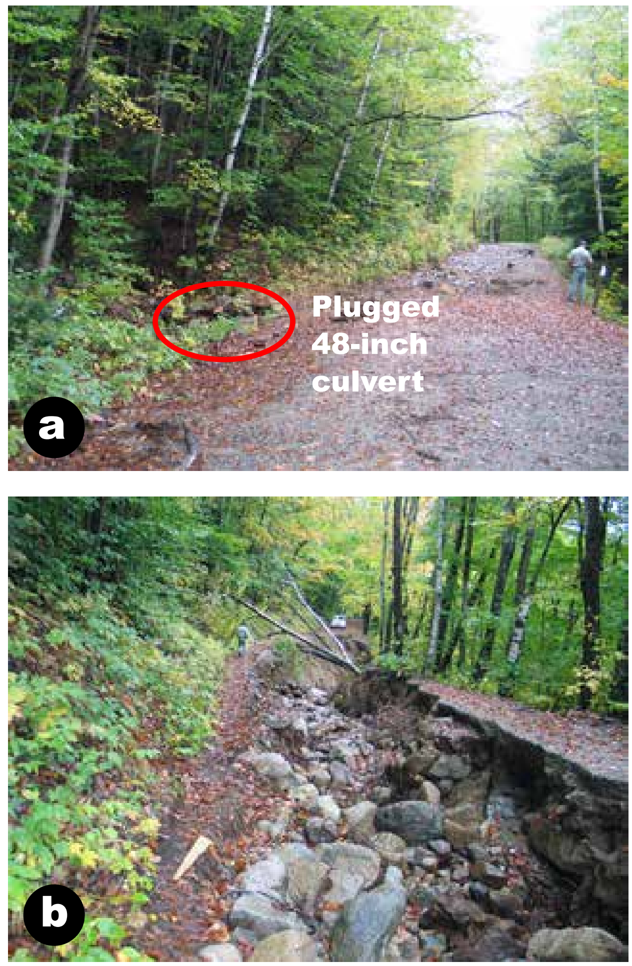


Figure 35—Stream diversion caused by a plugged 48-inch corrugated metal pipe that forced water down the road (a) and caused the roadway fill washout (b) when it exited the road, White Mountain National Forest. (Courtesy of Bob Gubernick.)

Figure 36 shows another stream diversion site where a culvert pipe plugged and sent the water down the ditchline, destroying the road. Here a cascading failure was created where excessive water in the ditchline caused a series of cross drains and culverts to plug and fail on down the road, compounding the problem at each new crossing. Stream diversion occasionally can be caused by accumulations of snow and ice in a channel or on the road that directs overflow out of the channel (Swanson, personal communication). Snow removal operations need to consider this potential effect and configure removed snow such that stream diversion will not occur (Furniss et al. 1997).

Stream diversion also can be caused where a channel has severe aggradation, particularly on a fan deposit, where the channel periodically aggrades and shifts to a new location. Figure 37 shows a stream diversion caused by stream aggradation at the location of a road-stream crossing. The site was aggravated additionally by the blocking of the small bridge with sediment and debris.

Typically, the solution to prevent stream diversion is to add a dip near the culvert pipe, as seen in figures 32a and 33, and in figures 38 and 39. The rolling dip can be placed directly over the pipe, but preferably it should be placed just downgrade of the drainage crossing at the transition point between the fill and the native ground to prevent stream diversion in the event that the drainage crossing culvert plugs (figure 33). This minimizes erosion delivered to the stream in the event of overtopping and is easier to reconstruct.

On relatively high-standard roads that have a risk of stream diversion yet travel speeds make a diversion dip or rolling dip undesirable, a designed failure point can be built into the road. This is a soft spot that will wash out if flow goes over it and is located where a dip would otherwise be located. This relatively soft failure point in the road subgrade can be constructed with fine gravel or sand rather than compacted soil (Gubernick, personal communication). With the dip or a designed failure point, water can be diverted back into the natural drainage before flowing down the road and causing road and additional resource damage. The cost of an overflow dip or designed failure point is relatively small compared to the cost of replacing the entire fill, or repairing major damage to the road.

Figure 36—Stream diversion caused by plugging of a 48-inch culvert (a) and subsequent cascading failure and road damage on down the road (b), region 6, Washington. (Courtesy of Robin Stoddard.)

Figure 37—Stream diversion down a road caused by stream aggradation that filled the channel and plugged a bridge. (Courtesy of Bob Gubernick.)

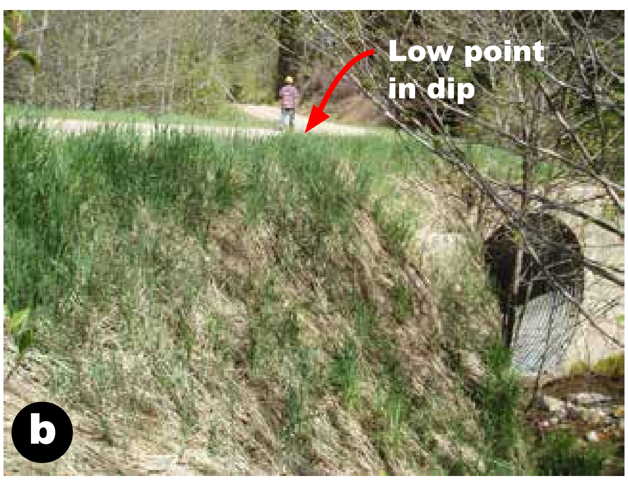


Figure 38—A concrete headwall (a) and an overflow dip placed just down the road (as seen at the low point where the person is standing down the road (b)) to prevent future stream diversion. This is the culvert repair and diversion-prevention dip installed at the damage site seen in figure 34.

Figure 39—Another storm damage diversion site with road damage down the road at the curve (a) and the diversion-prevention dip added up the road above the damaged area (b) just below the culvert crossing (not seen in photo) to prevent future stream diversion, Plumas National Forest.

For technical information on diversion potential, consult the "Water/Road Interaction Technology (WRIT) Series" publication "Diversion Potential at Road-Stream Crossings" (Furniss et al. 1997). The publication discusses the physical effects of diversion potential and provides design considerations for remediation of existing crossings that have diversion potential. Link to the document <http://www.fs.fed.us/eng/pubs/pdf/w-r/97771814.pdf>.

5.4 Bridge Protection and Improvements

Many changes can occur at a bridge site and in the watershed upstream of the bridge over time. Climate change and changes in the watershed can affect the peak flows and the amount of sediment transported through the stream or river system. More glacial melt may be expected in some regions. Thus, evaluate bridges carefully for increases in storm damage risks that were not anticipated at the time of construction. Understanding the processes at work in the watershed upstream and downstream of a bridge site is very important for determining the most cost-effective treatment.

Bridges are a large investment and, therefore, a large liability if they fail. Build good bridge design and bridge scour protection measures into the initial design, understanding that additional channel maintenance and cleaning often is required to maintain the bridge flow capacity and reduce the chance of blockage during a storm.

Channel Maintenance and Debris/ Sediment Clearing

Channel debris and vegetation may cause scour or plugging problems for bridges. Common countermeasures for an existing bridge with debris problems include:

- ❑ Monitor debris buildup for prompt removal.
- ❑ Clear undesirable upstream debris and vegetation.
- ❑ Install debris catchers or deflectors (which require maintenance).
- ❑ Remove sediment or areas of aggradation that decrease channel capacity.

Channel clearing and maintenance are important to maintain bridge-flow capacity. The key thing to understand about this type of treatment is that the symptom is likely the result of natural stream and riparian processes, or altered processes due to the presence of the structure itself or an encroaching roadway or land use upstream. Most treatments are temporary and will require occasional clearing of debris and vegetation. For the best long-term solution, consider the replacement of the bridge with a longer, higher structure, or relocation of the structure to a less susceptible site.

Remove undesirable vegetation, brush, trees, and debris from the channel near the structure, particularly for the bankfull width of the channel. This work may be controversial since channel disturbance should be minimized, yet the structure flow capacity should be maximized and risk of blocking a bridge should be minimized. A balance is needed to remove counterproductive vegetation yet leave vegetation needed for channel stability and ecological benefits. Clearing and removing channel material can be damaging and difficult. **Thus, decisions regarding the extent of channel clearing should be an interdisciplinary process.** Figure 40 shows a channel encroached on by vegetation while figure 41 shows a channel relatively clear of vegetation and debris. Vegetation established in a stream-channel bottom is not normal unless there has been a change in the runoff pattern or volume. Try to understand the watershed condition, what has caused the change, and what ramifications the change has on streamflow at the structure site.

Figure 40—Stream channel under a bridge that needs clearing and tree removal if flows are being blocked, diverted, or if there is risk of plugging the bridge.

Figure 41—A bridge opening and channel relatively free of vegetation and debris.

Aggradation in the channel also can reduce the cross-sectional area of a bridge and reduce flow capacity, as seen in figure 42. This tends to occur on a river bend where a point bar develops on the inside of the bend. Some channel deposits need to be removed periodically to maintain bridge flow capacity. This material typically is sandy gravel, so it may be useful as a fill material or surfacing material elsewhere. Note that some gravel and boulders should be left in the channel for fish spawning bed material. The timing of removal must consider the presence of fish in the channel. Coordinate and work with a fisheries biologist.

Figure 42—A bridge with significant channel aggradation on left from a growing point bar on the inside of a river bend that now needs removal to maintain bridge flow capacity. The point bar will rebuild with time, creating a continual maintenance problem at this bridge site. Bends are often poor locations for bridge sites.

Figure 43 shows a damaged bridge that nearly failed due to minimum freeboard and its location on an alluvial fan. During a storm, tall trees fell into the drainage and formed a log jam at the bridge. This subsequently caused aggradation in the channel at the bridge (seen in the photo), thus losing hydraulic capacity through the bridge, and this forced a large amount of stormflow around the left abutment of the structure. This damaged the bridge approach and washed out a section of road.

“Steepland Forests: A Historical Perspective of Protection Forestry in New Zealand” (McKelver 1995) offers some insights into stream channel aggradation problems, particularly when moving from a steep upland topography to a flatter alluvial plain.

Figure 43—A bridge with minimum freeboard and located on an alluvial fan that nearly failed due to a log jam and subsequent aggradation in the channel. This forced some flow around the left abutment of the structure. (Courtesy of Bob Gubernick.)

5.5 Erosion Prevention and Erosion Control

Erosion Prevention and Drainage Improvements

Erosion prevention on roads, the entire road prism, and on disturbed areas is fundamental for the protection of water quality, particularly during storms. Two causes of erosion are the concentration of flowing water and lack of ground cover over the soil. Vegetative ground cover and good water infiltration are the primary long-term defenses against erosion.

Implement erosion control measures immediately following construction and every time an area is disturbed. Implement the measures before the first winter period following construction or ground disturbance and before any major storm event. In areas of construction, ground cover is difficult to achieve, so sediment typically is trapped around the site. The area of disturbance also can be limited and areas can be rehabilitated progressively.

Prevent waterflow concentration or armor/stabilize eroding channels. Trap any sediment before it enters natural drainage channels, but give priority to treatments at the source of the erosion. Cover bare ground with some form of matting or mulch to reduce initial erosion and to promote growth of grass seed or other types of appropriate vegetation (ideally native) for long-term erosion control. Use rapid-growing annual grasses to provide quick ground cover; then replace with native vegetation over time.

As discussed in “Forest Roads: A Synthesis of Scientific Information” (Gucinski et al. 2001), surface erosion from road surfaces, shoulders, cuts, and fills is significant. Movement of sediment can occur during and after road construction, after road maintenance, during logging or mining activities, as the road is being used, if a road is closed but not stabilized, or from poor land management practices near the road. For instance, roughly half of the erosion from a logging operation comes from the associated roads and skid trails. Mass erosion rates from roads typically are one to several orders of magnitude higher than from other land uses. Much of that erosion occurs during storm events.

Erosion control is a two-step process; step one is to prevent short-term erosion from bare or exposed soil. Step two is control of long-term erosion through establishment of vegetation. Sometimes in steep or severe conditions, a structural solution, such as a retaining wall, ground armoring with rock or a gully plug, is required. The ideal erosion control solution promotes the germination and growth of plants and encourages the natural recruitment of the surrounding native plant community while it protects the soil from short-term erosion. Conserving native topsoil and respreading it over an area helps promote native plant growth. There are numerous treatments, combinations of treatments, and emerging products that may be suitable for a site.

An erosion control plan is a very useful tool for any project to help describe the local conditions and problems at the site, evaluate possible solutions, and determine the cost of the erosion and sediment control measures. Use this plan for construction projects, SDRR measures, and site repairs. Make an evaluation of the most effective physical, vegetative, or biotechnical treatments, or use of some combination of them. Plan short-term and long-term measures, as well as an evaluation of needs, such as fertilizers, irrigation, protection measures, and so forth.

The “Erosion Control Treatment Selection Guide” by Todd Rivas (2006) describes erosion control principles, erosion types, and soil types. The guide also details erosion control treatments and proper treatment selection for use by engineers, soil scientists, and other resource specialists. Link to the document <http://www.fs.fed.us/eng/pubs/pdf/hi_res/06771203hi.pdf>.

Another useful reference combining many erosion and sediment control practices in a forest road setting, including drainage control, vegetation, use of mulches, biotechnical measures, and various physical structures is presented in the publication “Erosion and Sediment Control Practices for Forest Roads and Stream Crossings” by Clayton Gillies with FP Innovations-FERIC Division in Canada (2007).

Where Erosion Occurs Along Roads

Most disturbed road areas, including the road surface, road fills, some road cuts, shoulders, and drainage ditches, are exposed to erosion at some time. Other associated areas, such as landings, skid roads, construction staging and storage areas, borrow pits and quarries, and other working areas can erode and produce sediment. Figure 44 shows the common types

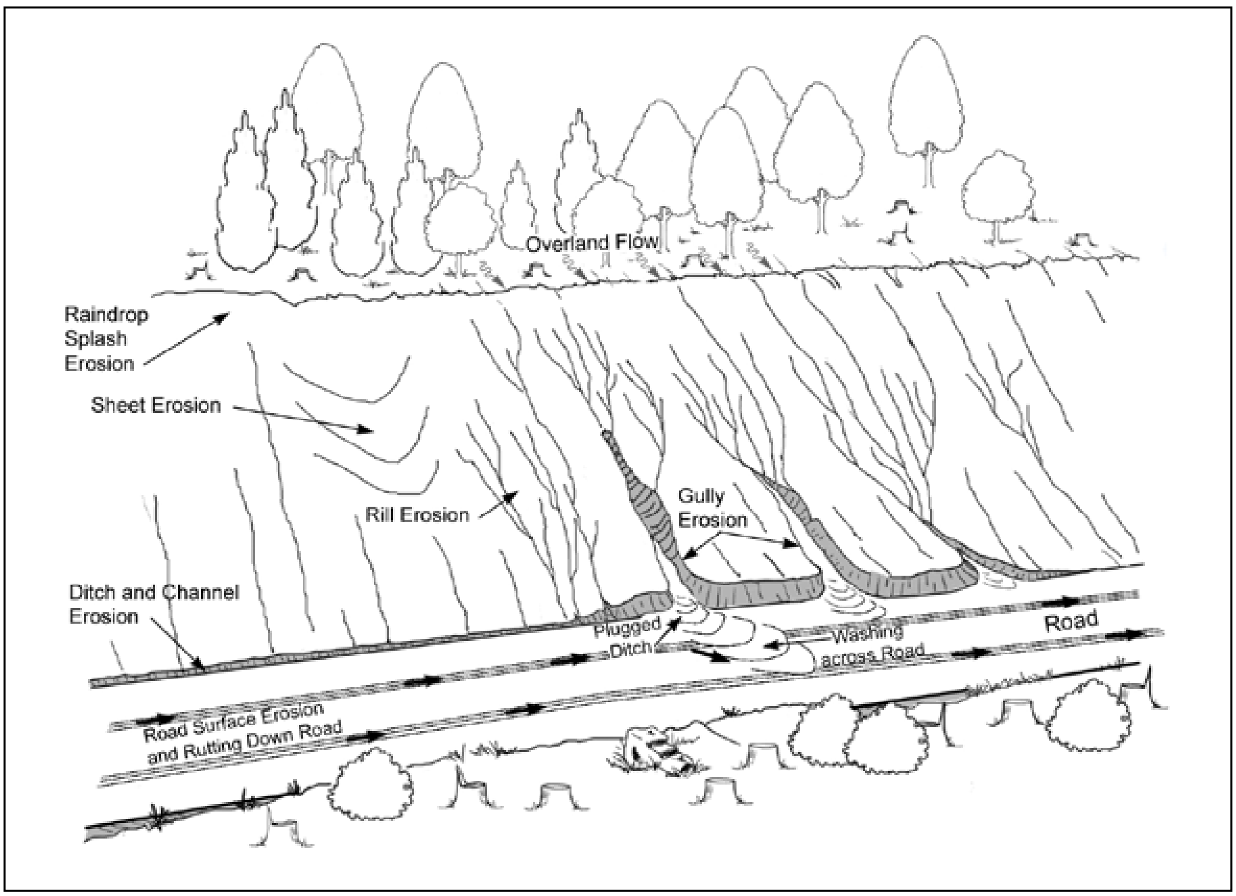


Figure 44—Common types of erosion along a road.

of road erosion, including sheet and rill erosion on the cutbank (and fillslopes), ditch and road-surface erosion, and gully erosion when water becomes concentrated. Figure 45 shows severe erosion in a road cut where a road passes through very erodible soil.

Figure 45—Severe erosion in a road cutslope in erodible soil. (Courtesy of Vincent Barandino.)

Most erosion control prevention practices fall into three basic types. They are physical methods, vegetative methods, and soil bioengineering or biotechnical methods.

Common erosion control practices include:

- ❑ Install drainage and sediment control structures.
- ❑ Disperse water/surface runoff.
- ❑ Armor surface and ground cover with netting, mulch, slash, rock, and so forth.
- ❑ Prepare bed, mulching, and grass seeding.
- ❑ Establish vegetation for ground cover.
- ❑ Use simple soil bioengineering methods.

Figures 46 through 52 show a variety of these erosion and sediment control methods. Many erosion control treatments exist, along with an entire profession and industry to help achieve effective erosion control. Effective erosion control requires assessment of the situation, attention to detail, inspection and quality control during installation, and post-project maintenance.

Physical Methods for Erosion Control

Drainage control is one of two key elements for physical erosion control (the other is ground cover). Prevent water concentration by dispersing the flow or controlling the water. Concentrated, fast flowing water has a large amount of energy and therefore a great ability to scour, erode, and form gullies. There are many physical erosion control measures to help disperse or control the flow of water, such as armored ditches, berms, check dams, or turf-reinforcing mats. Section 5.2 discusses many other measures used to disperse and control surface drainage, such as rolling dips, road shaping, and use of ditch relief culverts and leadoffs.

Physical methods also include the wide range of materials used to provide protective ground cover, such as mats and netting, silt fences, turf-reinforcing mats, slash and mulches, bonded fiber matrix, rock and concrete, and so forth. Often these products are used in conjunction with drainage and vegetation.

Physical methods include a range of alternatives:

- ❑ Berms to control and direct waterflow or berm removal to disperse runoff.
- ❑ Walls, barriers, and sinks or sediment basins to trap sediment.
- ❑ Mulch and soft ground cover with straw, wood chips, slash, leaves, bark, shredded paper, mats, bonded-fiber matrices, and so forth to temporarily protect the ground surface against erosion.
- ❑ Hard armor/ground cover with rocks, riprap, articulated concrete blocks, geocells, gabions, and so forth for permanent ground cover.

- ❑ Rock or aggregate on the roadway surface, particularly on steep road grades, erodible soils, areas of concentrated water flow, and hydrologically connected roads at approaches to stream crossings.
- ❑ Rolled erosion control products (erosion control and revegetation blankets) and mats to provide ground cover and promote vegetation. Mats and blankets need to have good contact with the soil and be pinned down in accordance with the manufacturers' recommendations.
- ❑ Turf reinforcement mats to armor high-flow channels.
- ❑ Silt or sediment fences to trap sediment, particularly around work sites.
- ❑ Stabilizers and tackifiers to modify the soil surface to make it more resistant to erosion.
- ❑ Hydromulch and hydroseed.
- ❑ Modified soil surfaces (terracing, roughening, etc.) to control runoff and aid revegetation.
- ❑ Waterbars, rolling dips, and other cross-drain structures to disperse and divert water from the road surface and ditches.
- ❑ Check dams and rock armor used in ditches to reduce velocity and prevent downcutting and erosion.

Each method has advantages or disadvantages, installation details and requirements, and performance characteristics. Most should have good contact with the soil, and mats need to be closely pinned down; hard products need a compact soil surface and often a filter layer under them; silt fences need support, the appropriate geosynthetic, and some soil embedment, and so forth. Some treatments require more maintenance than others. Treatment selection should consider whether it will be maintained. The "Erosion Control Treatment Selection Guide" (Rivas 2006) helps describe these methods and select the most appropriate or cost-effective solution. Figures 46 and 47 show some of these physical measures.

Figure 46—Common physical erosion control measures, including straw (a), netting, wood chips and straw wattles (b), to provide ground cover until vegetation can grow.

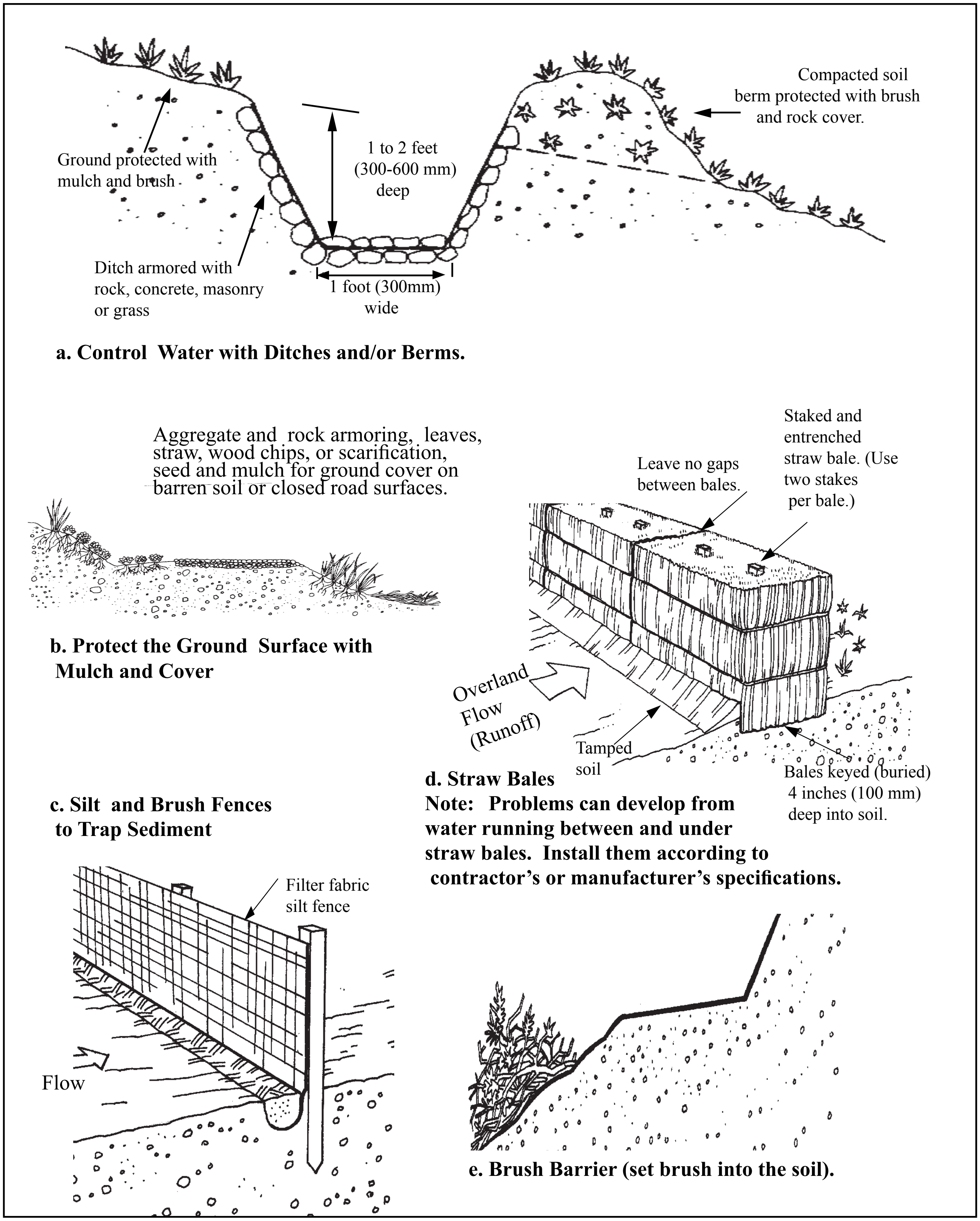


Figure 47—Common physical erosion control measures.

Vegetative Methods for Erosion Control

Ground cover is the most critical site factor influencing erosion. Vegetation is the most desirable type of long-term ground cover in forest and range settings and provides these major benefits. Vegetation:

- ❑ Reduces raindrop impact via top growth and leaf litter.
- ❑ Reduces runoff velocity via increased roughness from growing plants and leaf litter.
- ❑ Provides structural integrity (reinforcement) of the soil via the root system.
- ❑ Filters chemical pollutants and sediments from runoff.
- ❑ Increases water infiltration into the soil.
- ❑ Increases percolation through the soil (the lateral movement of water in the soil).
- ❑ Increases evapotranspiration (the vertical movement of water to the air through plant tissues).

Vegetative methods use grasses, brush, and trees to offer ground cover, root strength, and soil protection with inexpensive and aesthetic natural vegetation. Live vegetative hedgerows on contour help trap sediment on a slope. Figures 48 and 49 show some of the considerations and types of vegetative erosion control used in conjunction with physical methods.

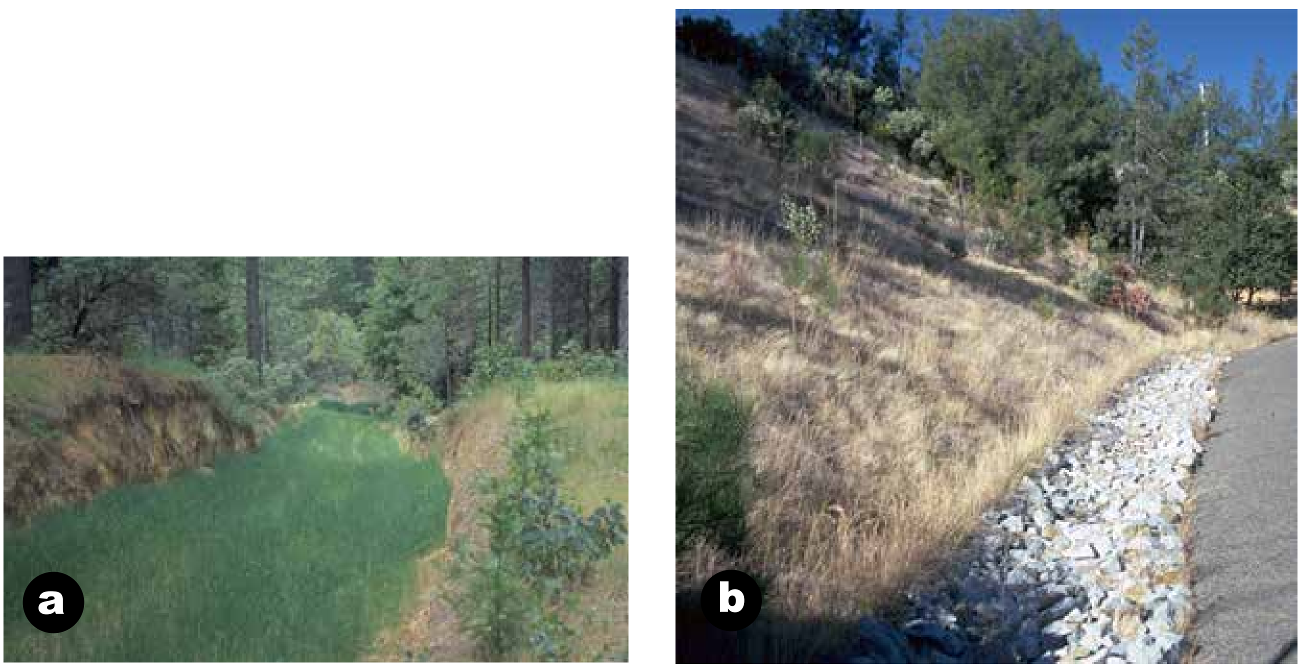


Figure 48—Common types of vegetative erosion control measures including grasses on a closed road (a) and deep-rooted shrubs and trees (as well as grass) on a cutslope (b).

Good soil preparation is key to the long-term success of vegetative treatments. The quality and fertility of the soil directly affects its productivity and ability to grow vegetation. Loosen compacted soils with scarification or subsoiling and add organic material. Sterile soils may need amendments to promote growth. Other chemicals or minerals in soil may retard growth and need mitigation. Native species do not typically require fertilizer since they are adapted to the nutrients available in the local soil.The erosion control plan should consider the soil condition and often include a chemical analysis of the soil.

Design and install vegetative treatments to provide immediate, short-term, and long-term protection. Often physical methods are used to protect seeds initially and promote long-term revegetation. Thus, a phased and/or mixed application of vegetation is needed, typically with a variety of plants. Ideally, select vegetation for good growth properties, hardiness, dense ground cover, and deep roots for slope stabilization. Local native species having these properties are preferable. Consider them first.

When natives are not practical, select nonnative plants with noninvasive characteristics. Some shrubs, such as willows (Salix family), have been used extensively in the Western United States, particularly in wet sites, because of their strong, deep roots; adaptability; and ability to resprout. Refer to local forest botanists and native plant guides and policies before prescribing vegetative treatments.

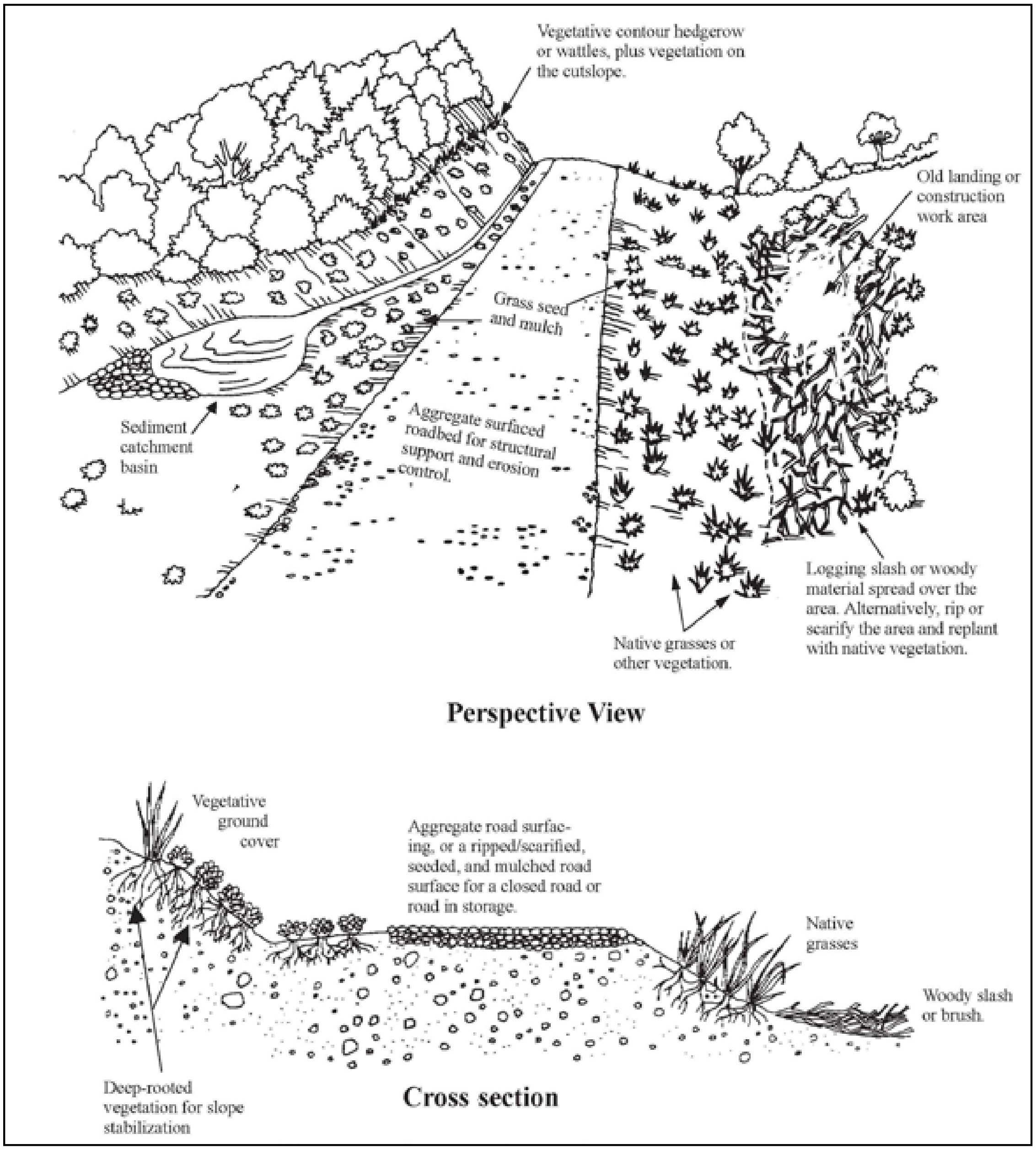


Figure 49—Vegetative erosion control measures along a road (often mixed with some physical measures).

Vegetation typically is the best, least expensive, and most aesthetic long-term treatment. Vegetation typically has the following characteristics:

- Plants need to be compatible with local climate.
- Vegetation needs water and sunlight.
- Local native species will likely do best.
- Vegetation is live and needs care; follow appropriate handling and planting procedures, and keep the materials moist during collection, transport, storage, and installation.

There are a number of considerations for the most effective use of seeds, cuttings, or potted transplants:

- Select seed for quality, resistance, and germination properties. Rates of seed application and specific mix for the location and time of year should be determined.
- Prepare, loosen, amend, and improve the seedbed, planting site, or individual planting holes as needed to promote growth. Add mulch and organic material to a site as necessary to retain soil moisture and improve the soil and microclimate.
- Handle plants with care and do not allow them to dry out during storage, transportation, and planting.
- Prune broken branches and reduce the size of woody shrubs by one-third prior to planting. Prune trees but do not prune the leader (center main growing trunk).
- Protect plants from animals and disease; fertilize, if needed; and maintain conditions for good growth.

Use native species whenever possible for the best growth and adaptation to the site. Nonnative species of annual grasses may be needed for the first few years to protect disturbed areas against surface erosion. For difficult sites, such as arid environments, test plots should be set up to determine what species and methods achieve the best results. Consider setting up onsite nurseries to harden and adapt plants to the local project area. In some cases, use completed projects as sources for live cut stock on a new project. Try to select native vegetation that does not require watering or fertilizers.

The U.S. Department of Transportation, FHWA publication “Roadside Revegetation: An Integrated Approach to Establishing Native Plants” (Steinferld et al. 2007) provides a thorough discussion of benefits and issues dealing with native vegetation, including project initiation, planning, implementation, and monitoring for roadside revegetation. Link to the Web site <http://www.wfl.fhwa.dot.gov/td/>.

Use of Deep-Rooted, Native Vegetation

Choose the type and source of vegetation carefully to accomplish the specific purpose. Project planning (the erosion control plan) should assess the problem and determine the effective solution. Information, such as location, aspect, climate and microclimate, soil type, fertility, time of planting, and subsequent land use, are critical factors in making the final design determination. Refer to the local forest botanist, soil scientist, or native plant specialists and policies before prescribing vegetative treatments. Check with local agricultural extension offices, the U.S. Department of Agriculture, Natural Resources Conservation Service, and State or local road departments.

The advantage of vegetation with deep root systems is that they are more resistant to drought conditions and the deep roots provide slope stabilization as well as ground cover. Many grasses provide excellent dense ground cover but have shallow roots that do little to deter shallow mass failures on saturated slopes.

Figure 50 shows two applications where vegetation with deep root systems help provide slope stability as well as ground cover.

Figure 50—Deep root systems from pine trees (a) and willows (b) that provide stability to slopes and streambanks. (Photos courtesy of Donald Gray (a) and Robbin Sotir (b).)

Soil Bioengineering and Biotechnical Erosion Control Methods

Soil bioengineering and biotechnical treatments can be applied to any number of instances where erosion protection is needed. Depending on the site conditions and the values at risk, the application of these techniques can be relatively inexpensive or expensive. Section 6.2 discusses soil bioengineering and biotechnical applications for streambank instability, and section 6.6 discusses uses for slope stabilization.

Soil bioengineering is a technology that uses integrated ecological principles to assess, design, construct, and maintain living vegetative systems to repair damage caused by erosion and slope failures (Sotir 2001). Biotechnical treatments combine the use of vegetation with other physical structures, such as vegetated gabions or vegetated reinforced soil slopes (Gray and Leiser 1982). Biotechnical stabilization is a specialized field, and consultation with experts and other guides is highly recommended.

Some more common soil bioengineering and biotechnical treatments include:

- ❑ Live stakes (willow and others) embedded in the face of the slope.
- ❑ Fascines/bundles/wattles; bundles of branches that are laid in a trench along contour lines that sprout and grow.
- ❑ Brush layering laid onto terraces in the slope, covered with moist soil and compacted.
- ❑ Vegetated reinforced soil slopes (that is, geosynthetic reinforced soil slopes with brush placed on each lift with the reinforcement).
- ❑ Vegetated gabions and walls, such as retaining structures interplanted with live vegetation cuttings.

- ❑ Live cribwalls, wooden cribwalls using material that will sprout or constructed with vegetation layers.

Figure 51 shows examples of biotechnical stabilization measures with live cribwalls and retaining structures. Figure 52 shows examples of common soil bioengineering and biotechnical measures used to control erosion and to stabilize cuts and fills and/or adjacent slopes.

The U.S. Department of Agriculture, Natural Resources Conservation Service publication EFH 18, “Soil Bioengineering for Upland Slope Protection and Erosion Reduction” (NRCS 1992) describes many of the common bioengineering techniques. It is available at <ftp://ftp-nhq.sc.egov.usda.gov/NHQ/pub/outgoing/jbernard/CED-Directives/efh/EFH-Ch18.pdf>.

Also “Soil Bioengineering–An Alternative for Roadside Management: A Practical Guide” (Lewis 2000) provides field personnel with the basic merits of soil bioengineering concepts and gives examples of several techniques especially effective in stabilizing and revegetating upland roadsides. Link to the document <http://www.fs.fed.us/eng/pubs/pdf/00771801.pdf>.

Figure 51—Biotechnical slope stabilization and erosion control methods, using a live crib wall (a) and gabions with live stakes (b). (Lower photo courtesy of John McCullah.)

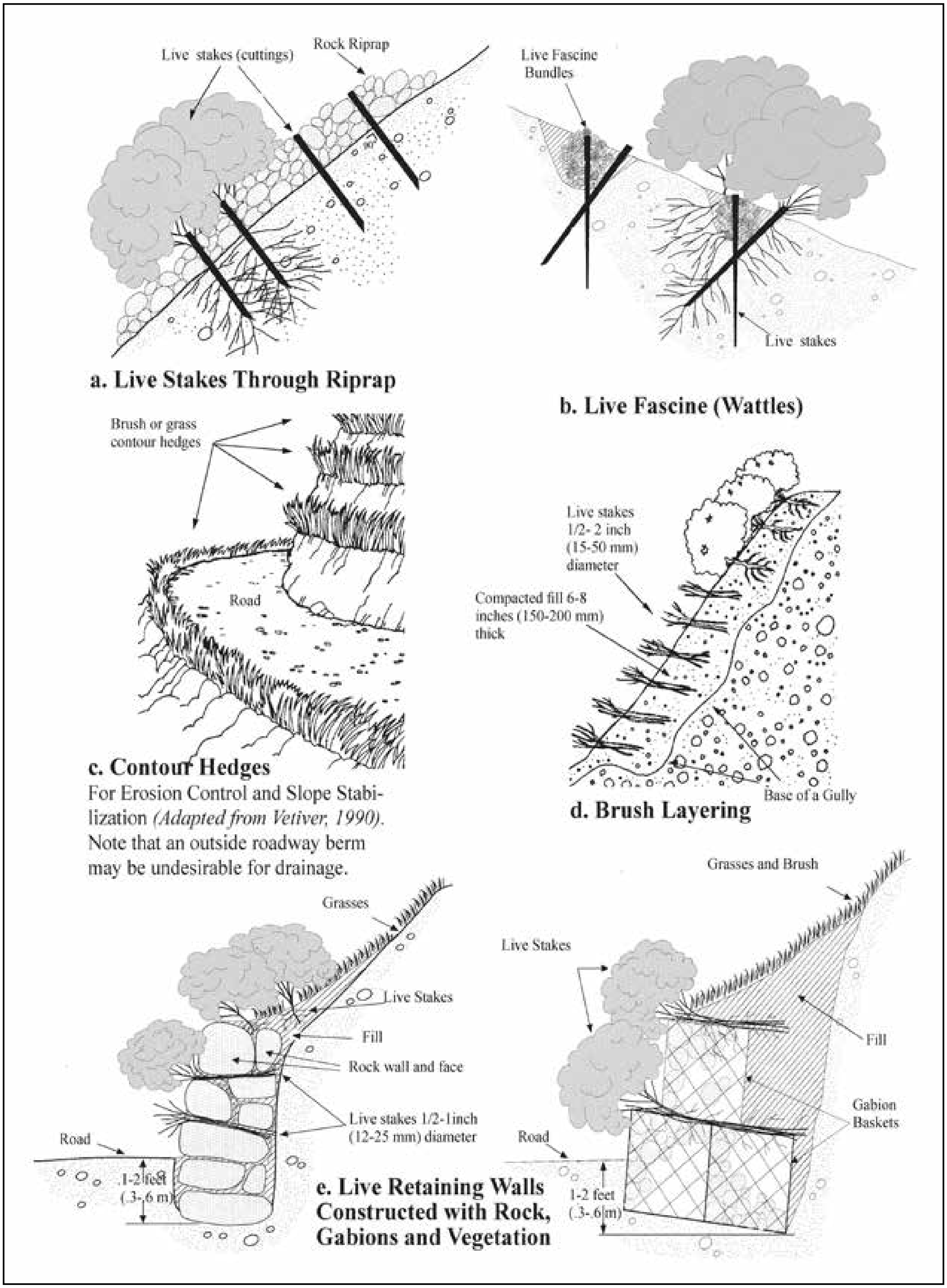


Figure 52—Examples of some common soil bioengineering and biotechnical erosion control measures.

Gullies and Gully Prevention

Gullies are a severe form of surface soil erosion. Typically, they are caused by concentrated waterflow on erodible soils. Concentrated waterflow may begin as a minor sheetflow (micro-rills) that produce rills, and eventually results in major gully formation. Gullies can have major impacts on an area by taking land out of production and by lowering the ground-water table, as well as being a major source of sediment. They can be caused by concentrated water flowing off roads or they can impact roads by creating another drainage crossing or need for more frequent maintenance. If a gully can be prevented by diverting or dividing a concentrated flow of water, damage typically can be prevented.

Gullies are particularly problematic and common in dry, arid climates and areas with deep, fine soil deposits. Rainfall is minimal, so vegetative cover is often sparse. When it rains, storms are often brief, high-intensity thundershowers that overwhelm the soil-infiltration capacity. Thus, gullies form and enlarge with each high-intensity event.

Once formed, gullies grow with time and will continue downcutting until resistant material is reached or the contributing flow is reduced or eliminated. They also expand laterally as they deepen. Gullies often form at the outlet of culverts or cross drains due to excessive and concentrated flows and relatively fast water velocities, as shown in figure 53. Occasionally gullies formed below cross drains have translated into debris slides that have caused extensive offsite damage. Also, gullies can form upslope of culvert pipes, especially in meadows, if the pipe is set below the meadow elevation. This causes a drop in the meadow or channel elevation and subsequent headward migration of the gully through the meadow.

Gully prevention is important, but gully stabilization measures and structures are infrequently used for storm damage risk reduction. However, stabilization measures are very useful to correct ongoing gully erosion problems and prevent their growth and headward migration. Section 6.5 discusses commonly used gully stabilization structures.

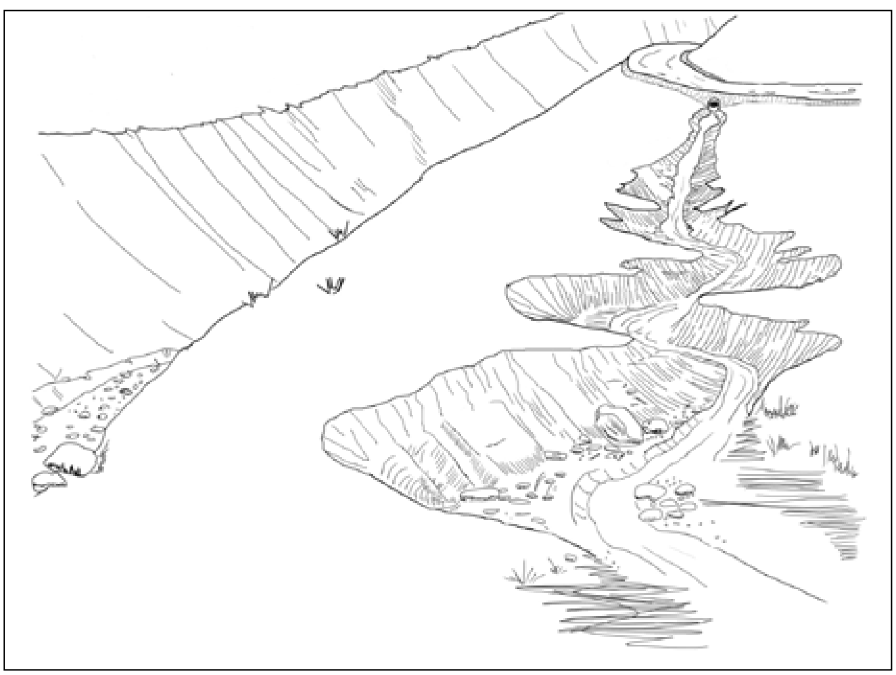


Figure 53—Gully formation below a road where excessive water was discharged from a ditch relief cross-drain culvert.

Gully Risk and Prevention

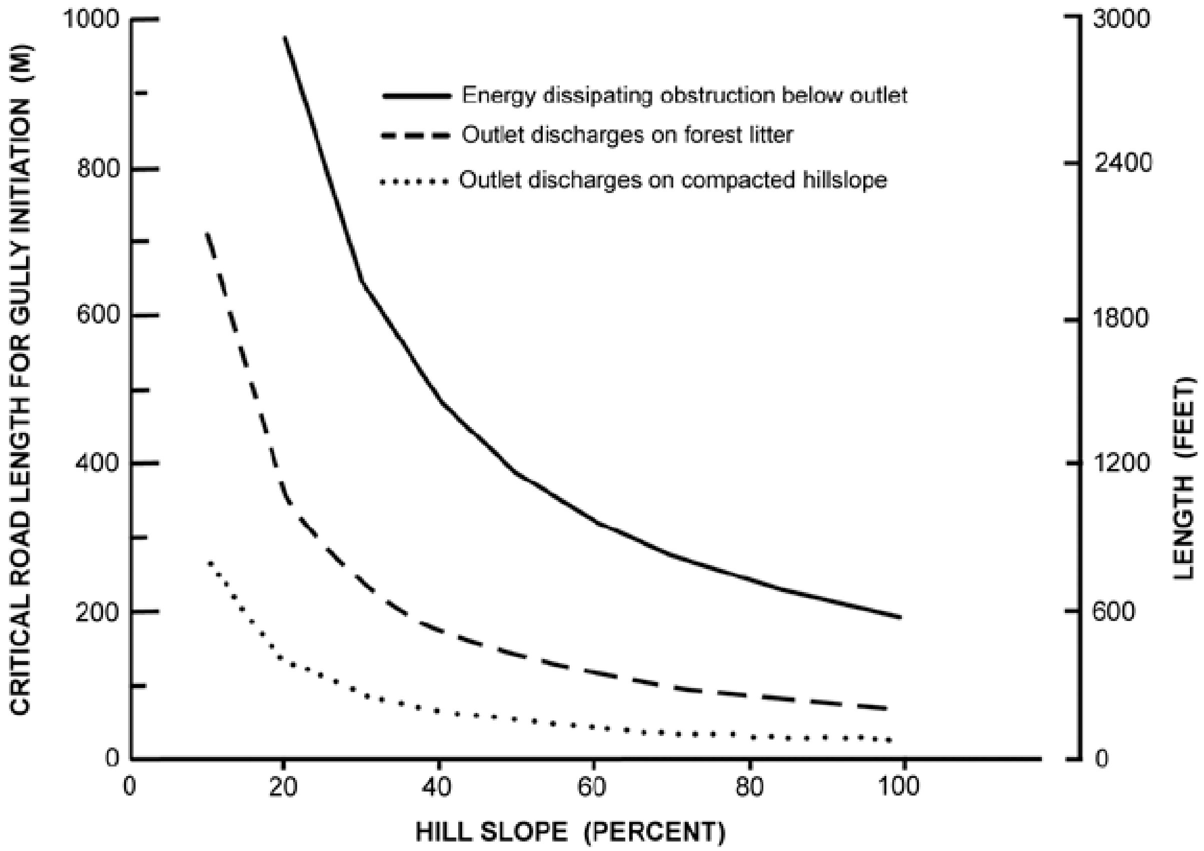
The ideal way to deal with gullies is to prevent them from happening. Investigate the source of the water and, if possible, remove the water source that is causing the gully. Gully formation at the outlet of cross-drain structures or road drainage points is a common problem and the subject of considerable research. Gully formation, or gully initiation along a road, is a function of the contributing area (road length) and the ground slope over which the water runs (hillslope gradient). These functions relate to the volume of water accumulated and the energy that water has to cause erosion. Resistance to gully formation also is a function of soil and vegetation characteristics where the water exits onto the slope; drain exit location is important. Thus, the spacing of road drainage features is particularly important in preventing gully formation.

On steep slopes, there is potential for gully initiation after a couple hundred feet (50 meters) if the pipe exits on an unprotected, compact hillslope. An outlet discharging on forest litter takes a longer distance to initiate a gully, and with an energy dissipator below the outlet, the initiation distance may be 1,000 to 2,000 feet (several hundred meters) long. Also, gully initiation is likely on shorter segments of road that have an inslope versus an outslope because of the more concentrated flow at the outlets. Figure 54 presents curves for the critical road length and ground slope factors observed to be critical for gully initiation, either with an outlet energy dissipater, or with discharge into forest litter or compacted soil. These curves represent a 50-percent probability of gully initiation if conditions are exceeded.

To prevent gully formation below cross-drain culverts, controlling the road length draining to the culvert effectively controls the contributing area and the amount and velocity of water; therefore, preventing gully initiation. This should be the basis for many culvert-spacing recommendations.

Figure 55 shows somewhat similar results for gully initiation as a function of contributing road length and hillslope for three different soil types with a low, medium, and high erodibility. The low soil-erodibility data was collected in volcanic soils in central Oregon, the medium erodibility data from granitic soils in the Idaho batholith, and the high erodibility data from young basalt and glacial deposits on the Olympic Peninsula, Washington. The critical Erosion Sensitivity Index is the parameter used to establish the three curves shown in figure 55 and define the limit between high incidence and low incidence (no formation) of gullies (Cissel et al. 2012a.)

Experiences in the Pacific Northwest, California, and Australia have shown variability in the data for gully initiation. Thus, values shown in figures 54 and 55 may be conservative but are recommended for use, particularly if the drainage outlet is in a critical or sensitive area, such as above a steep slope or near a stream channel. Updated research and ongoing monitoring data can be found at the following Geomorphic Road Assessment and Inventory Package (GRAIP) Web site <http://www.fs.fed.us/GRAIP/case_studies.shtml>.



NOTES:

1. Critical road length for gully Initiation inversely proportional to hillslope gradient.
2. Gully initiation less likely when energy dissipating obstructions are below the drainage outlet.

Figure 54—Gully initiation risk as a function of road length, hillslope gradient, and outlet area conditions. (Adapted from Drew Coe 2006).

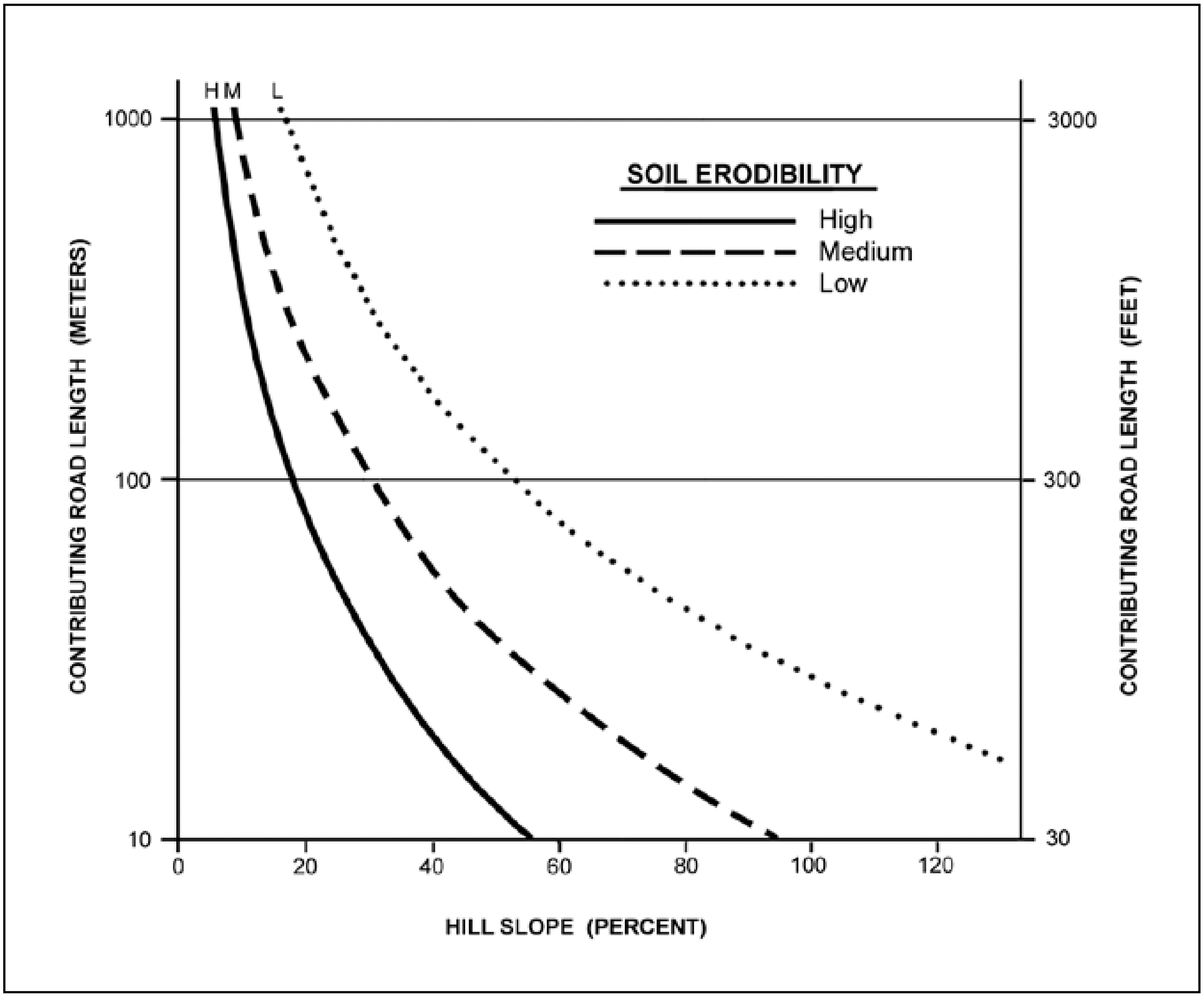


Figure 55—Gully initiation data from the contributing road length as a function of hillslope for various soil erodibility categories. (Adapted from Cissel et al. 2012a.)

5.6 Fillslope Stabilization Measures

A wide variety of slope stabilization measures are available to land managers, engineers, and resource specialists. Measures, such as use of vegetation and drainage, can be simple and relatively inexpensive, while measures, such as retaining structures, can be effective but expensive. One slope modification technique, removing loose, high-risk fill material, is a common storm damage risk reduction (SDRR) measure and is discussed below. Section 6.6 discusses the many other less commonly used but effective SDRR techniques, such as walls, reinforced fills, slope modification, soil nails, deep patch reinforcement, and so forth.

A summary of many cost-effective and sustainable slope stabilization techniques is presented in the National Cooperative Highway Research Program synthesis 430 "Cost-Effective and Sustainable Slope Stabilization and Erosion Control Practices" (Fay et al. 2012).

Sidecast Fill Pullback for Slope Stabilization

Sidecast fill material, or loose material placed on top of native soil on a slope, can absorb water and fail on the plane at the base of the sidecast material. Old logs or stumps used to support the fill will decay with time, leading to fillslope failures. These old sliver fills are common failures on older sidecast road fills on steep slopes where the fill material was not compacted. Newer roads do not use as much sidecast construction; excess material is end hauled to another flatter area or to a disposal site. However, there may still be fillslopes that exhibit instability and warrant treatment because of an excessively steep slope, rotting logs in the fill, or local groundwater conditions, as seen in figure 56. Also the toe of a fillslope can be undercut by a stream if the road is located too close to the stream.

Figure 56—Road fill failure in a sliver fill that was partially supported by old logs. The failure triggered a downslope debris slide, Olympic National Forest. (Courtesy of Bill Shelmerdine.)

In many cases, if road surface water is being properly managed and drained, sidecast fills may not pose a stability problem. If there is subsurface water that moves below the roadway and saturates fill material, the risk of fill failure remains high. Also, sidecast fill material in concave swales and drainages may fail under saturating rainfall conditions, independent of roadway drainage. The terrain tends to concentrate groundwater into this landform.

On steep, natural slopes (typically steeper than 50 to 60 percent), a road fill failure can trigger a debris slide downslope of the road fill. These debris slides can travel for long distances, increase the volume of material involved in the slide, and can damage the hillslope itself, particularly if there is infrastructure or watershed values (such as a stream or wetland) at the bottom of the slope. Debris flow hazards have presented problems worldwide and have been common on forest roads, particularly in the West and Northwest (figures 57 and 58). Many of the fill failures that cause such an event are both identifiable and preventable. Small scarps and curved cracks in the road surface, particularly in the outside half of the road, are indicators of fill settlement or incipient failure. One can map the potential flow path and assess the risks.

Figure 57—Debris slides, often triggered during a storm event from failing fills, that started at the upper road and ultimately impacted the lower road. (Courtesy of Jim Doyle.)

Treatments may include periodic maintenance of the site to seal the cracks against water intrusion; ditch the road or use measures to direct water away from the fillslope; repair the site using a deep patch (or other appropriate measure for the site); or remove the failing fill material. Collins (2007) discusses detection and mitigation measures in “Debris Flows Caused by Failure of Fillslopes: Early Detection, Warning, and Loss Prevention.” The U.S. Geological Survey publication “The Landslide Handbook” (Highland and Babrowsky 2008) also describes many useful debris slide mitigation measures.

Sidecast fill pullback or removal of high-risk fill material is one positive method to reduce the risk of failure. However, just pulling back sidecast fill (and end hauling it to a stable disposal site) has the drawback of narrowing the roadway. In some cases a roadway ditch can be eliminated to gain road width. If the road standard is changing from a maintenance level 3 to maintenance level 2, or a maintenance level 2 to maintenance level 1, narrowing the road may not be a problem.

For higher standard roads, and heavily used roads, road width may need to be retained. In those cases additional cutting into the hillside and/or changing the road grade or alignment may be required. On severe or very steep slopes, especially with subsurface water, retaining structures with drains may be needed to provide long-term stability.

Figure 58—Debris slides that subsequently formed gullies below the road in Colorado (a) and on the Blue Ridge Parkway, Pisgah National Forest, North Carolina (b). (Lower photo courtesy of Tom Collins.)

Figure 59 shows the process of pulling back loose fill material to stabilize a road shoulder. Either the road surface will be narrowed or a cutslope excavation will be needed to compensate for the loss of road width.

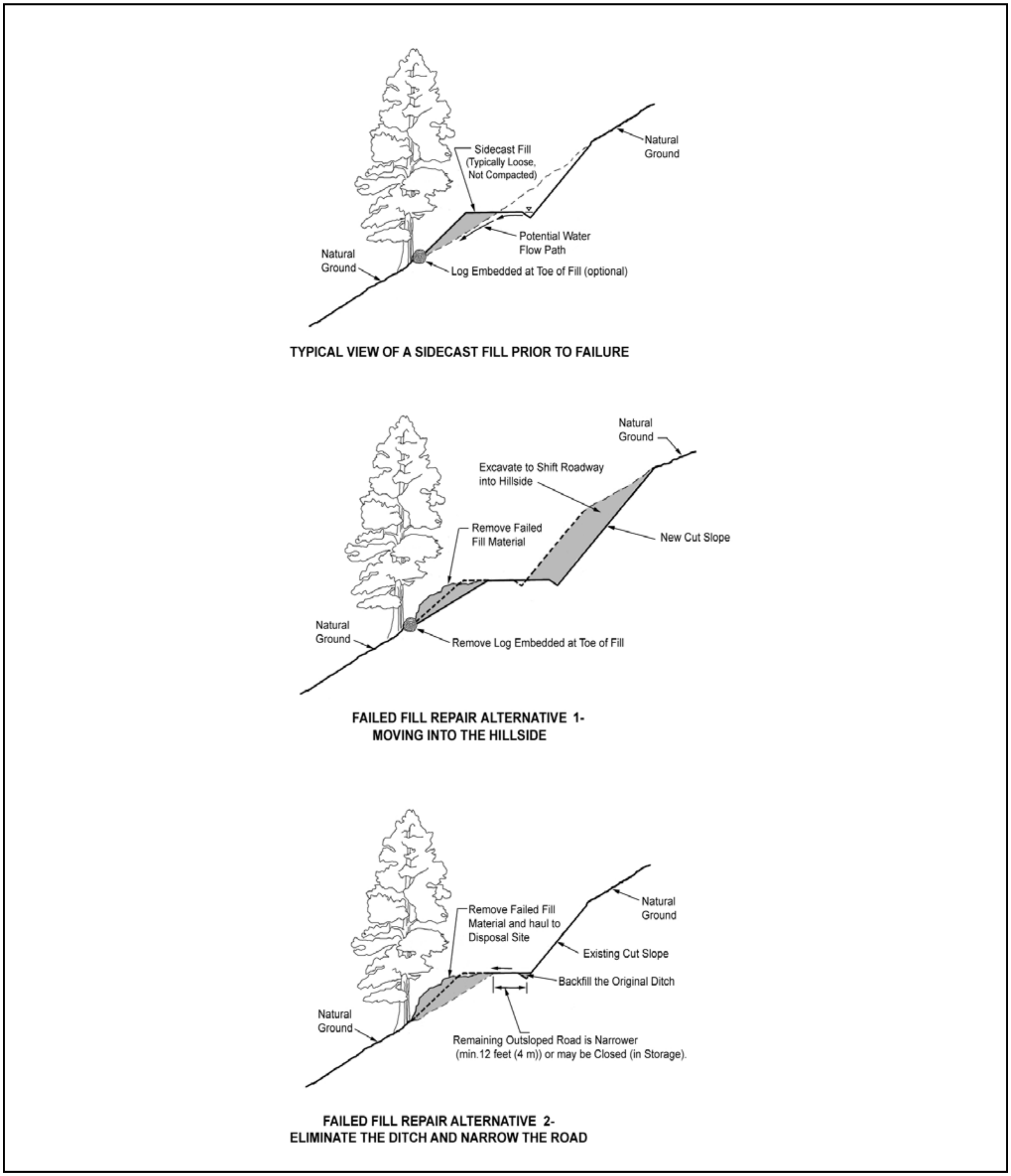


Figure 59—A fill failure repaired by pulling back or removing loose, sidecast shoulder and fill material and shifting into the hillside, or possibly narrowing the road.

CHAPTER SIX

LESS COMMON OR HIGHER COST STORM DAMAGE RISK REDUCTION (SDRR) TREATMENTS

6. LESS COMMON OR HIGHER COST STORM DAMAGE RISK REDUCTION (SDRR) TREATMENTS

6.1 Less Used Road Surface Drainage Treatments

Converting Inslope Roads to Outslope

Conversion of roads from an inslope template, typically with an inside ditch, to an outslope road has many long-term advantages, particularly if a road will receive minimal maintenance. It is a treatment that is discussed often to reduce the risk of storm damage. However, it also is an expensive treatment and one that involves a considerable amount of labor and earthwork. Thus, the reality is that despite its desirability it is not commonly used.

Advantages of an outslope road are that the roadway template is as narrow as possible (not requiring a ditch); there is a relatively small cut and fill; slumping in the cutslope is less of a problem, construction is least expensive; there is less maintenance without a ditch and cross-drain system; and the dispersed flow avoids water concentration and quickly gets the water off the road. Since ruts and berms concentrate water on any road surface, an outslope road functions best when built in conjunction with rolling dips. Thus, an outslope road can be the most desirable roadway template to use if it suits the local conditions. On most roads some combination of inslope and outslope exists to accommodate the terrain, drainage needs, and traffic safety. To function properly, ensure that maintenance on an outslope road does not build up a berm along the outside edge of the road.

Conditions that are not conducive to outsloping include where interception of water from the cutslope occurs, or where a slippery, icy, or erodible road surface and fillslope is a concern. Clay-rich soils, some silts and volcanic ash soils, or polished limestone rock can be quite slippery when wet. Intercepted water in the cutbank may cause erosion or instability downslope. Drivers can feel unsafe and fear that they will slide off the mountain, particularly on outsloped curves and in steep terrain. In steep terrain and on steep grades where the road surface may be slippery or have snow and ice, it is safer to use an inslope road template. Better to slide into the ditch than off the hillside. In some cases, use an inside ditch along with an outslope road template where there are seeps or springs in the cutbank.

Advantages of an inslope road are that water is better controlled; it moves into a ditch, and then the ditch can discharge onto a stable nonerodible location. Also, it can be safer and prevent a vehicle from sliding off the road. The disadvantages of an inslope road and a ditch are the need for additional road width, more excavation with a higher cut and more fill material, concentrated flow in the ditch, and the need for ditch relief cross drains or leadoff ditches. Cross-drain culverts commonly plug during large storms, leading to significant damage to the road.

Figure 60 shows the form and relative dimensions of an inslope versus an outslope road. Conversion of an inslope road to outslope requires removing some of the fill and road shoulder material, and typically filling the ditch, as seen in the lower figure. New material may need to be imported to fill and raise the roadbed at the inside ditchline. This is desirable from a drainage standpoint, but requires a considerable amount of work on the road. Some drainage slope conversion work has been as expensive as the initial road construction. Figure 61 shows an outslope road accentuated on an outside bend in the road.

The road cross slope with an inslope or outslope road should be accentuated or constructed to its maximum recommended slope for a road that will be closed or that will be maintained infrequently. The road cross slope is typically 2 to 6 percent, and a 4- to 6-percent range is recommended where maintenance may be infrequent. Under slippery conditions and log haul traffic, a 2- to 3-percent maximum outslope may be desirable. Traffic and time tend to wear down or smooth out a cross slope and flatten the road.

The importance of regular and proper maintenance cannot be stressed enough for the proper function of road surface drainage features, especially on native material and gravel roads. Traffic will eventually create ruts or surface depressions on the road surface. These ruts or gravel berms compromise the inslope and outslope of the surface and may concentrate water for long distances down (grade) the road. Eventually the concentrated water breaks through and often causes additional erosion problems where it leaves the roadway. Frequent use of rolling grade dips can mitigate some of the problems with rutting and infrequent maintenance. Over the full length of a road, insloping and outsloping combined with rolling grade dips may be the best drainage solution. More and more roads are being built this way or retrofitted with these drainage features.

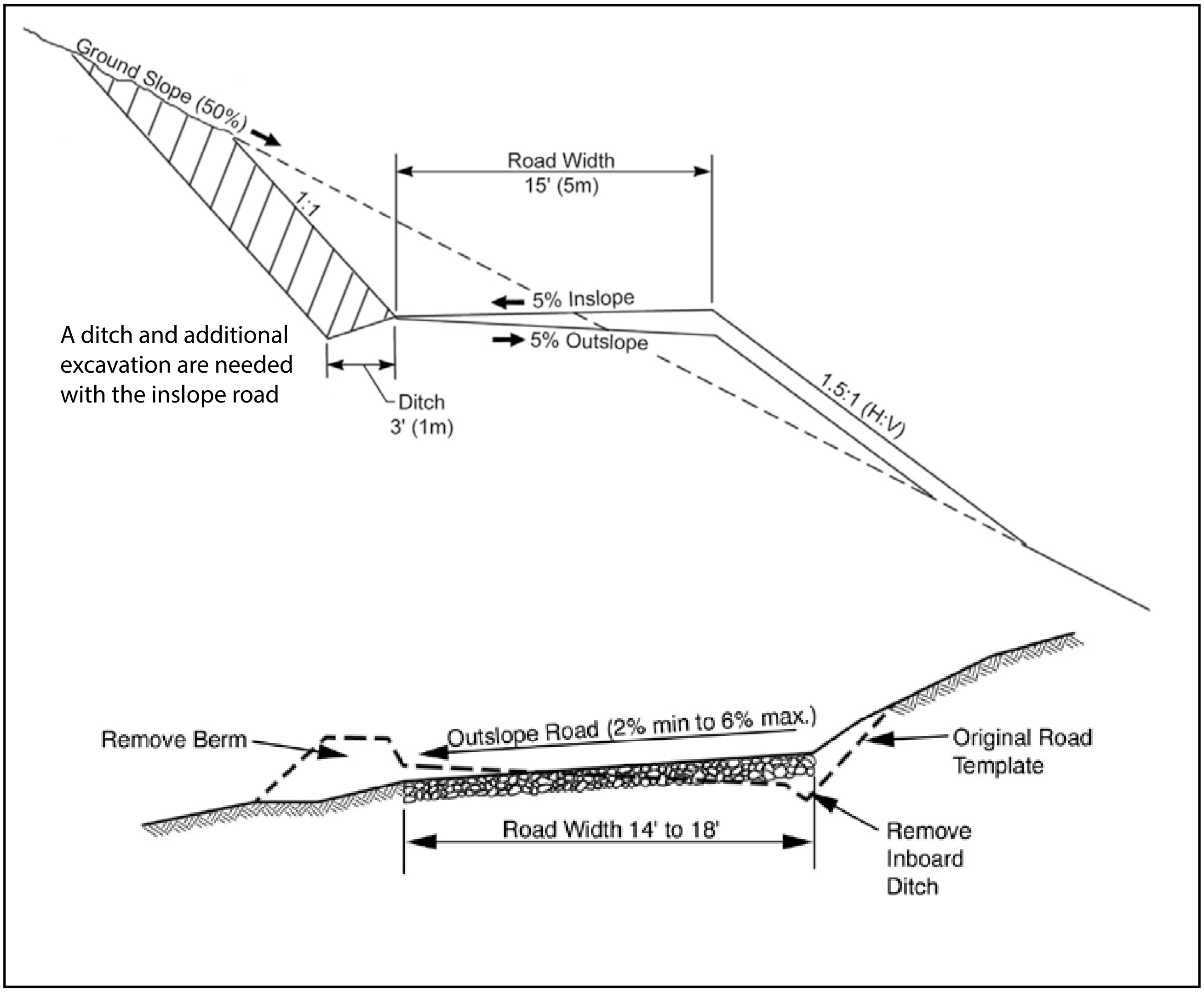


Figure 60—Examples of an inslope versus outslope road template and the work involved in converting an inslope road to an outslope configuration (lower figure adapted from Mendocino County, CA).

Figure 61—An outslope road template on a curve in the road. This photo also shows the tendency of a center and outside berm to form on gravel roads. The presence of these berms disrupts the dispersion of water and can cause significant water concentration if not eliminated by routine maintenance or dispersed with use of rolling dips.

Surface Water Diversion Structures

A variety of structures have been used to remove water off the road surface. Each can work in particular circumstances, and most are maintenance intensive because of their limited capacity for water and to accommodate sediment. Also, use of these other structures typically does make routine maintenance of the road more difficult. Rolling dips appear to be the most effective surface drainage measure for low-volume roads.

However, some successful use has been made of the following measures, particularly if the road has a smooth profile and a rolling dip is not wanted or appropriate. Other alternatives include:

- ❑ Open-top culverts.
- ❑ Rubber deflectors.
- ❑ W-beam guardrail channels.
- ❑ Small concrete canals.

Publications “Introduction to Surface Cross Drains” (Copstead et al. 1998) and “Cross Drain Update” (Gonzales 1998) document techniques and materials used to divert water off the road surface. They are available respectively at <http://www.fs.fed.us/eng/pubs/pdf/w-r/98771806.pdf> or <http://www.fs.fed.us/eng/pubs/pdf/w-r/98771804.pdf>. The National Technology and Development Center publication "Drain Dips, Waterbars, Diverters, and Open-top Culverts—A Guide for Surface Water Drainage of Forest Roads" (Russell et al., in preparation) provides a summary of water diversion structure options, their design, and construction/maintenance details.

Open-Top Culverts. Open-top culverts are the most common water diversion structure after rolling dips. They may be made from wood, logs, metal, small culverts, or concrete. The open top is wide enough to have surface water drop into the culvert and run off the road, yet narrow enough to allow vehicle tires to roll over it. Figure 62 shows a drawing of common wooden open top culverts. Opening width commonly is 3 to 4 inches (75 to 100 mm). Alternatively, some relatively wide open-top culverts have metal grates at the road surface to allow tires to drive over them smoothly, as seen in figure 63. Typically, they are placed at a skew, ranging from 0 to 30 degrees perpendicular to the road direction to divert water off the road surface, and are placed on road segments with a slight to moderate road grade (2 to 12 percent).

The greatest disadvantage of open-top culverts is that often they can fill with sediment and not work, particularly on native soil or gravel surfaced roads, as seen in figure 64 (a). They do function well on hard-surfaced roads and under circumstances where they can be cleaned frequently.

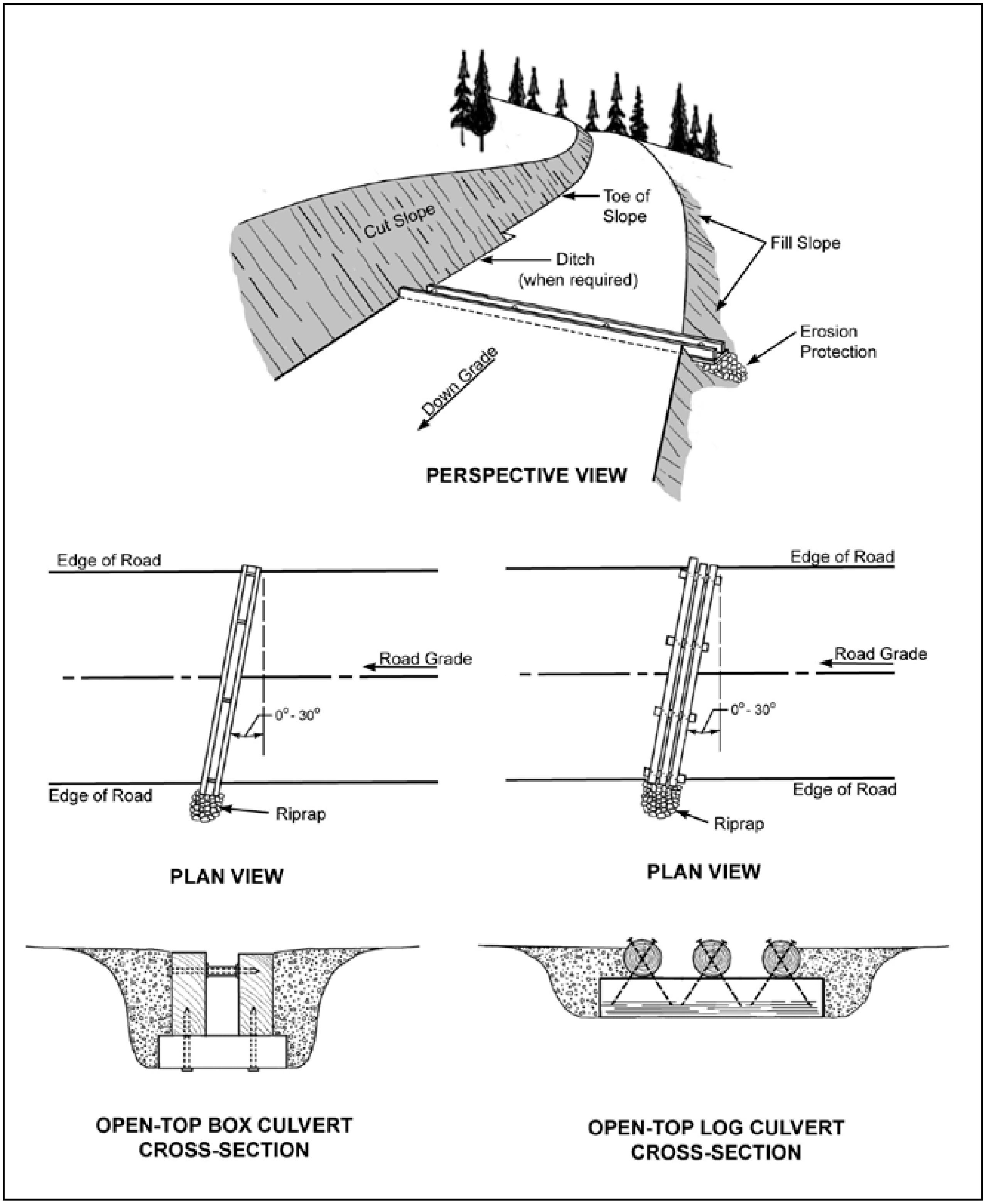


Figure 62—Drawing of typical open-top wooden box culverts using lumber or small logs.

Figure 63—A relatively wide concrete open-top culvert with a metal grate.

Figure 64—A narrow wooden open-top culvert that is plugged with sediment (a), and an open-top culvert that has been recently cleaned on a gravel road (b).

Rubber Deflectors. Deflectors, typically made of rubber strips or old conveyor belt materials, are buried in the roadway surface and stick up 2 to 4 inches (50 to 100 mm) above the road surface to deflect flowing water off the surface, as seen in figure 65. Tires from traffic bend down the deflector when driven over. Typically, they are installed at a skew to the road. They have been used effectively on relatively steep road grades (greater than 12 percent) where rolling dips are inappropriate, and on unsurfaced and paved roads. The main disadvantage of the deflectors is that they have a relatively short lifespan on roads with traffic.

Figure 65—Rubber deflectors used on a rocky native soil road (a) and a paved road surface (b).

W-Beam Guardrail and Small Concrete Channels. Place small channels, or canals, into the road surface to capture and deflect or direct water off the road surface. Use W-beam materials typically for guard rails. Other channels can be made of concrete or masonry, as seen in figure 66. Typically, each is set into the road surface at road grade and on a skew to deliver the water off the road.

The challenge with open-channel deflectors is that they have a very limited capacity to move much water. A large channel with moderate capacity becomes difficult to drive over. Like open-top culverts, these channels can fill with sediment and add challenges to maintenance.

Figure 66—Small concrete channels placed across a native surfaced road for surface drainage. (Courtesy of Simon Done, TRL.)

Culvert Cross-Drain Inlet Protection and Drop Inlets

Culvert inlet control structures (or drop inlets) occasionally are placed in the inside ditchline at the location of a culvert cross drain. Construct drop inlets with concrete or masonry boxes or from round metal or concrete pipe. They need to be consistent with the size of the ditch and pass the accumulated flow in the ditch. They are an alternative to a typical excavated culvert inlet basin (catch basin) and typically are used where the ditch carries large amounts of sediment or is eroding and downcutting. Figure 67 shows several drop inlet types. Sometimes a window is cut in the riser pipe and set at the desired ditch bottom elevation, as shown in figures 67 and 68. Thus, flow has to go over this edge at this elevation, preventing further ditch downcutting.

Figure 67—A variety of culvert cross-drain drop inlet structure types used on forest roads.

Make culvert inlet structures large enough to prevent debris accumulation and easy to clean and maintain. Inlet structures are useful to change the direction of water flowing in the ditch into a cross-drain pipe, particularly on steep grades. Also inlet structures are particularly useful to stabilize the ditch elevation at the level of the inlet window before entering the culvert. They also can be useful when the cutbank is steep, unstable, or has a high rate of ravel to buttress and help stabilize the cutslope, thus preventing sediment from entering the culvert inlet. Additionally, concrete and masonry box structures often have a bottom set below the cross-drain pipe elevation so that this area or reservoir serves as a trap for sediment (sand trap). Clean out trapped sediment periodically, particularly if there is a basket arrangement to facilitate sediment removal.

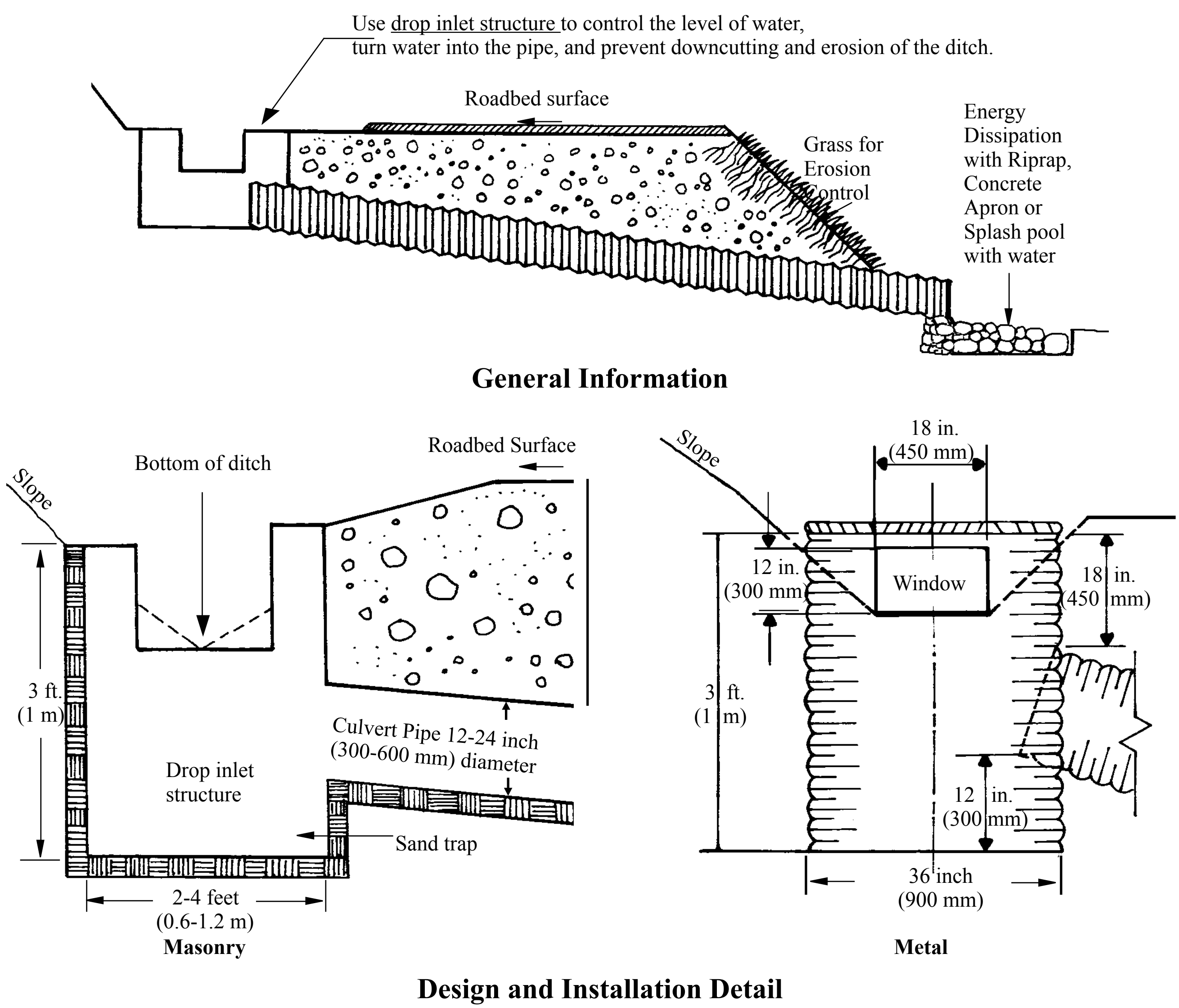


Figure 68—Drop inlet design and installation details for concrete box or corrugated metal riser pipe with built-in sand traps.

6.2 Stream Crossing Structure Protection and Improvements

Natural drainage crossing structures, including culverts, fords, or low-water crossings and bridges require hydrologic and hydraulic design to determine the proper type and size of structure. Also, it is important to identify and understand hillslope processes and landform features since many structures have failed during storm events from landslides and debris slides that initiate outside the stream channel and overwhelm the structure with sediment and debris. Fluvial geomorphology processes also are important to appreciate the dynamic nature of stream and river systems, and their ability to shift location with time. It is important to recognize the characteristics of the watershed and thus the type of material that may be moving through the river system. Evaluate structures considering their setting, changes to the watershed over time, and the types of material expected in the channel.

Culverts most often fail due to plugging with debris and sediment, and occasionally fail because of lack of capacity. Bridges often fail because of scour under foundations or the abutments. Low-water crossings have failed due to scour, channel erosion, or end runs around the structure. Impacts from failures include degraded water quality, bank erosion, channel scour, and impacts to aquatic organisms. Traffic delays and costly repairs often are associated with these failures.

The likelihood of a culvert failure can be minimized in several ways. A culvert should be properly sized consistent with the width of the natural stream channel (ideally with a culvert width matching at least the channel bankfull cross-section width), aligned with the upstream channel, and have an efficient inlet to have the least chance of being plugged with debris. Debris comes in two types: organic and inorganic. It is important to know the dominant type for the site. Some sites are subject to high levels of both organic and inorganic debris.

Organic woody debris is the most common type in forested environments, resulting from tree breakage, blowdown, and logging. Even small limbs and branches can lodge across a culvert inlet and trap other organic and inorganic material, reducing culvert capacity or causing complete blocking of the culvert entrance.

Streams with highly mobile beds or steep channels subject to debris flows may deliver huge volumes of gravel, cobbles, and even very large boulders to a stream crossing, burying the culvert inlet (figure 7a). The best solution for these sites may be a structure that also will pass the debris over the road rather than through the culvert. Most culverts that are properly designed will work fine. However, debris flows and torrents can plug even very large pipes, so in these circumstances, some overflow protection is recommended or a vented ford may be a better design. The structure must include provisions to prevent stream capture or stream diversion.

Culvert failure risk might be managed with appropriate flow and debris capacity for the culvert size, proper installation and alignment, lowering the height of the fill over the pipe, providing a spillway for overtopping, the addition of trash racks, or additional flood capacity through other structures in the floodway. Figure 69 summarizes a number of problematic installation details for a culvert and solutions to minimize the likelihood of plugging. Plugging commonly occurs because of the following factors:

- ❑ Figure 69a. A high headwater-to-pipe diameter (Hw/D) ratio that promotes accumulation of debris above the culvert inlet.
- ❑ Figure 69b. An atypically wide culvert inlet excavation that promotes debris accumulation.

- ❑ Figure 69c. A flattened culvert gradient that promotes accumulation of sediment.
- ❑ Figure 69d. A sharp change in alignment that allows floating debris to lodge across the pipe inlet.
- ❑ Figure 69e. Large rocks lodging against the inlet lip of a culvert. A flared end section can help minimize this problem.

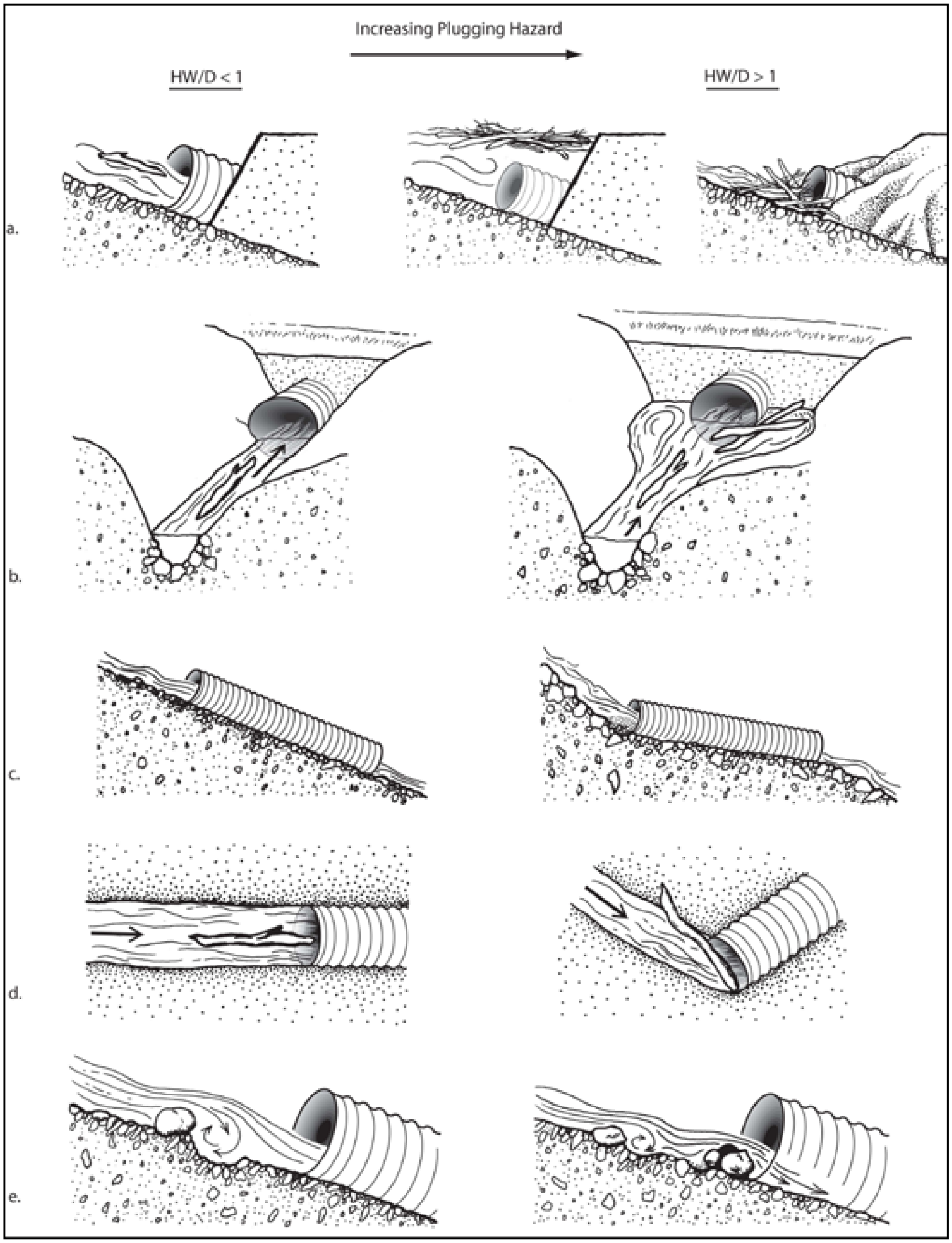


Figure 69—Common plugging hazard problems found with culverts (Furniss et al. 1998).

Flow velocity typically accelerates in a culvert pipe, so the pipe outlet area commonly is subject to scour and may need armoring or other scour protection. Armoring, such as riprap is common, cutoff walls may be used, or a stable energy-dissipation pool can be designed at the pipe outlet.

Two publications that provide insight into culvert failures during storms and provide information to reduce the likelihood of culvert failures are "Response of Road-Stream Crossings to Large Flood Events in Washington, Oregon, and Northern California" (Furniss et al. 1998), and "Water/Road Interaction: Examples of Three Flood Assessment Sites in Western Oregon" (Copstead and Johansen 1998). They are available at <http://www.fs.fed.us/eng/pubs/pdf/w-r/98771807.pdf> or <http://www.fs.fed.us/eng/pubs/pdf/w-r/98771805.pdf>.

A California Department of Forestry and Fire Protection document that discusses a number of treatments to help design and prevent pipe failures during major storms is "Designing Watercourse Crossings for Passage of 100-Year Flood Flows, Wood, and Sediment" (Cafferata et al. 2004). It is available at <http://www.fire.ca.gov/resourcemanagement/PDF/100yr32links.pdf>

One large pipe is almost always better than multiple small pipes. Not only is a larger pipe more efficient hydraulically, a single, relatively large pipe is much less susceptible to plugging compared to multiple smaller pipes. The fill area between multiple pipes acts as a trash rack to catch debris and plug the pipes. However, multiple pipes often are used to minimize the height of the structure (for vertical alignment considerations), to drain a flood plain, and in emergency situations, small pipes often are readily available. Avoid multiple pipes if aquatic organism passage is an issue because they can create a barrier for passage.

Pipes often are designed with an Hw/D (headwater depth to pipe diameter) ratio of 1.0 to 1.5, allowing for some buildup of water in front of the pipe to maximize pipe capacity. However, in a mountainous environment, such a practice contributes to plugging potential with debris that can accumulate at the mouth of the culvert. To minimize plugging potential, an Hw/D ratio of around 0.8 often is used. In watersheds with considerable woody debris that must pass through culverts, Hw/D ratios in the range of 0.5 to 0.67 are recommended (Furniss et al. 1998).

Improve pipe capacity somewhat with the addition of a concrete headwall, smooth liners, or ensuring that the inlet is not damaged. If a pipe might plug and there is diversion potential, construct an armored dip over or near (just down gradient from) the culvert to accommodate overtopping without washing out the structure or diverting water down the road, thus preventing additional damage (section 5.3).

If a stream channel contains considerable debris and there is a history of or potential for culvert plugging, add a trash rack in the channel or onto the culvert to trap debris before it plugs the pipe. However, trash racks are one more item that requires periodic cleaning and maintenance. A discussion of trash racks follows.

To function properly with less risk of failure, install culverts properly and align with the drainage. If the inlet is not aligned with the channel, a directional change of flow must occur. This may result in deposition on one side and erosion from an eddy on the other side. Debris is less likely to be directed into the structure, leading to plugging. Misaligned pipes will erode the hillslope on the downstream end and possibly destabilize the slope. Culverts can create a deep plunge pool at the outlet after the channel has adjusted to the different alignment. Remove and reinstall poorly installed pipes if possible.

Accelerated flows out of culverts often cause embankment and stream channel scour. To prevent this type of damage, add armoring with riprap, gabions, biotechnical measures, or other solutions around pipes as a preventative measure or for outlet stabilization. Other energy dissipation measures also may be used. Some culverts may need beaver protection to prevent beaver dams from plugging the structure.

Where flow fluctuates dramatically or where a channel is subject to debris slides and torrents, culverts may have a history of plugging. In these instances, a lifetime cost analysis may indicate that fords or vented low-water crossings are a better alternative than culverts. This conversion requires a moderate amount of work, but low-water crossings have advantages over culverts in certain settings and are less likely to fail during major storms.

For all natural stream crossings, the need for fish and other aquatic organism passage must be determined. If passage is needed, there are tools to assess the structural requirements necessary to retrofit or replace the existing structure. In most cases, replacing the existing structure, if it is a barrier, is more desirable. For techniques for determining the barrier effect of a structure and designing aquatic organism-friendly stream crossing structures, see the section on aquatic organism passage considerations and the "Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings" publication (Forest Service Stream Simulation Working Group 2008).

Increasing Culvert Capacity

Regardless of the culvert type used, check the high-flow capacity of the culvert. This ensures the survival of the culvert and road fill during extreme storm flow events. Most new culverts are designed to pass at least a 50- to 100-year storm event (Q_{50}-Q_{100}). However, many older pipes were designed to pass only 20- to 25-year events, or less. Also, design flows may increase due to changes in the watershed, a recent fire, global climate change with increased snowmelt, and so forth. Road-fill stability, road overtopping, allowable headwater depth, the likelihood of debris plugging the culvert, backwater effects, or a combination of these factors may determine the culvert high-flow capacity. In some instances, culvert capacity is dictated by forest plans or other Federal, State, or local regulations or documents. The "Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl" (U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management 1994) amended many forest plans with a standard of culverts passing the 100-year stormflow plus debris.

Whether a pipe or structure is being designed for a 25-, 50-, or 100-year storm event (Q_{25}, Q_{50}, Q_{100}), you must determine that design flow. Fortunately, many methods exist to determine streamflows, and in particular peak-design stormflows, using methods such as the U.S. Department of the Interior or U.S. Geological Survey (USGS) regression equations, various agency or USGS hydrology programs (Ries 2007), local stream gauging data, or the Rational Method for small watersheds.

The US Geological Survey has published state reports with regression equations for every state in the United States. See the fact sheet describing the National Streamflow Statistics (NSS) program "The National Streamflow Information Program: Estimating High and Low Streamflow Statistics for Ungaged Sites: U.S. Geological Survey Fact Sheet 2007-3010" (Turnipseed and Ries 2007). Updated State information is available at the USGS Web site <http://water.usgs.gov/software/NSS/>. Additionally the US Geological Survey Program

"StreamStats" is a Web-based Geographic Information System (GIS) that can be very useful since it allows the user to choose a location in most States of the United States and determine hydrologic data for that site. StreamStats data is available at <http://water.usgs.gov/osw/streamstats/>.

A summary of many of the useful hydrologic methods can be found in "Highway Hydrology," FHWA HDS-2 (McCuen et al. 2002), the "Highway Drainage Guidelines" (AASHTO 2007a), or the California Department of Forestry publication "Designing Watercourse Crossings for Passage of 100-Year Flood Flows, Wood, and Sediment" (Cafferata et al. 2004).

For culverts in small watersheds and for ditch relief cross-drain culverts, use of the Rational Method may be most appropriate. The Rational Method relies on rainfall intensity data (as well as the watershed area and runoff characteristics of the terrain). It can be a very useful method to estimate current watershed discharge when the characteristics of the watershed have changed since the original design of a culvert, such as after a fire or for some development in the watershed. These watershed changes affect the value of the Runoff Coefficient. Rainfall intensity can be quite localized, but information on rainfall intensities is generally available in all areas of the United States. One of the best sources of Rainfall Intensity-Duration-Frequency data nationwide is from NOAA, the National Oceanic and Atmospheric Administration <http://hdsc.nws.noaa.gov/hdsc/pfds/>.

Compare different hydrologic methods since each method has advantages and limitations, such as period of record, consideration of climate change, and changes in watershed characteristics. Note that most hydrologic methods do not consider debris loading in a channel, so considerable judgment and local experience is needed to properly assess plugging potential from vegetation and sediment (fine sediment, boulders, and rocky debris).

Determine the design flow and check the existing pipe capacity, using methods, such as the U.S. Department of Transportation, FHWA pipe capacity nomographs found in "Hydraulic Design of Highway Culverts" (Normann et al. 2005). If pipe capacity is found to be inadequate, then assess the degree of risk of a failure.

The most obvious way to reduce the risk is to increase culvert capacity by increasing the size of the pipe or adding additional pipes in some circumstances. Where additional pipes are added, maintain the primary pipe at bed level for proper function (and aquatic organism passage), while additional pipes can be set higher at a flood-plain level to accommodate floodflows.

However, since adding pipes is expensive and typically requires excavation, alternatives exist that slightly increase the capacity of existing pipes. Increase culvert capacity somewhat by:

- ❑ Improving the pipe inlet efficiency with concrete headwalls, beveled inlets, or metal end-sections rather than a projecting pipe.
- ❑ Reducing the pipe friction by installing a smooth liner, such as epoxy or a plastic liner (that may be detrimental to aquatic organism passage).
- ❑ Removing any obstacles or damaged portion of the pipe inlet.
- ❑ Increasing the headwater elevation at the pipe entrance (Note that this does increase capacity, but is not recommended because it also promotes the pipe plugging with debris).

Headwalls and metal end sections (figure 70) added to pipes have the SDRR benefits of slightly increasing the capacity and improving resistance to plugging or overtopping failure. Figure 70 (top) shows a culvert with a concrete headwall that was overtopped but did not fail.

Figure 70—Culverts with a concrete headwall (a) and a metal end section (b) that offer improved resistance to plugging and damage from overtopping.

Increasing the headwater depth (the possible water height above the culvert before overtopping the road) at the upstream entrance to the pipe can increase pipe capacity. This could require raising a road fill. However, it should be understood that this treatment increases the potential damage should the culvert crossing fail (due to a higher fill) and also increases the likelihood of the pipe plugging from debris that can accumulate around the pipe inlet. Some increased capacity might be gained by the addition of a riser pipe, or snorkel (with trash rack), as seen in figure 71. The snorkel can increase culvert flow substantially in a long pipe, but its primary purpose is to allow some flow if the culvert inlet has a history of becoming plugged.

Figure 71—Culvert with a riser pipe and trash rack to prevent plugging in a channel that carries a lot of debris. Note that the roadway barely is seen in the background above the riser-pipe elevation.

Another treatment for organic debris at culvert crossings where the fill depth is sufficient is to add additional (usually smaller) culverts higher in the fill, adjacent to the existing pipe, or at other locations across a broad flood plain, as seen in figure 72. Use these where the site and the additional culverts are accessible during storm events. The smaller or additional culverts are at a greater risk of plugging than the larger main culvert and may need to be cleaned during a storm event. The additional culverts serve as an emergency overflow and may prevent a complete crossing failure by adding more capacity and providing extra time before reaching capacity during a flood.

Repair old and damaged pipes to extend their life by grouting the damaged areas. This involves placing a concrete or epoxy lining in worn out sections of the pipe, such as the bottom, that receives the most constant flow and abrasion from sediment. Also, installing a new slip lining of plastic or rubber inside an old pipe, as seen in figure 73, can preserve the life of the culvert, prevent a failure, and possibly increase the capacity of the pipe by using a liner with a relatively low Manning's (n) roughness coefficient. However, smooth liners may create additional problems for fish or other aquatic organism passage. Many new lining and installation options are available today within trenchless technology for culvert rehabilitation or replacement. For additional technical information about the trenchless technology, consult "Summary of Trenchless Technology for Use with USDA Forest Service Culverts" (Piehl 2005). Techniques for replacing or rehabilitating corrugated metal pipe culverts 18 inches (450 mm) or greater in diameter are emphasized because they commonly are used for culverts. Link to the document <http://www.fs.fed.us/eng/pubs/pdf/05771201.pdf>.

Figure 72—Increase culvert capacity using multiple pipes or stacking pipes on top of the original pipe. Typically, stacking pipes is only an emergency solution. Also note that multiple pipes increase the risk of plugging.

Figure 73—Culvert rehabilitation with a cement grout or a new rubber slipliner. (Bottom photo courtesy of Clackamas County, Oregon.)

For damaged culvert inlets repair, replace, or add an end section to the pipe to maintain its hydraulic capacity as well as to minimize plugging potential (figure 74). A relatively small reduction in inlet area causes a significant decrease in pipe capacity, as seen in figure 75.

Figure 74—Damaged culvert inlets that need repairing and cleaning. Damaged culvert inlets can greatly reduce the culvert flow capacity.

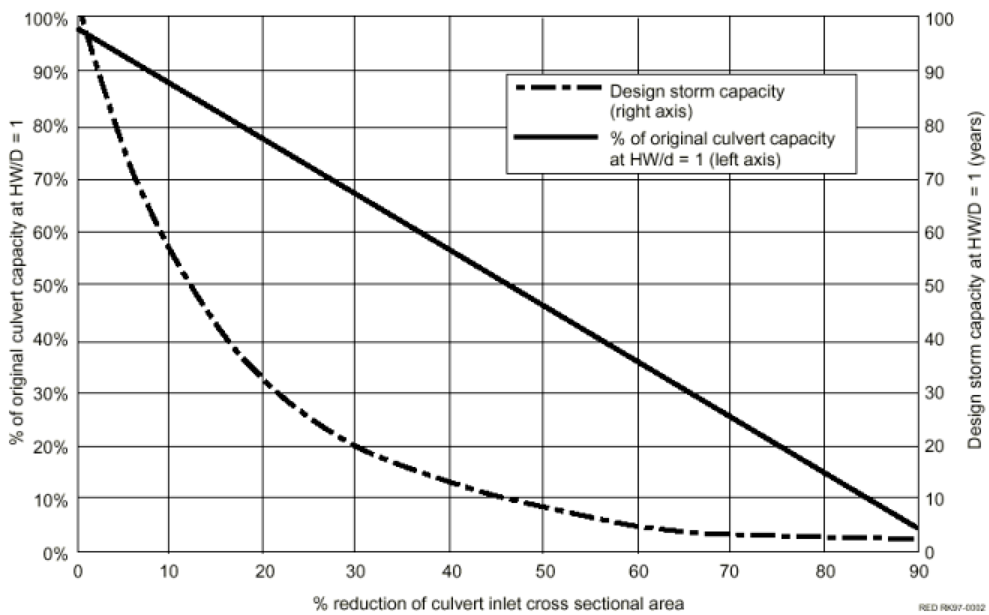


Figure 75—Culvert capacity versus reduction in inlet area (Flanagan and Furniss 1997).

Information regarding culverts, design, installation, problems and solutions, and so forth is found in the U.S. Department of Transportation, FHWA publication HDS No. 5, “Hydraulic Design of Highway Culverts” (Normann et al. 2001) (Revised May 2005). This comprehensive culvert design publication is available from FHWA at the following Web site <http://www.fhwa.dot.gov/engineering/hydraulics/culverthyd/index.cfm>.

Trash Racks

In forest environments, culverts fail far more often due to plugging with organic debris, sediment, and rock than due to lack of flow capacity. Trash racks can be effective in channels with significant amounts of organic debris to prevent pipe plugging. Place the trash racks upstream of a pipe or, in some cases, place immediately at the inlet of the culvert, as seen in figure 76. Large debris racks also are placed occasionally in channels upstream of bridges. If a trash rack is placed upstream of a pipe or bridge, ensure that there is access to the location for periodic cleaning of the trash rack.

Limit trash racks to stream crossings where culverts are undersized and/or prone to plugging. **They are one more item that requires maintenance.** Generally, a better solution or new construction is the installation of a larger pipe or an overflow pipe or dip in case of plugging. However, many types of trash racks have been used effectively to minimize the chance of culvert plugging on an existing culvert.

Before adding a trash rack to a crossing, carefully evaluate the site and assess the conditions that cause debris accumulation. These conditions can potentially cause more bank scour as water tries to flow around the structure and can cause channel diversion. Trash racks also may create a barrier to fish passage. Trash racks that are not maintained may become a severe liability. Certainly before any storm event, trash racks need to be clean. Figure 77 shows large trash racks placed in large channels to trap heavy sediment.

Figures 77 through 79 show a wide variety of materials and configurations of trash racks. The spacing of the bars on a trash rack should be about the same as the diameter of the culvert, or it can depend on the size of material moving in the channel. A riser pipe with trash rack is commonly placed on small pipes where there is a lot of debris or sediment in the drainage, such as after a wildfire. The slanted trash rack over the culvert inlet is more self-maintaining since organic debris will slide up the rack, keeping the entrance to the culvert free. However, the inlet capacity of the culvert is diminished due to the change in entrance hydraulics. Consider the altered inlet hydraulics in sizing the pipe. Figure 79 shows a trash rack both before and after a storm event. It shows the need for maintenance and cleaning of the structure after any storm (and before a storm hits).

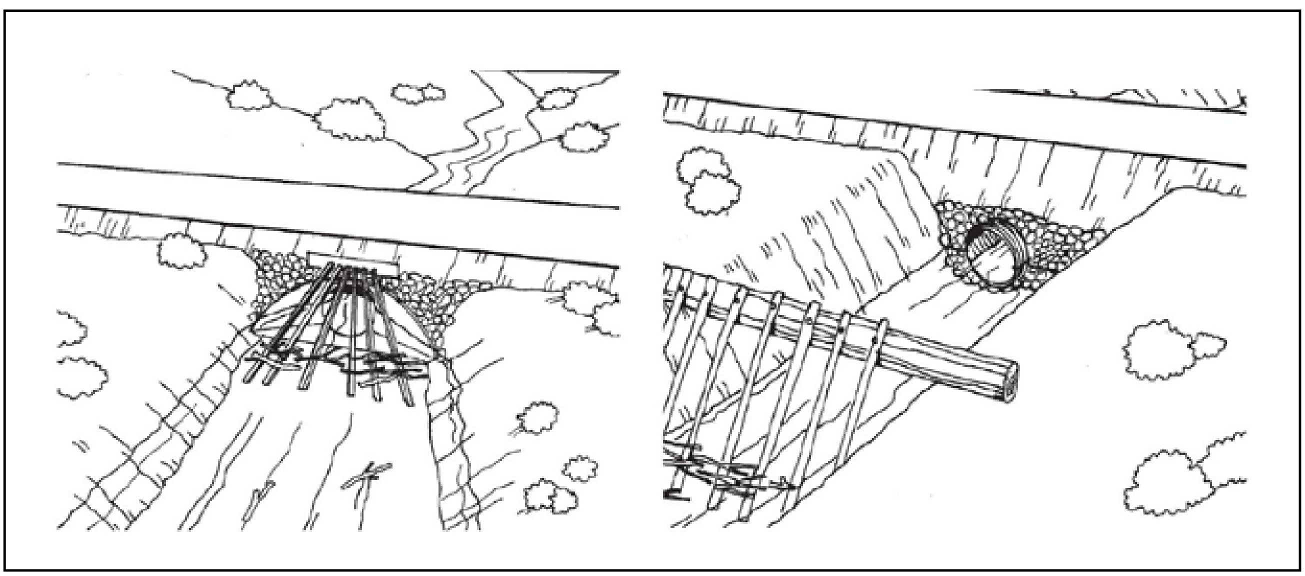


Figure 76—Options for trash racks used with culverts.

Figure 77—Use of trash racks to prevent plugging of a culvert or bridge from upstream large boulders and debris. (Bottom photo courtesy of Vincent Barandino.)

Another form of trash rack that has been effective for small-to-moderate streams is a single-post trash rack placed about one culvert diameter upstream of the pipe inlet. This post turns floating debris so that it will go through the pipe. If the debris is wider than the channel, then the post stops the debris and backs it up against the post and streambank before it reaches the pipe entrance. Flared inlet sections on pipes and their wing walls also serve to turn debris and funnel it through the pipe.

The order of desirability to prevent culvert failure is (1) a vented ford (discussed in Fords versus Culverts below), (2) an oversized pipe, and (3) an overflow dip. A trash rack may be the least desirable way to prevent long-term pipe plugging, but it also is a relatively simple and inexpensive solution on many existing pipes.

Evaluate each site to determine the most cost-effective and best solution to protect a pipe.

Figure 78—Examples of trash racks added to small culvert pipes to prevent plugging. Note that the riser with trash rack (a) is downstream of a fire area where considerable sediment is anticipated that often plugs small pipes. Debris can float over the culvert inlet at high flows (b). The single post (c) upstream of the pipe is used to help orient debris to go through the pipe rather than plugging across the inlet.

Figure 79—A trash rack upstream of a culvert, both before a storm ((a) looking downstream) and full of debris after a major storm event ((b), looking upstream). Note that trash racks must be cleaned and maintained!

Figure 80—Problematic culverts due to piping under the structure (a) or deterioration from a worn-out bottom (b). These culverts are at risk of failure, particularly during a major storm event.

Culvert Reinstallation and Realignment

Culverts may need to be replaced, reinstalled, or realigned because of poor alignment, which causes scour on an adjacent streambank; poor performance, such as piping under the old culvert; plugging; or deteriorating due to age. Figure 80 provides examples of a problematic, undermined culvert and an old, deteriorating culvert that has a high risk of failure during major storms.

Some regions are inappropriate for small culvert pipes because the culverts tend to plug with sediment and debris. This is particularly true in desert-to-semiarid regions where channels typically are dry but are subject to infrequent but periodic flashfloods or debris torrents. This is a condition observed in many areas of the Southwest, drier areas of the Rocky Mountains, and in parts of southern California. It also can be a problem in any steep, rocky mountainous terrain. Channels that transport large amounts of coarse sediments frequently plug culvert pipes, particularly if the pipes are small. In these areas, use either relatively large box culverts or small bridges. Alternatively, simple unvented fords may be most appropriate; they can pass a large amount of debris right over the top of the structure. Figure 81 shows examples of two culvert pipe installations that have plugged from coarse channel debris. Figure 82 shows the same problem with relatively large, multiple culvert pipe vents used in vented low-water crossings.

Figure 81—Culverts that have plugged due to their location in sediment and debris laden channels in a semiarid region.

Figure 82—Culverts in vented low-water crossings that have totally or partially plugged with coarse channel debris.

Other important culvert reinstallation and alignment considerations and factors are shown in figures 83 and 84. These important installation details for culverts include:

- ❑ Minimizing channel modifications.
- ❑ Avoiding constriction of the bankfull flow channel width.
- ❑ Maintaining the natural channel grade and alignment.
- ❑ Using quality, well compacted bedding and backfill material.
- ❑ Using inlet, outlet, and streambank protection measures.

Align culverts as close to the specific reach of the channel where it is being placed as possible. Avoid location on channel bends, but if necessary, the culvert needs to fit into the bend as much as possible, keeping in mind plugging and scour possibilities at the inlet and bank scour at the outlet. Set the pipe right at the elevation of the natural stream channel bottom, as seen in figure 83. Consider the average channel thalweg elevation through that reach of the stream. A culvert set too low can fill with sediment, lose capacity, and possibly cause headward (upstream) channel erosion. A culvert set too high can create a waterfall at the outlet, causing downstream channel scour and a possible fish and aquatic organism passage barrier. Culverts installed as described here also may constitute a fish barrier simply by increasing the water velocity through the pipe. Culverts specifically designed for fish passage may include oversizing the pipe and burying the bottom in stream substrate to simulate natural channel characteristics. See the next section, Aquatic Organism Passage Considerations, for additional culvert installation considerations.

Bedding and backfill material for culverts commonly is specified as select granular material or select mineral soil. Most soils are satisfactory if they are free of excess moisture, muck, lumps of frozen soil or highly plastic clay, roots, or rock larger than 3 inches (75 mm). Bedding material beneath the pipe should not have rocks larger than 1½ inches (38 mm). Clay soil can be used if it is carefully compacted at a uniform, near-optimum moisture content. Ideal backfill material is a moist, well-graded granular or sandy gravel soil with up to 10 percent fines and rock free. The material should be well compacted, to at least the density of the adjacent ground, and preferably to at least 90 to 95 percent of the American Association of State Highway Transportation Officials T-99 maximum density, and placed in 6- to 8-inch- (150-200

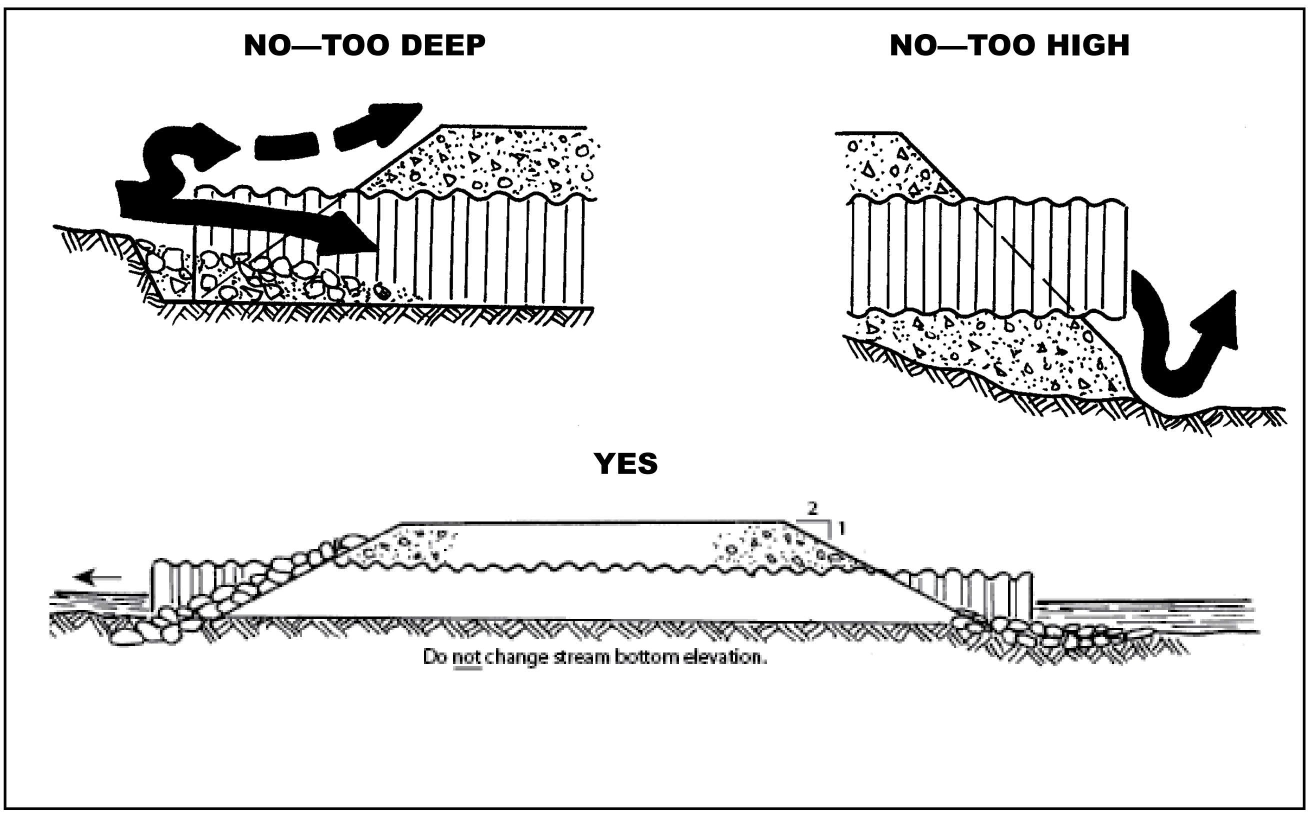


Figure 83—Installation of a culvert right at the natural channel elevation.

mm) thick layers (lifts), brought up uniformly on both sides of the pipe in lifts, as seen in figure 84. A dense, uniform backfill is important to structurally support the lateral pressure from the pipe. Compaction is particularly important in the haunch area of the pipe and for aluminum and plastic pipe that easily deform.

Installation details should follow the manufacturers' information and recommendations, and manufacturers' literature is available for all types of pipes, including plastic pipe, concrete pipe, and metal pipe. Concrete and metal pipes (usually corregated metal pipe) have been the most traditionally used products. They have performed well if they were properly designed and installed. Today, plastic pipe is used frequently, particularly because of its lower cost, ease of installation, and its suitability in corrosive environments. However, plastic pipe can burn, particularly in a forest environment, so consider the potential for fire when contemplating its use; add concrete or masonry headwalls to reduce this risk. Manufacturers of each type of culvert material have their own handbooks or manuals for design and installation information. For use of corrugated metal pipe, the "Handbook of Steel Drainage and Highway Construction Products" (Corrugated Steel Pipe Institute 2007) is an excellent reference. It is available at <http://www.cspi.ca/node/158>.

Uniform fine sand and silt soils can be problematic when used for culvert bedding or backfill material. These fine, noncohesive soils are very susceptible to scour and piping from moving water (figure 80a). Thus, their use is discouraged. If used, they should be very well compacted against the pipe. Ideally, place antiseepage collars, made of metal, concrete, geotextile, or a zone of compacted clay around the culvert pipe to force any water channel to flow in a longer path through the soil and prevent a piping failure. Concrete headwalls also deter piping.

Aquatic Organism Passage Considerations

Most stream crossing structures built or replaced today need to ensure adequate aquatic organism passage. A goal is often to replace or retrofit a culvert to improve aquatic organism passage, as seen in figures 85 and 86. Implementation of SDRR measures only need to avoid work that would degrade fish passage, and hopefully work would improve fish and other aquatic organism passage.

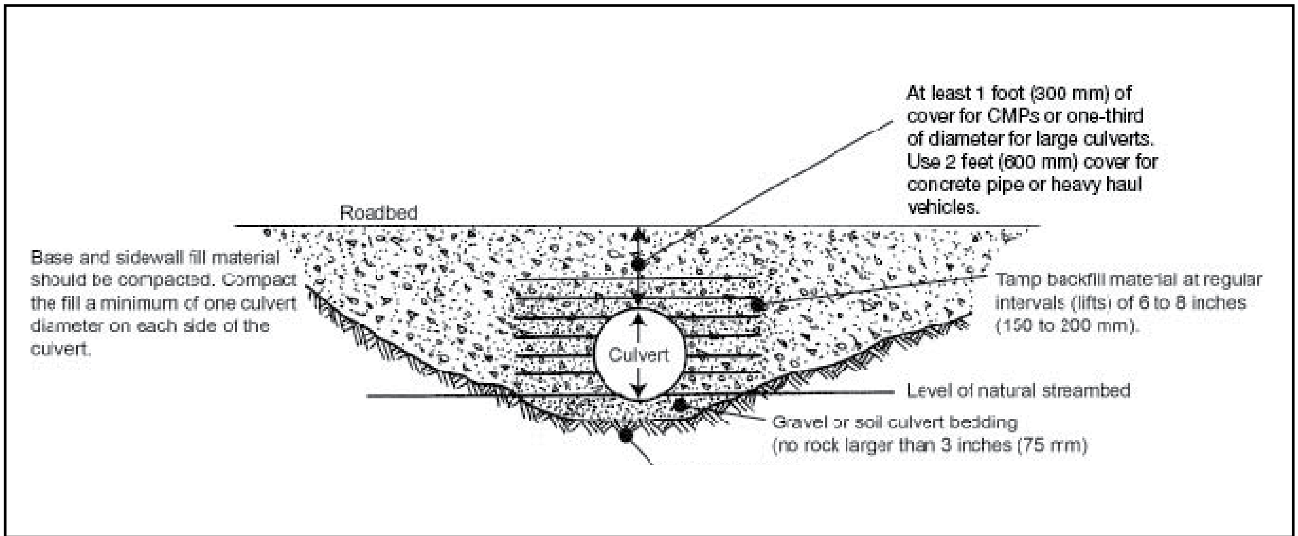


Figure 84—Ideal bedding and backfill compaction around a culvert pipe. (Adapted from Montana Department of State Lands 1992.)

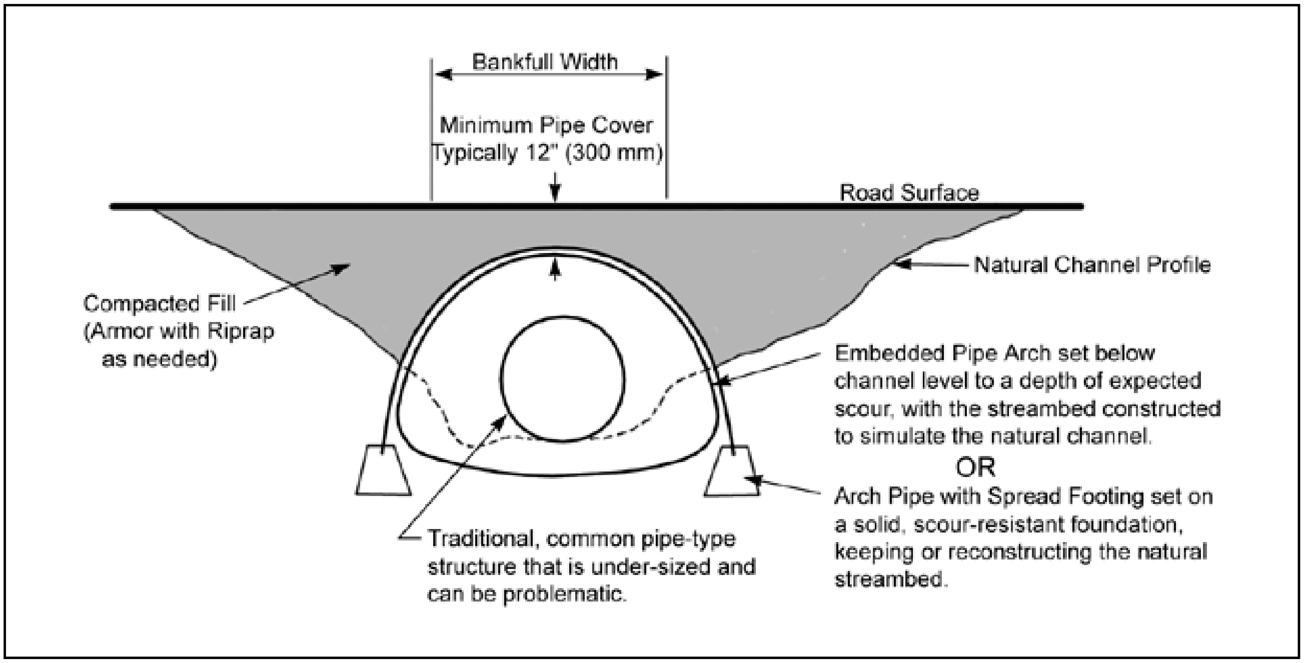


Figure 85—An improved or stream simulation culvert installation compared to many traditional culvert installations.

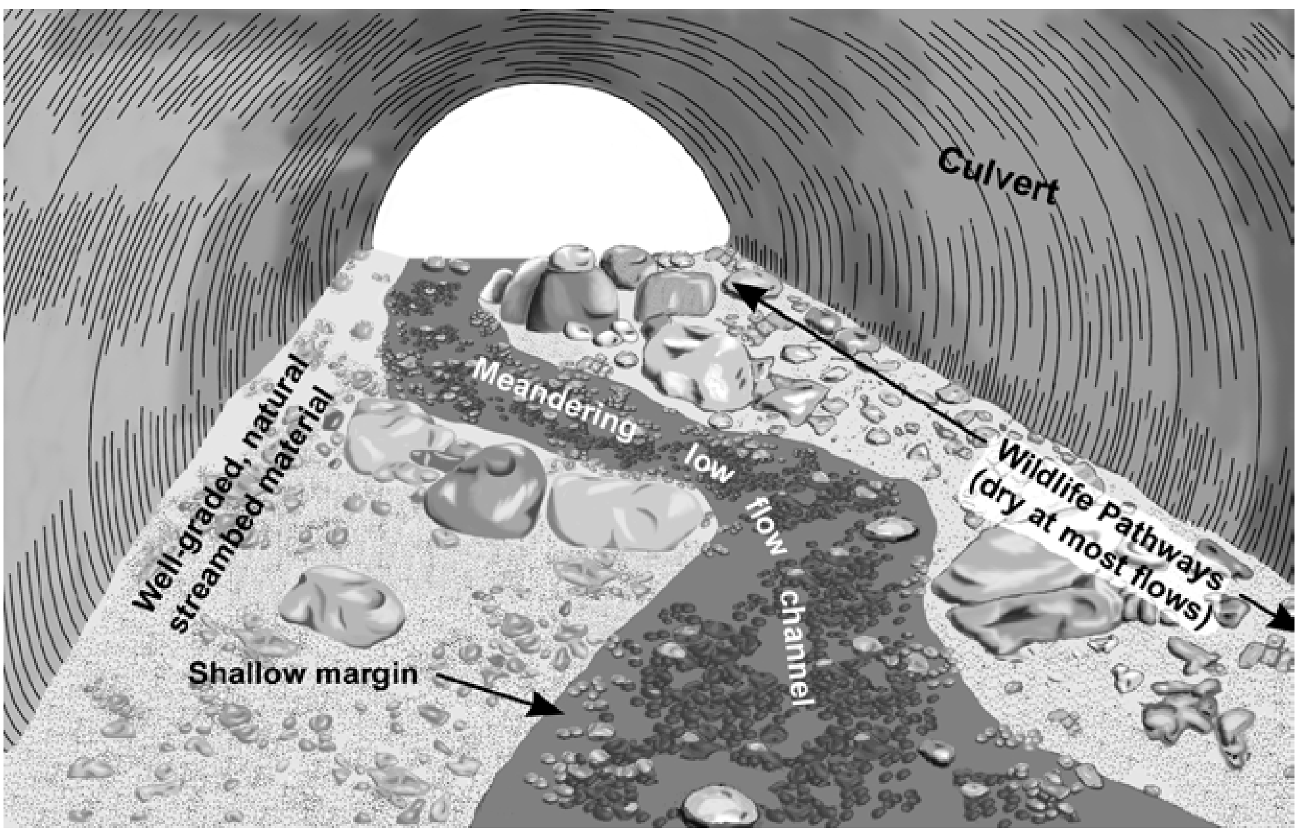


Figure 86—A stream simulation design through a culvert.

Properly designed stream simulation projects for aquatic organism passage should function well during major storms, particularly where the structure width is equal to or greater than the channel bankfull width. Several stream simulation culvert projects with flows exceeding the Q_{100} design flood were evaluated on the Green Mountain National Forest, Vermont, in September 2011, after the storm impacts from Hurricane Irene. Each structure survived well with minimal problems and performed flawlessly, maintaining aquatic organism passage at each site (Gillespie et al. 2014). Only some movement of the bed material was observed (Gubernick 2012a and b). Many other conventional culverts and bridges in the region were damaged or destroyed.

For a comprehensive discussion on aquatic organism passage, consult the U.S. Department of Agriculture, Forest Service publication “Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” (Forest Service Stream Simulation Working Group 2008). The document is available at <http://fsweb.sdtdc.wo.fs.fed.us/pubs/pdf/StreamSimulation/index.shtml>. Forest Service policy is to use stream simulation for aquatic organism passage.

The U.S. Department of Transportation, FHWA, also has produced a comprehensive summary of fish passage options in its publication titled “Culvert Design for Aquatic Organism Passage,” Hydraulic Engineering Circular (HEC) 26 (Kilgore et al. 2010). Available at <http://www.fhwa.dot.gov/engineering/hydraulics/pubs/11008/index.cfm>. This circular is not based on stream simulation.

Pipe Inlet/Outlet Protection

There are several ways to minimize the likelihood of a culvert failure. A culvert should be properly sized consistent with the design flow and width of the natural stream channel, aligned with the upstream channel, and have an efficient inlet for the least chance of being plugged with debris. You also might manage risk with appropriate flood and debris capacity and culvert height, a critical dip and spillway to prevent stream diversion and for minimizing overtopping damage, and/or increased flood capacity through additional structures in a floodway. Flow velocity typically accelerates in an undersized or narrow culvert pipe, so the pipe outlet area commonly is subject to scour and may need armoring or scour protection (figure 87).

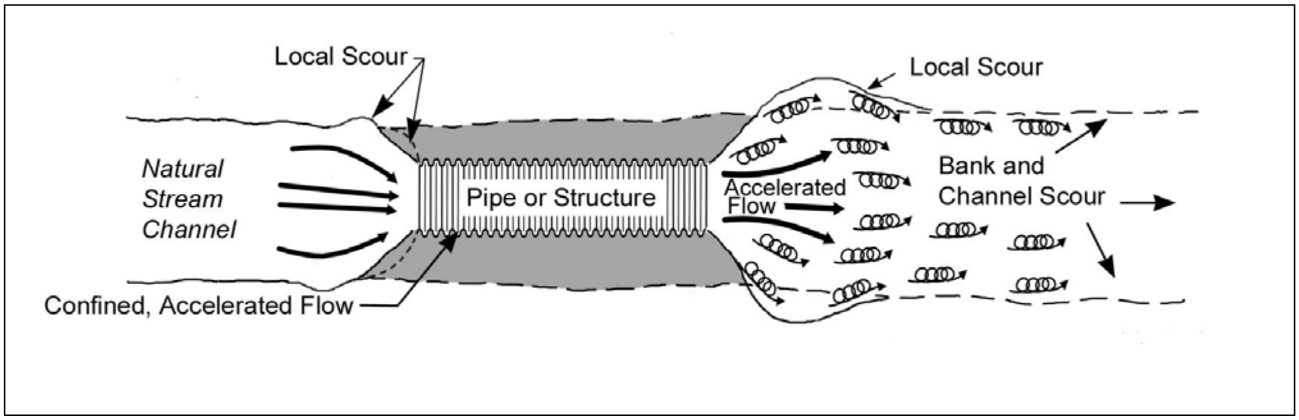


Figure 87—Common scour problems with a culvert due to confining the flow at the inlet and accelerated flows, producing scour at the pipe inlet and outlet. A properly sized crossing structure would span the full natural bankfull stream channel.

Many old pipes are undersized and installed in fills that partially block or constrict the natural stream channel. For culvert pipe and fill protection, armoring the fill with materials, such as riprap, or using concrete headwalls is common (figure 88). For 2:1 or flatter fillslopes, riprap armoring may only extend slightly above the top of the culvert. For steeper fillslopes, armor the entire fillslope. Extent of armoring also depends on the design capacity of the pipe and expected headwater elevation. Use biotechnical measures in place of rock riprap. An advantage of a concrete or masonry headwall is that it can reduce the needed length of culvert pipe exiting the fill. Thus, weigh the cost of concrete and labor to build the headwall against the cost of additional pipe.

Design downstream cutoff walls, roughened energy dissipation slabs, splash aprons, or stable energy dissipation pools (plunge pools) at the pipe outlet to reduce erosion and scour, as seen in figure 89. These measures reduce the likelihood of scouring and undermining a pipe at its outlet, but evaluate these measures carefully as they can create problems for fish passage.

The size of a splash apron or riprap basin depends on the diameter of the culvert and the flow exit velocity and volume. For small drainage culverts and culvert cross drains, place a few cubic yards (cubic meters) of riprap at the pipe outlet. Some recommended outlet protection details are shown in appendix A3.

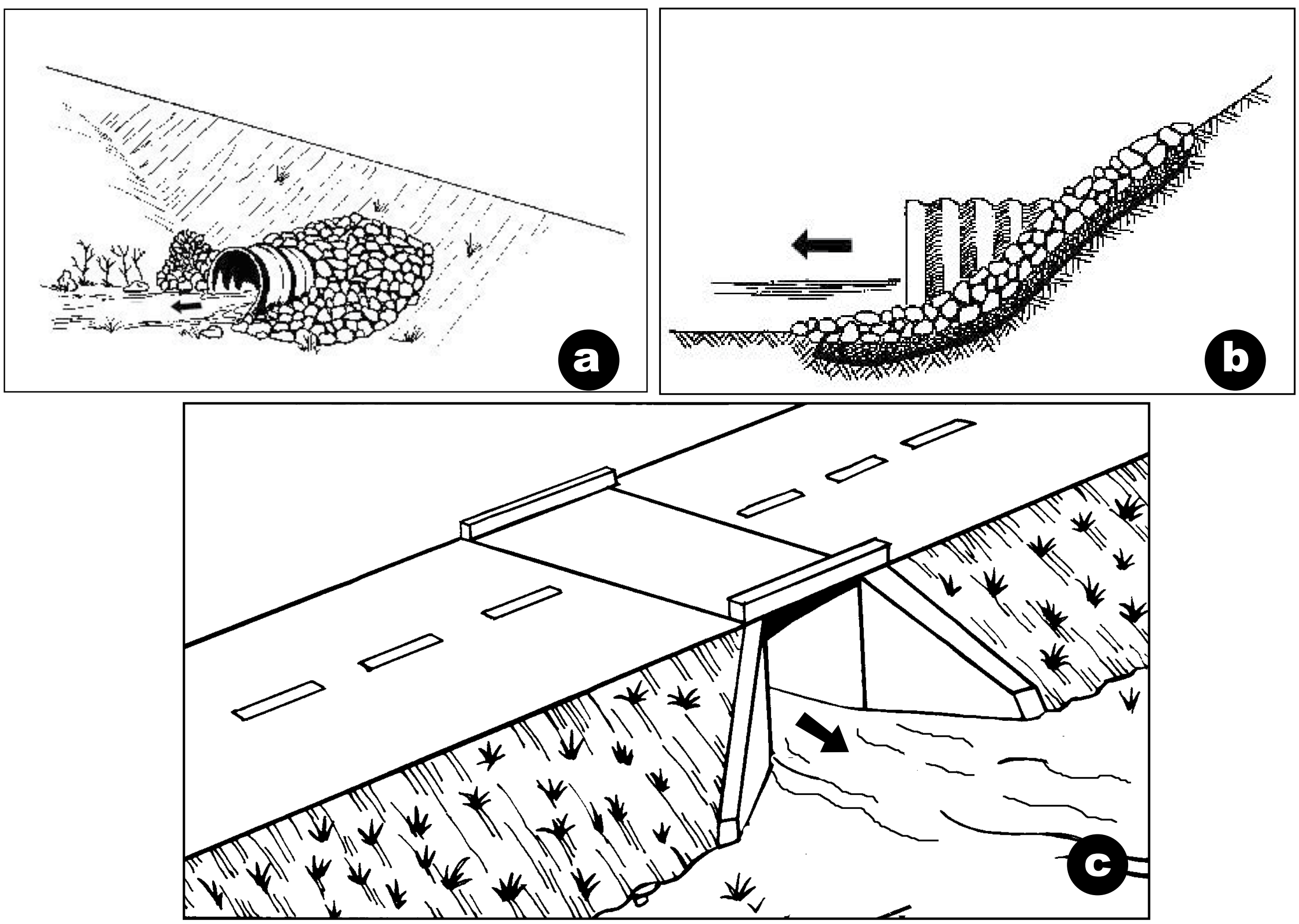


Figure 88—Armoring and protection of a culvert pipe fill using riprap (a) (b) or concrete headwalls and wingwalls (c).

For major culverts, the apron length typically is 4 to 8 times the pipe diameter. Riprap size and thickness are functions of pipe size and discharge. Specific design equations are found in HEC14 and other FHWA references. Useful information specific to the design of structures to protect against outlet scour is found in the U.S. Department of Transportation, FHWA publication "Hydraulic Design of Energy Dissipators for Culverts and Channels," HEC 14 (Thompson and Kilgore 2006). It is available at <http://www.fhwa.dot.gov/bridge/hec14SI.pdf>

Fords or Low-Water Crossings versus Culverts

Low-water crossings, or fords, can provide a desirable alternative to culverts and bridges for stream crossing repairs or replacement on low-volume roads where road use, streamflow conditions, and topographic setting are

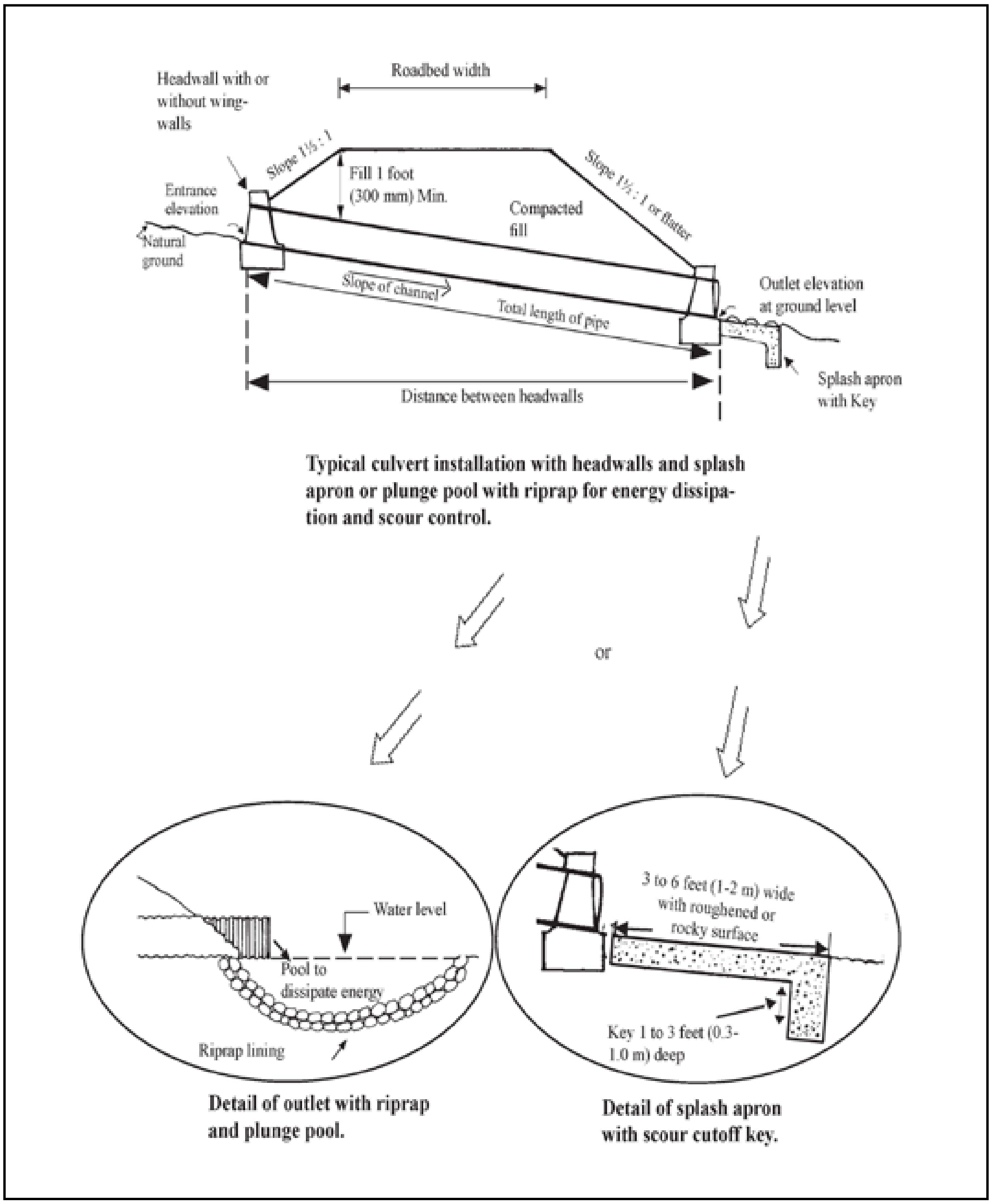


Figure 89—Outlet protection options to prevent scour at the pipe outlet.

appropriate. Like other hydraulic structures for stream crossings, their construction or repair requires specific site considerations and geomorphic, soil, hydrologic, hydraulic, and biotic analyses. Conversion or selection of a ford is useful, particularly if a culvert pipe has had a history of plugging from channel debris. Construct fords, and particularly vented low-water crossings, to pass large flows and large amounts of debris, and provide suitable aquatic organism passage (figure 90). In this example, a large waterway open area is provided, and the natural substrate material is maintained through the structure.

Figure 90—A large vented low-water crossing with predominantly natural stream channel bottom material that is ideal for fish passage.

For good foundation conditions, locate low-water crossings at a relatively narrow, shallow stream location in an area of bedrock or coarse soil. An armored ford can be narrow or broad, but do not use it in deeply incised drainages that require a high fill or excessively steep road approaches. These settings require either a culvert or an armored fill. An improved ford with a hardened driving surface is a desirable structure on some very low traffic roads to minimize turbidity and potential pollution problems. However, some State agencies discourage fords because of negative impacts to the stream and fish when driving through the water and for traffic safety concerns. A vented low-water crossing can resolve this problem.

Design a ford to not create a low-flow depth barrier to fish passage. This can happen if a ford is wider than the natural channel. Ensure that neither scour nor perching develops along the downstream edge of the ford, which may turn into a fish passage barrier.

Fords and low-water crossings may have a simple, rock reinforced (armored) driving surface, as shown in figure 91, or an improved, hardened surface, such as gabions or a concrete slab (figure 90). Vented low-water crossings combine culvert pipes, box culverts, or open bottoms (figure 90) to pass low flows and a reinforced driving surface over the culverts to support traffic and keep traffic out of the water most of the time. The reinforced driving surface over the pipes also resists erosion during overtopping at high waterflows. Protect the entire wetted perimeter of the structure to a level above the anticipated design high-water elevation. Because basic designs require tailoring to individual site requirements and locally available materials, many variations of each of the basic types of low-water crossing structures have developed over time.

Figure 91—A simple rock-armored ford in an ephemeral channel. Coarse rock is placed across the channel bottom and a fine aggregate is placed on the road surface for driver comfort.

Key factors to consider for the location, design, or repair of a low-water crossing include:

- ❑ Low- and high-water levels.
- ❑ Foundation conditions.
- ❑ Scour potential.
- ❑ Allowable traffic delays.
- ❑ Approach grades of the road.
- ❑ Channel cross-section shape and confinement.
- ❑ Protection of the downstream edge of the structure against local scour.
- ❑ Stream channel and bank stability.
- ❑ Material transported in the stream, particularly from debris slides or debris torrents.
- ❑ Locally available construction materials.
- ❑ Ability to dewater the site or work during the dry season.
- ❑ Hydraulics for fish passage.

For fish or aquatic species passage, maintain a natural or rough stream channel bottom through the ford, and do not accelerate water velocities, similar to requirements through a culvert. Ideal structures are vented fords with box culverts and a natural stream bottom or simple on-grade fords with a reinforced, rough driving surface. Some fords can be designed as low-water bridge structures. They must be designed to be overtopped periodically and have an erosion-resistant deck and approaches. This structure is ideal for fish passage.

Vented fords have a driving surface elevated some distance above the streambed with culverts (vents) that enable low flows to pass beneath the roadbed (figure 93). The vents can be one or more pipes, box culverts, or open-bottom arches. In streams carrying large amounts of debris, the driving surface over the vent may be removable, such as a cattle guard, permitting debris to be cleared after a large flow event. Figure 92 shows a large pipe that had plugged several times in large storm events. Eventually the pipe was replaced with a concrete-vented ford designed with a metal cattle guard top that can be removed for cleaning. Note that a fish barrier exists at the downstream edge of the concrete ford, and the entire downstream wetted perimeter of the structure needs to be armored.

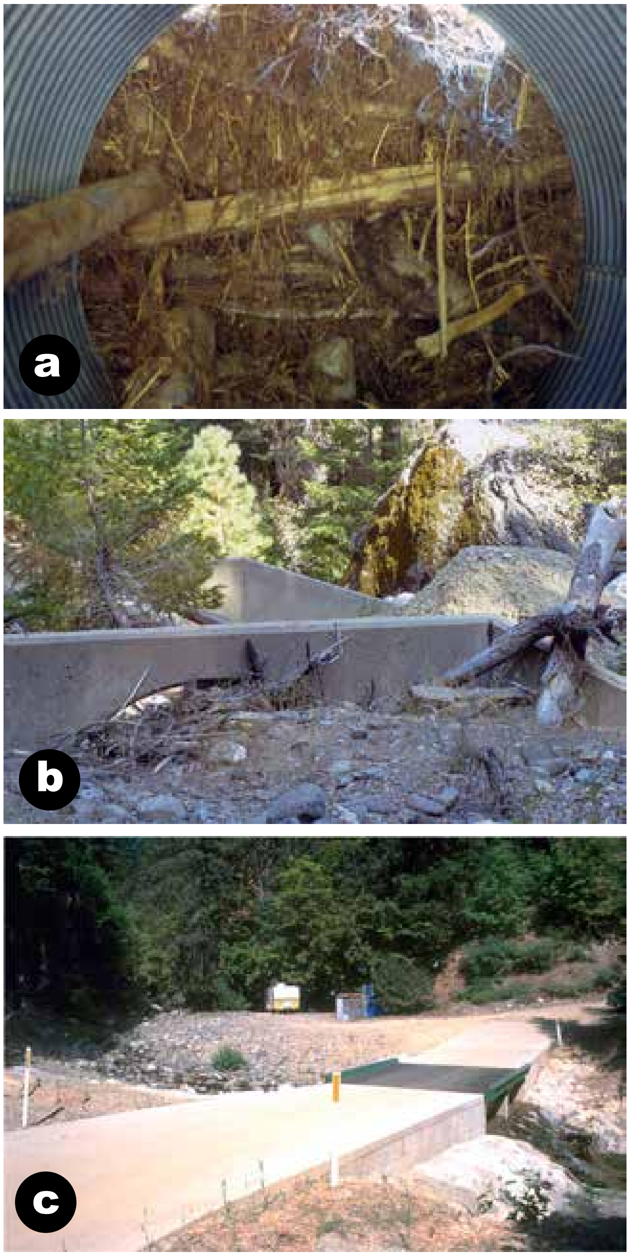


Figure 92—A large, 10-foot-diameter culvert that had plugged several times with debris (a)(b) and was replaced eventually with a vented low-water crossing (c).

Vented fords fall into two categories—low vent-area ratio (VAR) and high VAR—each affects stream channels differently. Vented fords with culverts that are small relative to the bankfull channel area have a low VAR. The Forest Service and other agencies have built many low-VAR fords. A vent opening that approximates or exceeds the size of the bankfull channel has a high VAR, as seen in figure 93. Low-VAR structures plug with debris easily; act as a dam and cause deposition of sediment upstream of the structure; and may accelerate flows downstream, creating a barrier to fish passage through the pipes, as well as channel scour. A high-VAR structure is much better for aquatic organism passage and to maintain the natural function of the stream.

Figure 94 summarizes many of the key design issues necessary to make a ford or low-water crossing function properly and avoid damage.

Many existing fords found throughout the United States and used by the Forest Service have been damaged at some time during a flood and have required repairs or have been replaced. To avoid damage to the structures as well as to the environment, consider the following key design issues:

- ❑ Provide an armored surface through the high-water wetted perimeter of the entire structure, plus some freeboard.
- ❑ Keep the driving surface as low and as close to the natural stream channel elevation as possible.
- ❑ Provide scour protection below the downstream edge of the structure.
- ❑ Maintain a natural stream channel bottom through vented fords.
- ❑ Stabilize and properly drain the road surface on both approaches to the crossing using aggregate, concrete, or paving.

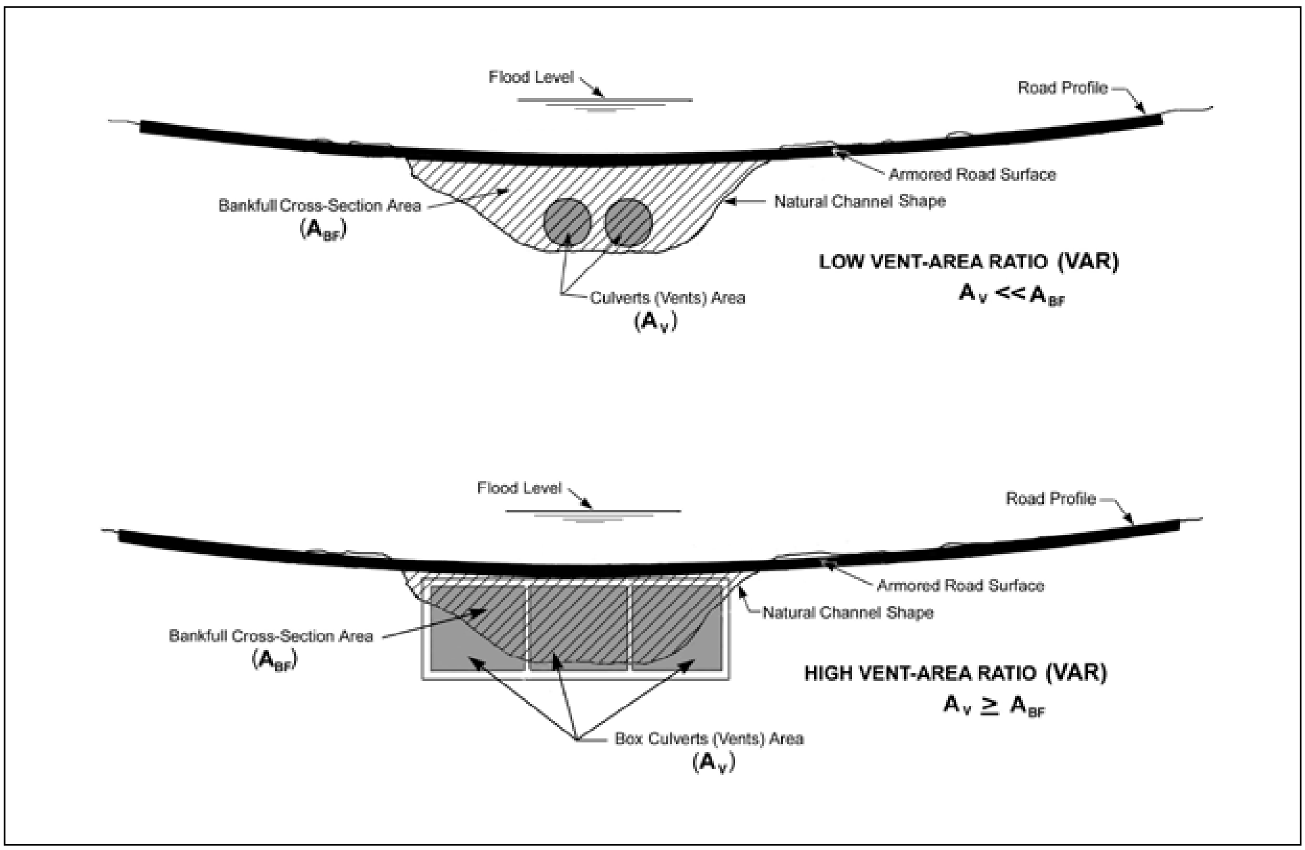


Figure 93—Examples of fords with a low and a high vent-area ratio.

- ❑ Use appropriate vertical and horizontal alignment through the crossing to accommodate the anticipated traffic safety and use.
- ❑ Use delineators, signs, and depth markers as needed to make the crossing safe.

For additional technical information about fords and low-water crossings, consult "Low-Water Crossings: Geomorphic, Biological and Engineering Design Considerations" (Clarkin el al. 2006). The publication reviews both the advantages and disadvantages of a variety of low-water crossing structures in various

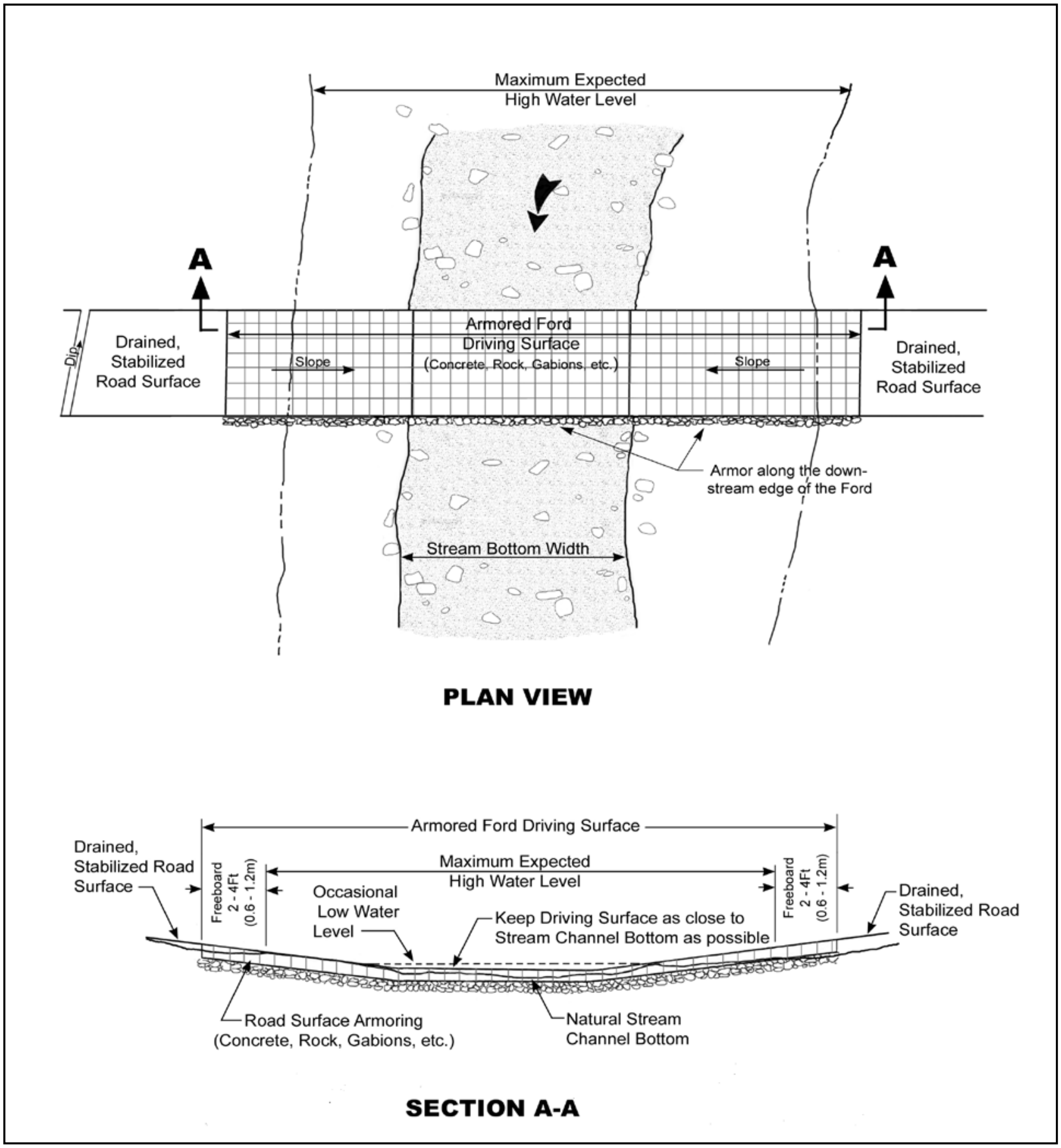


Figure 94—Key design components for an unvented, improved low-water ford.

stream environments and illustrates situations in which low-water crossings may be the optimal choice of crossing structure. Link to the Web site <http://www.fs.fed.us/eng/pubs/pdf/LowWaterCrossings/index.shtml>.

Local Structure, Streambank, and Channel-Stabilization Measures

If local or average velocities exceed the permissible velocities of the materials for movement (shear stresses), erosion and scour will result. These problems often occur where a structure has confined or redirected the flow of the channel, where flows have increased in the channel, or where natural protection, such as vegetation, has been removed from the channel or around a structure. Therefore, either take measures to reduce the velocities, redirect the flow, dissipate the energy of the flow, provide stability below the likely depth of scour, or armor the areas with materials that can resist the flow's forces. Reducing stream velocity is generally more desirable and cost-effective than streambank armor.

A variety of streambank-stabilization treatments are available to minimize the susceptibility of structures or streambanks to disturbance-caused erosion processes. They may be engineered grade-stabilization structures or vegetation-oriented remedies ranging from conventional plantings to a combination of biological and engineering elements, such as soil bioengineering. Measures include the use of rock riprap, gabions, concrete slabs, cable concrete, vegetation, and various biotechnical treatments. Use lighter treatments, such as turf-reinforcing mats, in small channel banks in some circumstances to help promote the growth of vegetation.

Historically, many organizations involved in water resource management have given preference to engineered structures; they are viable options. However, in a growing effort to restore sustainability and ensure ecological diversity, give preference to those methods that restore the ecological functions and values of stream systems as well as protect the structure. The value of vegetation in civil engineering and the role woody vegetation plays in the stabilization of streambanks has gained considerable recognition in recent years.

Once a stream-crossing structure is placed in a channel, it may change the dynamics of the site or the structure itself may need protection. The structure may need armoring, the stream channel may need protection, streambanks may need stabilization, or it may be desirable to control the flow in the channel with some river training measures to protect the structure and/or the banks. "River engineering" is an evolving field, and measures should not be undertaken without proper consultation with qualified engineers, hydrologists, and geomorphologists. Improper design and implementation of river engineering techniques can create additional localized and systemic problems.

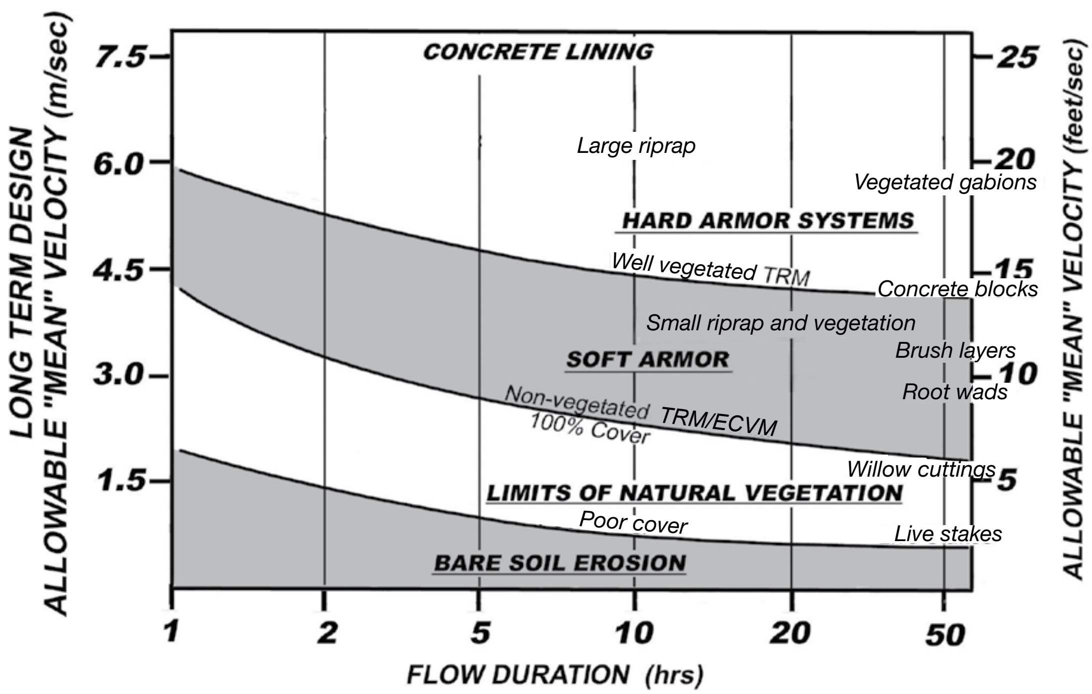
Different structures have different scour risks that commonly need protection. Some structures accelerate flows through pipes or vents, some confine channel flow, some accelerate flow across the driving surface, and some create water drop off the downstream edge. Many structures create more than one of these effects. Depending on the velocity of flow and erosion potential, scour protection and/or bank stabilization may be needed. The following options are available:

- ❑ Vegetation, erosion control mats, or small riprap for low velocities.
- ❑ Soft armor systems, such as biotechnical treatments, vegetated turf-reinforcing mats, rootwads, logs, and boulders for moderate velocities.
- ❑ Hard armor systems, such as articulated concrete blocks, gabions, large riprap, grouted riprap, or concrete for high channel velocities or high shear stress areas where flows are turbulent or impinging upon the streambank.

Figure 95 provides general guidelines for selecting channel and bank stabilization measures as a function of mean channel velocity and the duration of flow (i.e., how long the area is subject to inundation). Note that often a transition zone is needed between a hard armor zone and the native streambed material. Ideally, this work is tied into a stable channel feature, such as bedrock or large boulders. “Environmentally Sensitive Channel and Bank Protection Measures” (McCullah and Gray 2005) presents an excellent summary of the many river training, channel modification, and bank stabilization/ armoring options available today in this National Cooperative Highway Research Program Report 544. Link to the document <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_544.pdf>.

Local Scour Protection

Scour protection is needed in many areas for stream-crossing structures (culverts, bridges, and fords). Scour is one of the principal causes of failure or damage to structures during major storms. Thus, scour protection around structures is a key mitigation to reduce the risk from storm damage. Many scour protection measures are similar to streambank stabilization measures. Figure 96 shows some of the areas where local scour affects stream



NOTES:

1. Hard armor—includes concrete, riprap, gabions, concrete blocks, etc.
2. Soft armor—includes turf reinforcement mats (TRM), erosion control vegetation mats (ECVM), vegetated geocells, and many biotechnical treatments.
3. Available data shows considerable variability in the allowable velocity limits.

Figure 95—Allowable velocities and flow duration for various erosion and bank protection measures. (Adapted from Fischenich 2001 with information from Theisen 1992 and McCullah and Gray 2005.)

channels and structures the most, including the following:

- ❑ Vertical streambanks, particularly on the outside bend of a channel where flow velocities are the fastest.
- ❑ Areas where there is a sharp bend in the channel, leading to scour on the outside edge of that bend.
- ❑ Over waterfalls and around midchannel structures where flow is accelerated and may be turbulent.
- ❑ Where flow is constricted, thereby accelerating stream channel velocity, such as through narrow bridges, box culverts, or in culvert pipes.

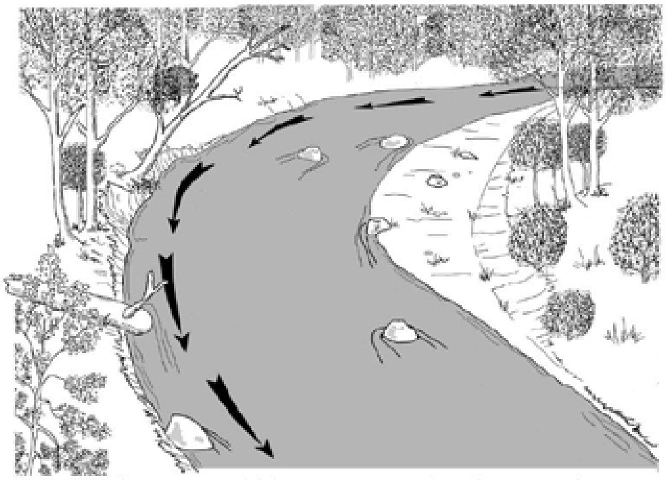
Section 6.3 discusses some of the scour protection measures, such as riprap, logs, and soil bioengineering treatments. The following sections present additional scour information.

Use of Rock Riprap

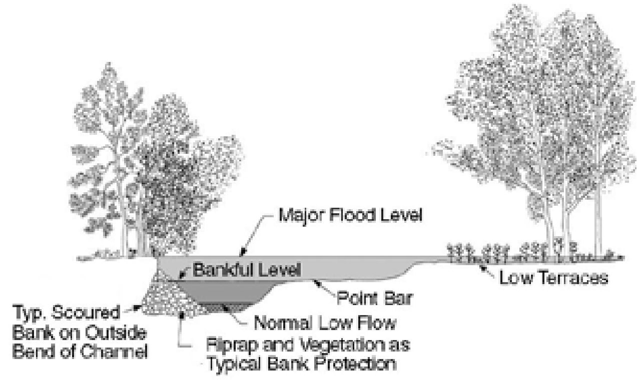
Rock riprap is one of the most commonly used, and misused, erosion and scour protection measures because of its resistance to high stream velocities when properly installed, availability, relatively low cost, durability, adaptability to many sites, revegetation opportunities, and self-healing aspects of loose rock. As an SDRR treatment, riprap is useful for structure and erosion protection, such as around the inlet and outlet of culverts, for culvert or ford fill armoring, around bridge abutments to protect against scour, at the outlet of cross-drain culverts, leadoff ditches, and rolling dips, or to protect and maintain the shape of a rolling dip. However, avoid armoring lengths of streambanks if possible. Road relocation should be thoroughly investigated in cases of road encroachment next to a stream, especially fish-bearing streams (section 6.4). Also rootwads, boulders, vegetation, and other materials can be used as alternatives to rock riprap. Because riprap is a loose-rock structure, it can move to some degree, deform, and conform to scour areas and still offer erosion or scour protection. It can armor an entire channel cross section (above water and underwater), armor streambanks to the expected high-water level, and armor a plunge pool or stilling basin. Place riprap at the outlet of pipes, along the downstream edge of a structure, in a scour hole, or around and along channel protrusions, such as bridge piers.

The two most common reasons for riprap failure are improper sizing and poor installation. Many agencies have developed riprap-sizing criteria. The most rigorous criteria are based upon shear stresses or tractive forces exerted by flowing water and sediment moving along the rock surface. The U.S. Department of Transportation, FHWA publication HEC-11, "Design of Riprap Revetments" (Brown and Clyde 1989) provides a comprehensive design process for riprap sizing, using permissible tractive forces and velocity, along with design examples. HEC 23, "Bridge Scour and Stream Instability Countermeasures" (Lagasse et al. 2009) also discusses riprap design. Both publications are available at <http://www.fhwa.dot.gov/engineering/hydraulics/>.

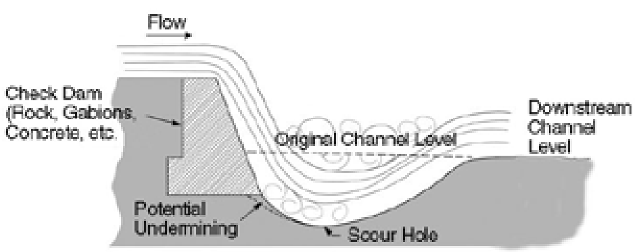
Criteria based upon permissible velocity often are used because velocity information may be available from Manning's Equation, direct measurements, or other sources. Install rock large enough that the forces of flowing water do not displace it. Figure 97 shows relatively simple riprap-sizing criteria based upon average channel velocity determined using Manning's Equation. Depending on the slope of the bank, the riprap diameter (median size) is chosen based on the average streamflow velocity (V_{ave}). Use smaller rock on areas of straight, parallel flow to the bank (V_p), while larger riprap is needed in curves where the flow is impinging (V_i) upon the rock. The impinging velocity (Vi) is estimated at 4/3, or 133 percent of the average channel velocity (V_{ave}). Use well-graded riprap and ensure that half of the stones are at least as large as the median size.



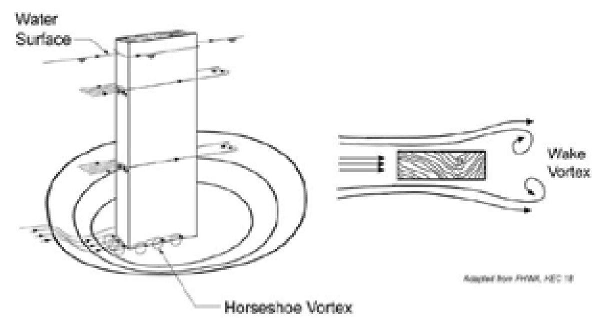
ACTIVE BANK SCOUR WITH VERTICAL CUT BANKS, SLUMP BLOCKS, AND FALLING VEGETATION



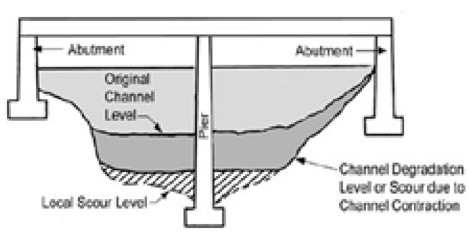
CROSS-SECTION OF ACTIVE STREAMBANK SCOUR



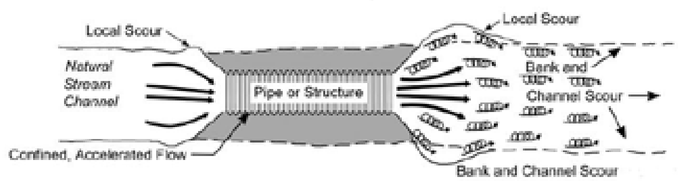
EFFECTS OF WATER SCOUR AT TOE OF A CHECK DAM OR WATERFALL



STREAM CURRENT AND SCOUR AROUND A MID-CHANNEL PIER



SCOUR THROUGH A STRUCTURE CAUSED BY NATURAL CHANNEL DEGRADATION, CONTRACTION, OR LOCAL SCOUR AROUND PIERS



FLOW CONTRACTION THROUGH A STRUCTURE NARROWER THAN THE NATURAL CHANNEL WITH ACCELERATED FLOW AND RESULTING SCOUR AT BOTH THE INLET AND OUTLET

Figure 96—Common scour problem areas found along stream channels and around structures.

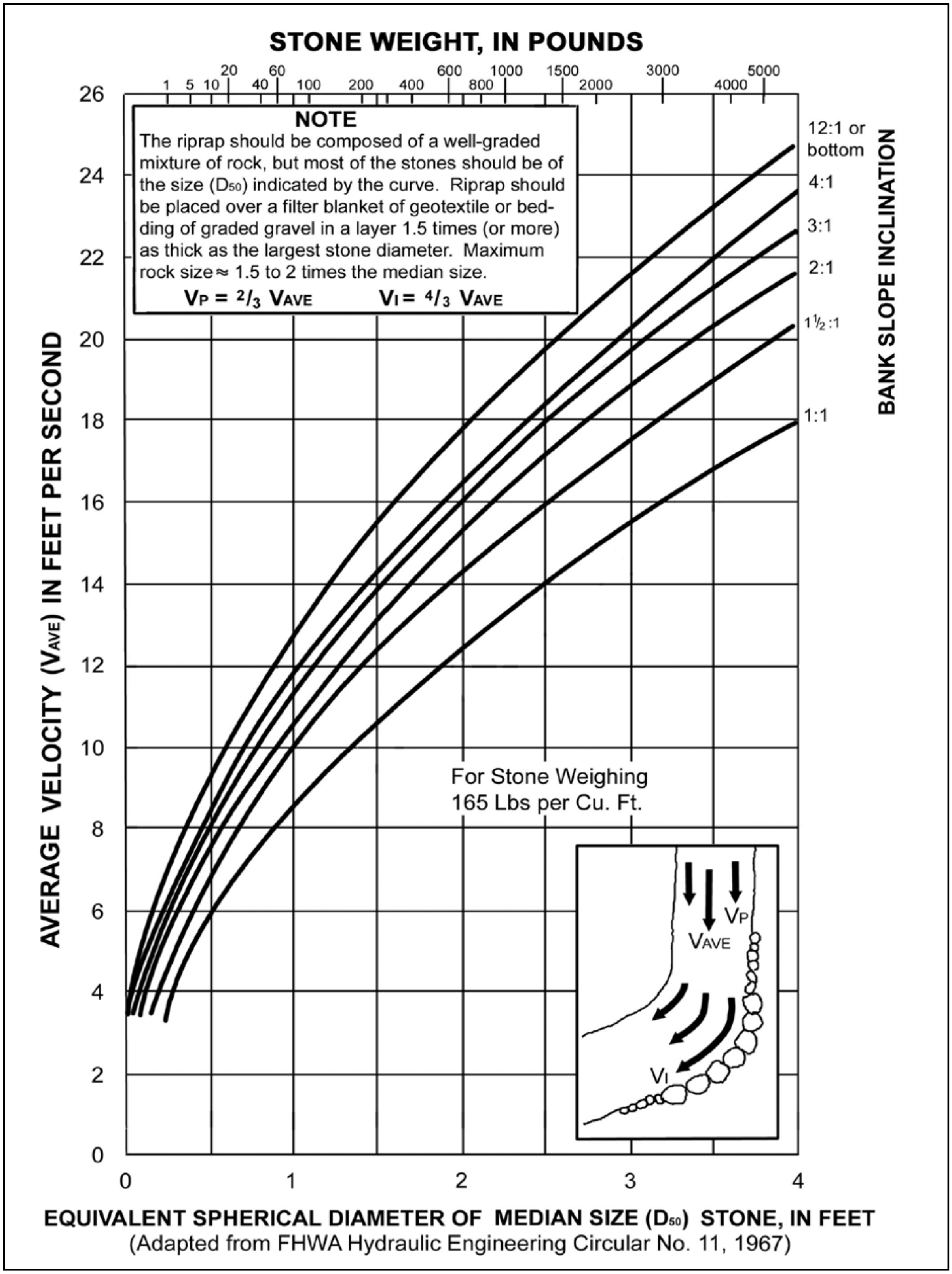


Figure 97—Sizing criteria for riprap based upon average channel velocity (Note that 1 foot/second=0.305 meters/second and 1 pound=0.454 kilograms).

Common modes of riprap failure, in addition to undersized rock, are failures at the end of a section of rock armoring or undermining of the rock by scour at the toe of a slope. The armored reach of the stream or structure should begin and end ideally at a strong or hard point in the channel, such as a bedrock outcrop, at large boulders, or a heavily vegetated bank area. Also, on steep streambanks, the slope can fail under the riprap, particularly if the toe area scours and is not well buttressed. Riprap also can fail by sliding if it is placed upon a smooth bedrock surface. If riprap is placed upon in-place smooth boulders or bedrock, pin down the riprap with rebar or bolts anchored into the rock.

The maximum rock size used in remote areas is often dictated by the rock size available. If large rock is not available, then grout smaller rock with concrete or use gabions. Otherwise, risk of failure becomes higher, the investment is wasted, and the structure may become a liability. Relatively large riprap is needed around a bend in a stream where the streambanks are subject to the force of impinging flows. Use smaller riprap in areas of parallel flow along the streambank (figure 97).

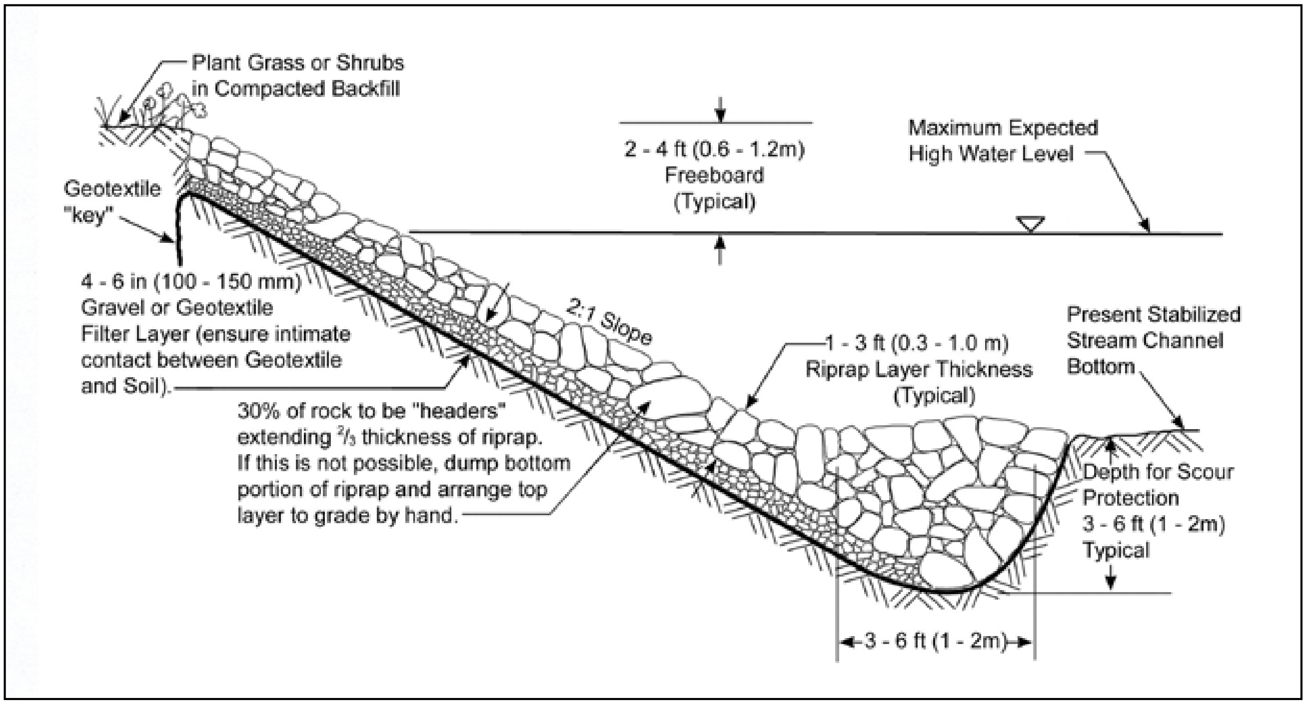
Figure 98 shows a stream channel with light riprap armoring but little channel and toe protection. Additionally, the riprap has encroached upon the channel, reducing its capacity. Thus, this site is likely to fail in a future storm. Place large riprap in the bottom of the channel and bury in the toe of the fill to at least the depth of expected scour along the channel, as shown in figure 99. Bury large footer rocks below the level of scour, then build upon these footer rocks. Scour depth will depend on the flow, velocity, and materials, as discussed previously and in section 6.3, but is frequently at least several feet (a couple meters) deep.

Also, the channel is relatively smooth, with little roughness to help slow the velocity of flow and dissipate the channel energy. An armored, hard, smooth section of stream can accelerate the flow and move or create a problem downstream where the stream enters a less resistant channel material. Use energy-dissipation structures, such as rock vanes, weirs, large boulders, log jams, and so forth, in conjunction with riprap wherever possible. Dissipate the energy or else it just moves away from the hardened area (Gubernick, personal communication). This is discussed further in section 6.4.

Figure 98—A stream with light riprap armoring on the roadway fill, but the channel bottom is not armored, nor is the toe of the riprap slope keyed into the channel below the depth of potential scour. This site is likely to fail in a future storm. Also the channel is constricted. Road relocation should be considered here. (Photo courtesy of Bob Gubernick.)

Several other design and installation details are important when using riprap, as seen in figure 99:

- ❑ Use well-graded riprap to provide a dense, armoring layer. The riprap layer should be at least as thick as the maximum rock size, and preferably 1.5 times the maximum.
- ❑ Use hard, durable, and angular rock.



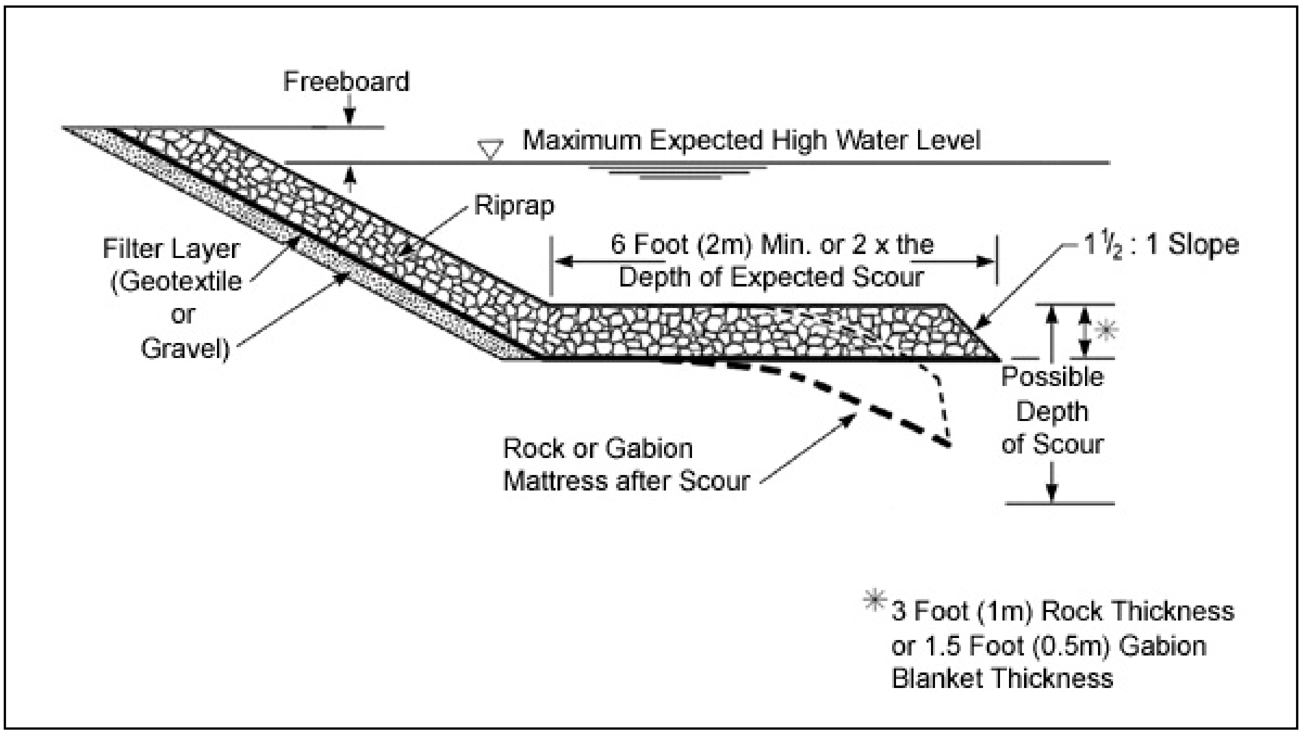


Figure 99—Typical riprap installation details for streambank protection. The upper drawing shows the use of riprap while the lower drawing shows a detail using gabions, with both showing measures for toe scour protection.

- ❑ Place riprap upon a filter layer of either gravel or geotextile. The filter allows water to drain from the soil while preventing soil particle movement behind or beneath the riprap. In critical applications, a multiple filter layer may be desirable. A sand cushion over a geotextile can be desirable to prevent damage to the geotextile.
- ❑ Key in riprap around the layer's perimeter, particularly along the toe of an armored slope and at the upstream and downstream ends of the rock layer such that scour will not undermine the whole structure, nor make an end run behind the structure. Extend the protection through a curve or beyond the area where fast or turbulent flow is expected. Excavate the toe key to the depth of expected scour or to at least several feet deep.
- ❑ Place riprap with an excavator or by hand to help achieve interlocking of the individual pieces. Dumped riprap results in an uneven thickness and an unstable structure overall.
- ❑ Add extra rock or an extra length of gabions at the toe of the protected area to help prevent scour and undermining of the structure.

Other Solutions for Streambank Instability

The solutions for streambank instability often involve a combination of physical and soil bioengineering techniques. Streambank stabilization measures often are needed at road-stream crossings where a road fill may encroach on the stream, a culvert fill is placed across the stream, or where a flow constriction accelerates the natural stream channel velocity, leading to local scour.

The two basic categories of protection measures for structures and streambanks are:

1. Those that armor the soil and increase the local resistance to erosion.
2. Those that reduce the force of water against the structure or streambank through flow redirection or energy dissipation.

Examples of ways to increase local resistance to erosion include:

- ❑ Conventional vegetation.
- ❑ Soil bioengineering measures, such as live stakes, joint planting, brush mattresses, and live fascines.
- ❑ Conventional engineering measures, such as rock riprap, gabions, concrete, structural biotechnical measures, erosion control blankets, turf reinforcement mats, root wads and boulder revetments, articulated concrete blocks, and so forth.

Examples of ways to reduce the force of water include many river training structures, such as spur dikes, groins, jetties, barbs, weirs, drop structures, in channel logs (large woody debris) and boulders, increased channel sinuosity, vegetated floodways, and so forth. Section 6.4 provides more information on some of these treatments.

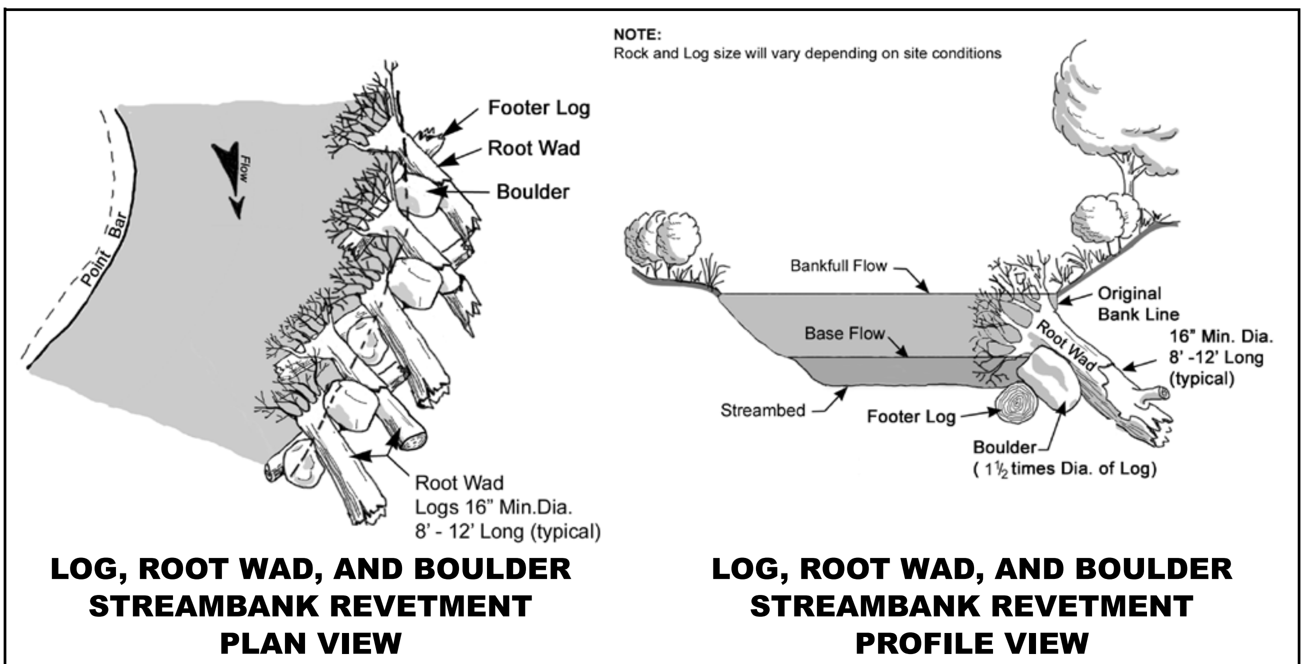
Often a combination of methods is used. Soft treatments, such as wood and vegetation, typically are the most desirable to emulate natural energy dissipation features and to help create the best fish habitat. Figure 100 shows a style of streambank stabilization using logs, rootwads, and boulders; figure 101 shows logs and rootwads and brush layering for streambank stabilization where channel-flow velocities are low. Log, rootwad, and boulder revetments have the advantage of creating channel roughness along with streambank protection; they create fish habitat, too.

Some considerations for the type of stabilization method to use include:

- ❑ Selecting self-sustaining, permanent solutions that, in the case of soil bioengineering measures, have the ability to grow stronger with age and require minimum future maintenance.
- ❑ Protecting or restoring the natural functions and values of the stream as much as possible.
- ❑ Using materials that will add channel roughness and help dissipate stream energy.
- ❑ Using native, natural living plants and locally available inert materials.
- ❑ Protecting or improving water quality by reducing water temperatures and sedimentation problems.
- ❑ Selecting measures that are strong or durable enough to resist the erosive forces of the stream during a major storm event.

One key reference on this topic is the U.S. Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook, Chapter 16, “Streambank and Shoreline Protection” (NRCS 1996). This classic reference describes and emphasizes use of vegetation, soil bioengineering, and biotechnical methods, as well as traditional structural streambank stabilization methods. Link to document <http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17553.wba>.

Another reference for streambank stabilization is the Washington State Department of Fish and Wildlife publication “Integrated Streambank Protection Guidelines” (Cramer et al. 2003). It is available at <http://wdfw.wa.gov/publications/00046/wdfw00046.pdf>.



Adapted from Rosgen (1996); NRCS Engineering Field Guide Handbook, Chapter 16; and USDA Soil Bioengineering Guide (2002).

Figure 100—Log, rootwad, and boulder streambank stabilization measures. (Note: 1 foot = .305 meters)

Figure 101—Rootwads, logs, and boulders (a) and brush layering (b) used for streambank stabilization (Upper photo courtesy of John McCullah).

Soil Bioengineering Solutions for Streambank Instability

Soil bioengineering is a technology that uses sound engineering practices in conjunction with integrated ecological principles. It takes advantage of the benefits of vegetation systems, arranged in specific ways, to prevent or repair damage caused by erosion and stream scour. Soil bioengineering for streambank stability is instrumental in road rehabilitation and stabilization for use along the road, adjacent to an eroding streambank, or at structures, such as a bridge. Adapted types of woody vegetation (shrubs and trees) are installed initially in specified configurations that offer immediate soil protection and reinforcement.

Additionally, soil bioengineering systems create resistance to sliding or shear displacement in streambanks as they develop roots or fibrous inclusions. Environmental benefits derived from woody vegetation include diverse and productive riparian habitats, shade, organic additions to the stream, cover for fish, temperature reduction, and improvements in aesthetic value and water quality.

Under certain conditions, soil bioengineering installations work well in conjunction with structures to provide more permanent protection and function, enhance aesthetics, and create a more environmentally acceptable product. This combination is called biotechnical stabilization. Soil bioengineering systems normally use plant parts in the form of live, cut branches and/or rooted plants. For protective measures for streambanks, live stakes, live fascines, joint planting through rock (vegetated riprap), vegetated geogrids and gabions, live cribwalls, branch packing, and live brush mattresses are used in various configurations as appropriate for a specific location. Figure 102a shows a joint planting system with live stakes inserted through riprap, and an installation after several years of growth.

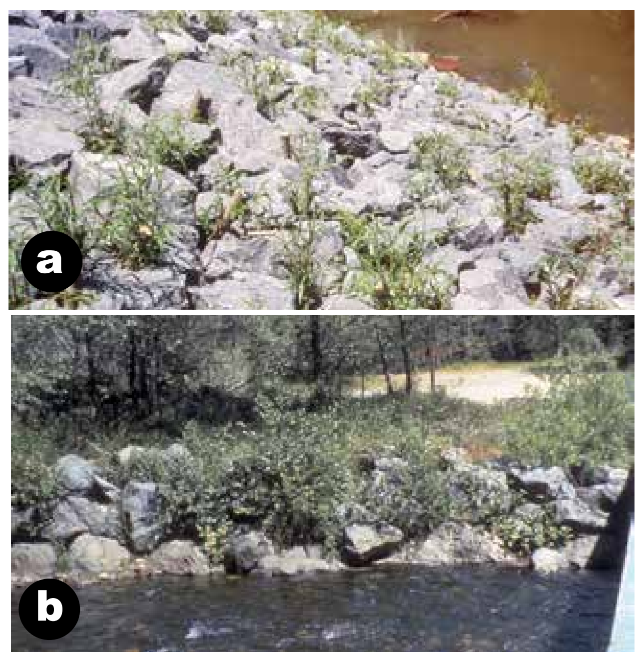


Figure 102—Biotechnical streambank stabilization using rock riprap and live willow stakes. (Photo (a) courtesy of Robbin Sotir.)

Useful information on streambank stabilization is found in the publication "A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization" (Eubanks and Meadows 2002). Link to this document <http://www.fs.fed.us/publications/soil-bio-guide/>.

Beaver Plugging Prevention

Beavers often build dams or structures that block culvert inlets. They may plug culverts to create ponds upstream of the pipes. Consequently, the pipes may not function or they may have reduced capacities, increasing the chances of culvert failure during a major storm event. Keeping beaver dams cleaned out from culverts also increases the cost of culvert maintenance. Removal of the beaver structures is a common and sometimes chronic treatment.

Frequent removal of beavers and their structures from an area is not desirable or cost-effective. It also is difficult to keep beavers from colonizing a suitable site, and efforts often have been unsuccessful. Removing food sources is difficult; trapping and relocating is expensive; and no environmentally safe chemicals or toxins are available for specific use against beavers. Additionally, beavers may be an important part of the local natural environment and be native to the area. Thus, removal of the beavers may be undesirable, but the culverts need to be kept functioning.

A recommended practice is to keep an inventory of sites where beaver problems are found. Then, these sites can be a high priority for cleaning in advance of storms, and also for storm patrol inspections. Figure 103 shows a typical beaver structure decreasing the capacity of a large culvert.

Figure 103—A beaver dam partially plugging a large culvert, Routt National Forest. (Courtesy of Steve Coupal.)

Beavers seem to be able to plug culverts faster than staff can clean them, and beavers are able to repair a dam or lodge by the next day. To alleviate this problem, staff have developed measures to thwart the efforts of beavers to plug culverts and to discourage beaver dam construction at culverts. These include exclusion fences, secondary flow bypasses, water control devices, perforated pipes through culverts, or ways to regulate the water and pool level in a pond behind the culvert. Place coarse screens and meshes on the inlet of pipes to keep beavers out. However, they make a good location for beaver activity at the pipe inlet (outside the pipe). Also,the screens and meshes restrict the flow of water and can easily plug with debris. Water control devices also may create a problem for fish passage, so evaluate the implications of various treatments carefully.

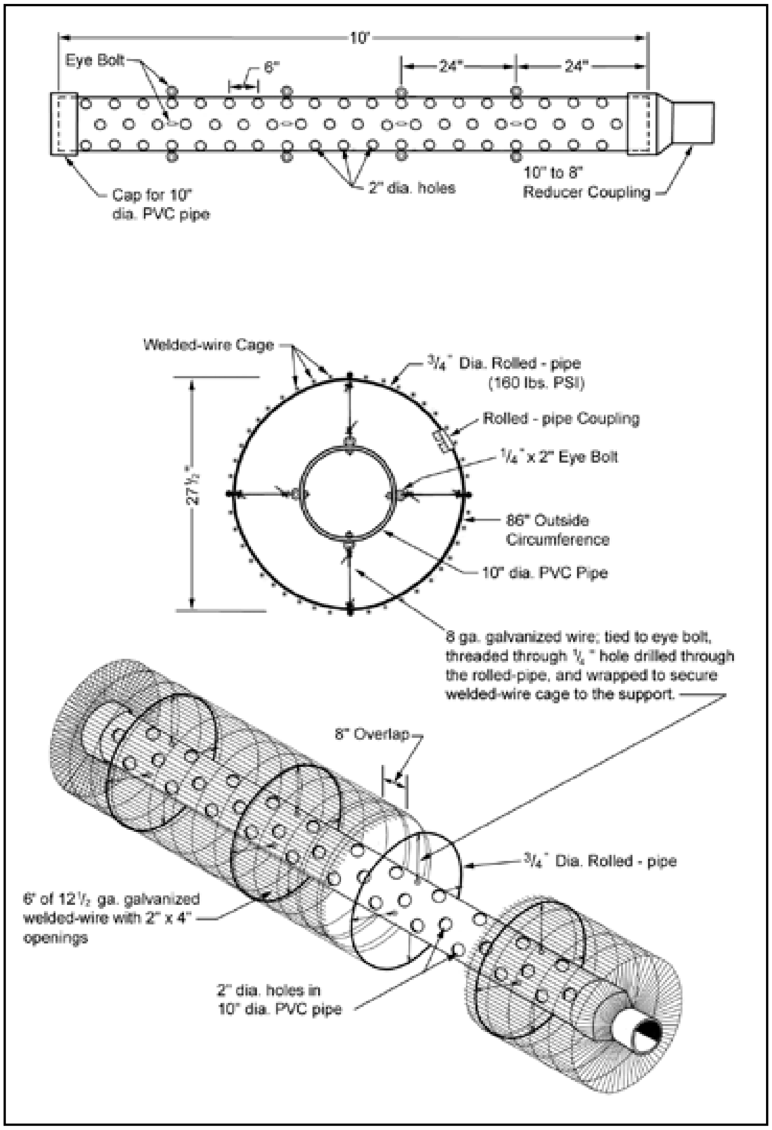
Figures 104 and 105 show retrofits that have been added to large culverts to prevent them from being totally plugged by beavers. Figure

104 shows drop-inlet pipes connected to the culverts (a pond is behind the pipes in a meadow) with additional larger rings to allow waterflow into the pipes even if the top is covered with debris. Figure 105 shows small perforated pipes running through the large culvert pipe to ensure some waterflow (and to frustrate the beaver). Figure 106 shows a screened-in cage in front of the culvert inlet, known as a beaver deceiver, to prevent plugging.

Figure 104—Large riser pipes connected to culverts with entrance rings to allow waterflow into the pipe, yet thwart beaver activity, Plumas National Forest, California.

Figure 105—Perforated pipes flowing through or next to larger main pipes to maintain some flow through the pipe even with beaver dam activity.

Figure 106—Beaver deceiver protection by screening off the entrance to the culvert in Wyoming. (Courtesy of Steve Coupal.)



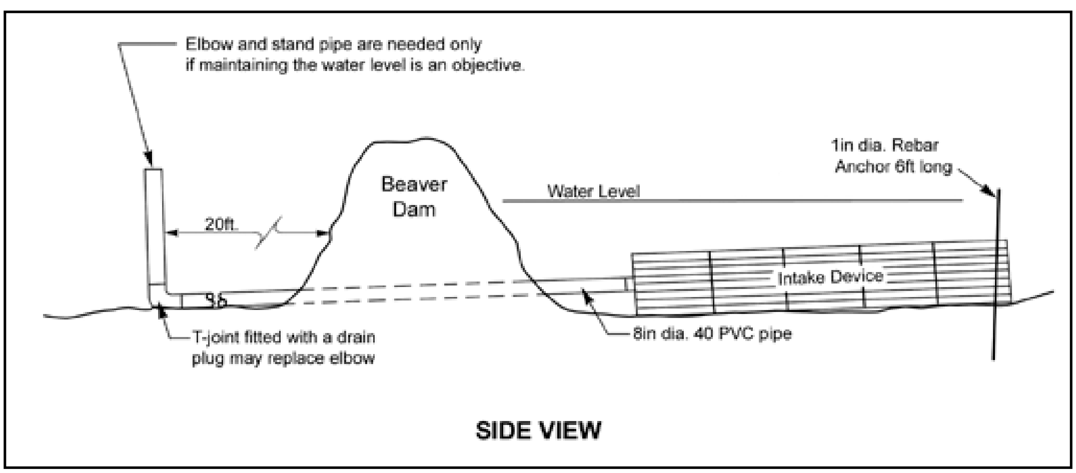


Figure 107—A Clemson beaver pond leveler to control water level and/or provide bypass flow to plugged culverts and beaver dams. (Wood et al. 1984) (Note: Metric units were not available on this drawing.)

The Clemson beaver pond leveler (figure 107) is a relatively low-cost, low-maintenance device to pass water through a beaver dam or plug (Wood et al. 1994). It can control the level of water in a pond behind a beaver dam or ensure that some flow goes through a plugged pipe or past a beaver dam. Staff in the southern and northern regions of the country have used this successfully since 1987. A Forest Service publication discussing methods used to mitigate beaver problems is “How to Keep Beavers from Plugging Culverts” (Nolte et al. 2005).

6.3 Bridge Protection and Improvements

Bridges are a major investment for rural infrastructure and need to be protected to prevent failures. Incorporate good bridge design and bridge scour protection measures into the initial design. However, changes over time can affect the hydrology of the watershed and increase stormflows, putting existing bridges at risk. Watershed characteristics may change due to new land uses, logging, or forest fires. Global climate change may be contributing to more intense storms, longer duration storms, or more glacial melt-water runoff. Thus, old bridges may have marginal hydraulic capacity for storm runoff. Some bridge protection may be needed over time and erosion and scour protection added to prevent undermining of foundation piers or abutments. Since bridges are costly, scour prevention measures can be a high-priority item. This may involve the following work:

- ❑ Foundation repairs and grouting.
- ❑ Riprap placement around piers or abutments.
- ❑ Channel lining with riprap or gabions.
- ❑ Redirecting flows with barbs or rock jetties, and so forth.

Work should involve an interdisciplinary process including fisheries biologists, hydrologists, geomorphologists, earth scientists, and engineers.

For some structures with a known inadequate flow capacity, raise the superstructure to increase freeboard. In some circumstances, an overflow dip can be built into approach fills, particularly fills that block a historic flood plain, to provide a controlled failure point that can be repaired easily rather than losing the bridge structure.

Channel maintenance, as discussed earlier, also can increase the bridge flow capacity and reduce the chance of plugging or blocking during a storm.

The publication “Stream Instability, Bridge Scour, and Countermeasures: A Field Guide for Bridge Inspectors” (U.S. Department of Transportation, FHWA 2009b) has many insights into bridge instability problems, what to look for, and appropriate countermeasures.

Increasing Freeboard

Lack of capacity and freeboard can lead to bridge failure. Lack of freeboard may be a lack of capacity for the design flow or, as shown in figure 108, it may cause a bridge failure by catching floating debris that can push the superstructure off its abutments. Stream channels in areas of aggradation, on alluvial fans, and channels carrying significant amounts of large woody debris, all have the potential of plugging a bridge. In these areas, evaluate bridges for their freeboard and consideration given for raising the structure if possible. Alternatively, some channel clearing may be warranted (after consideration of other adverse environmental impacts of channel clearing) as discussed in section 5.4.

Figure 108—A failed bridge due to lack of freeboard and accumulation of debris behind the bridge deck.

Solutions to lack of freeboard are not simple. Either replace the structure with a longer span to increase the waterway open area of the structure or raise the superstructure (girders and deck). The success of these measures depends on the topography around the bridge. Raising the bridge deck in flat terrain may accomplish nothing if the floodwaters just spread out across a flood plain. Here a longer structure would be more useful. Figure 109 shows a Bailey Bridge (a portable, temporary bridge) superstructure with marginal freeboard and debris stuck in the superstructure after a flood. The problem was solved by adding height to the abutments and piers (right photo), thus raising the deck a couple feet, and placing a new concrete superstructure across the span.

Figure 109—A bridge with marginal freeboard (a) where the abutments and piers were raised (b) to add freeboard and flow capacity, Plumas County, California.

Major Bridge Scour Protection

Bridge foundation scour is one of the most common causes of bridge damage or failure during storm events. The most common forms of scour at bridge sites are contraction scour, general channel scour, and local scour around piers and abutments, as shown in figure 110. Section 6.2 presents some additional discussion of scour.

Determining the depth of scour and amount of potential bedload movement are critical factors that need to be evaluated at bridge sites, particularly if the site has had historic scour problems or appears undersized. In coarse, rocky channels with boulders, scour depth may be minimal or only a couple feet (a meter); in gravel channels with cobbles, scour may be as deep as several feet (a few meters); and in fine sandy river channels, scour depth has been observed to over 50 feet (15 meters plus). Determining scour depth requires study and careful evaluation of the channel and bed-material characteristics. The references listed here provides information on determining scour depth. The U.S. Army Corps of Engineers HEC-RAS programs for analysis of river systems have methodologies for determining scour depth. It is available at <http://www.hec.usace.army.mil/software/hec-ras/>.

Key areas needing scour protection include:

- ❑ Along the downstream edge of an in-channel grade-control structure, where accelerated velocities or water dropping off a structure produces a waterfall with erosive energy.
- ❑ Around or beneath mid-channel piers, posts, piles, or box walls that create turbulence or accelerated flows (figure 111).
- ❑ Along the edges and beneath abutments and footings, where locally accelerated flows and scour occur.
- ❑ Along or around the approaches to structures (outflanking) or wingwalls, where the high-water level may exceed the elevation of armoring or a shifting channel scours behind the approach armoring.

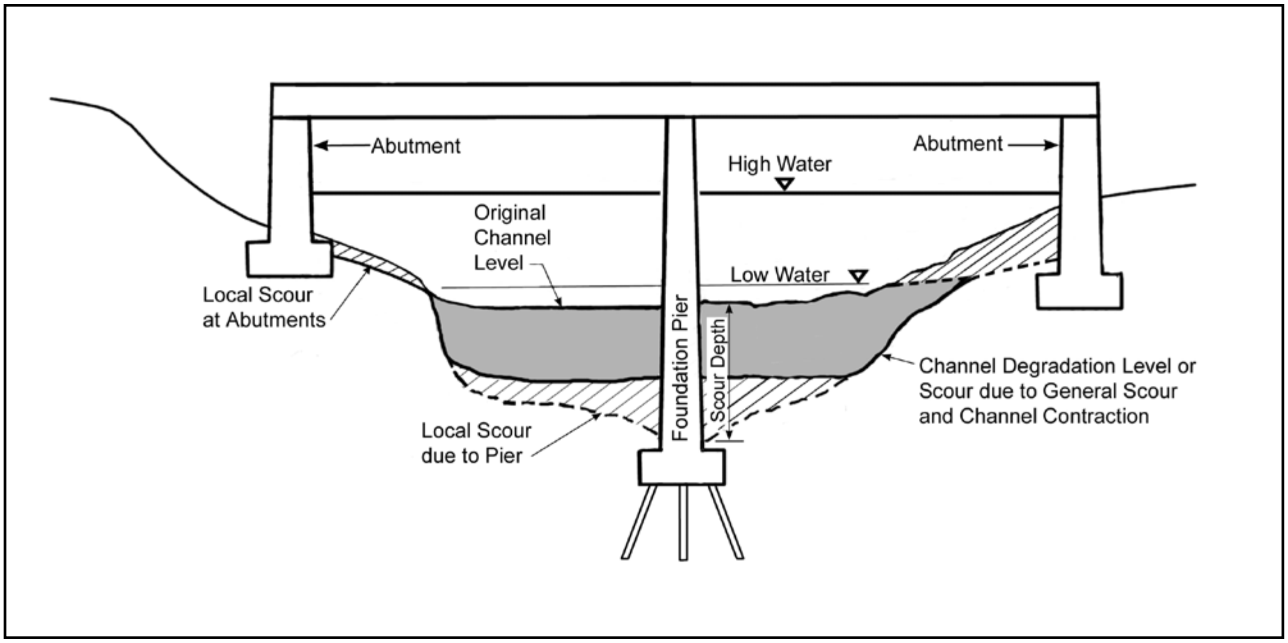


Figure 110—Types of scour and common scour problem areas around a bridge. (Adapted and reproduced with the express written authority of the Transportation Association of Canada, from Neill 1973.)

Figure 111—Common scour seen around a mid-channel pier or abutment. Thus mid-channel piers and abutments are problematic, undesirable, and should be avoided if possible.

Common mitigation measures used for protecting bridges against scour include the following:

- ❑ Move a structure to a location where the local materials are not scour susceptible, such as areas of coarse rock and bedrock.
- ❑ Widen a structure to avoid constricting the flow channel, thus avoiding flow acceleration.
- ❑ Armor the entire channel with scour-resistant materials (grouted gabions, riprap, concrete, and so forth).
- ❑ Protect the channel, streambanks, and abutments against local scour, using vegetation, rootwads and logs, riprap, sack concrete, articulated concrete blocks, vegetated turf reinforcing mats, gabions, and so forth, as seen in figure 112.
- ❑ Redirect stream-channel flow with barbs, spur dikes, weirs, cross vanes, and so forth (section 6.4).
- ❑ Install deep foundations, placed below the anticipated scour level, such as relatively deep spread footings, or drilled or driven piles and piers.
- ❑ Add shallow scour cutoff walls, gabions or concrete splash aprons, plunge pools, or riprap layers along the downstream edge of an in-channel structure.
- ❑ Install deep cutoff walls or deep sheet piles installed to a depth below the depth of scour, or to scour-resistant material, such as bedrock.

For additional technical information about scour, consult U.S. Department of Transportation, FHWA, HEC-18 “Evaluating Scour at Bridges” (Richardson and Davis 2001). The manual is part of a set of Hydraulic Engineering Circulars (HECs) issued by FHWA to provide guidance for bridge scour and stream stability analyses. A companion document is HEC-23, “Bridge Scour and Stream Instability Countermeasures” (Lagasse et al. 2009). Links to HEC 18 <http://isddc.dot.gov/OLPFiles/FHWA/010590.pdf> and HEC 23 <http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=23&id=142>.

Also, technical information about bridge scour evaluation is provided in “Bridge Scour Evaluation: Screening, Analysis, and Countermeasures” (Kattell and Eriksson 1998). Link to the document <http://www.fs.fed.us/eng/pubs/pdf/98771207.pdf>.

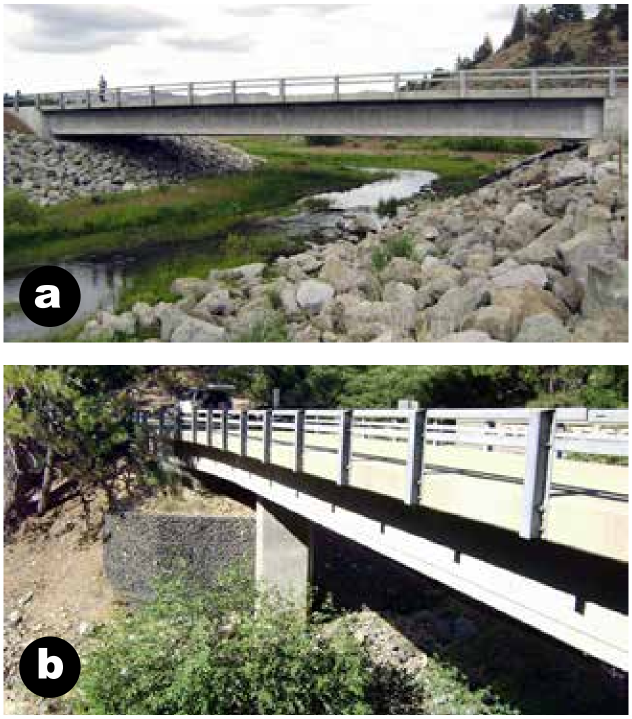


Figure 112—Bridges with rock riprap (a) and gabion (b) scour protection around the abutments since the bridges are located on bends in the stream (river bends are problematic locations).

Figure 113—Abutment scour caused by channel meander (a) and the repair (b), extending bank protection upstream from the bridge. Note that the bridge also constricts the original stream channel, Plumas National Forest.

Stream channels are dynamic and tend to meander or shift laterally, longitudinally, and vertically over time, particularly in low-gradient environments. They can change flow direction during flood events, move out of an existing channel, and may reoccupy some historic flood plain deposit. Figure 113 shows a bridge site where stream meander or change in flow direction eroded a bridge abutment and approach fill. The repair involved extending the concrete wingwall and providing upstream bank protection with riprap. Evaluate the location of bridge abutments for long-term channel stability and possible stream channel adjustments. Figure 114 shows a damaged bridge approach due to channel widening from a debris torrent in the watershed. Figure 115 shows a bridge damaged due to channel constriction and scour on the outside of a river bend.

Figure 114—Channel widening and scour around a bridge abutment, removing part of the approach fill, caused by a debris torrent and shifting river channel. A temporary Bailey Bridge is being used to cross the gap, Mount Hood National Forest. (Courtesy of Mark Leverton.)

Figure 115—Bridge failure during Hurricane Irene due to a bridge span too short for the channel width, with the abutments constricting the channel and accelerating the streamflow, plus the bridge is located on a river bend, all causing abutment scour, White Mountain National Forest. (Courtesy of Bob Gubernick.)

6.4 Road-Stream Encroachment

Historically, roads were located following the path of least resistance; in essence, where construction required the least amount of excavation. This resulted in most of the initial roads into a watershed located on river terraces adjacent to the river and or in channel flood plains. These areas, now referred to as channel migration zones, are where rivers shift in response to storm flows, sediment, and obstructions to shape and reshape their flood plain. Areas where there are significant changes in stream gradient, or alluvial fan areas, are particularly problematic since over time the stream channel may fill with sediment and shift. Road work, such as raised embankments or levees, may in fact block off a stream's access to its historic flood plain or an overflow channel, thus concentrating more flow in the channel that can lead to erosion and scour problems, or create a problem elsewhere downstream.

The constant shifting by rivers frequently undermines or removes road sections, which are costly to repair and disruptive to travel (figure 116). At times, the road may capture the entire river, resulting in a complete relocation of the channel to the road alignment. A road located in or near the channel migration zone is an encroachment on the river and its natural function. Figure 117 shows road damage and a nearly total road washout caused by constriction of the natural stream channel by the roadway and fill. Note that the road is located in a relatively steep, narrow canyon.

Figure 116—Examples of roads located in flood plains (a) and on the edge of a channel migration zone (b) where flood damage may be frequent and costly. Road access may be lost for long periods of time, Pacific Northwest. (Courtesy of Roger Nichols.)

Figure 117—Road-stream encroachment where a road is located too near the stream in a narrow river canyon, confining the streamflow during a major storm event, Green Mountain National Forest. (Courtesy of Bob Gubernick.)

The usual response following road damage is to move the road or restrain the river with rock armor placed on the road fill to protect the road from the erosive power of the river. The roadbed elevation may be raised above expected flood levels and the fill armored to maintain the alignment. The river reacts to this displacement by shifting the erosion downstream or by totally removing an obstruction, such as an undersized bridge or culvert crossing.

Section 5.3 covers some common treatments for stream encroachment and protection at stream crossings. Use the treatments included in this section where roads parallel streams and at stream crossings when appropriate.

In more recent road construction practices, road locations along streams, within flood plains, and within or adjacent to channel migration zones are viewed as high-risk sites that should be avoided. **Close high-risk roads or relocate. Move roads away from the channel or upslope on a hillside, outside any potential channel migration zone.** As storm damage occurs to roads located in these sites, relocation should be the first option. While relocation may be costly and administratively and physically difficult, relocating roads away from streams, flood plains, and channel migration zones will eliminate future costly channel encroachment repairs and loss of road function for extended periods. In addition, channel functions will be better managed if road features do not interfere with natural stream processes.

If road relocation is eliminated from possible solutions, a detailed review of stream processes at the site and geomorphic processes in the watershed should be used to determine the hydraulic forces and channel dynamics that need to be included in treatment selection and design.

The most common stream encroachment site is when a road encounters the outside boundary of a channel meander. Select treatments that treat the site where the road and meander are in contact; however, meanders migrate (laterally and in a downstream direction) and remember that the outside of a meander bend is where considerable stream energy is expended.

Also aggradation of the streambed or channel widening due to loss of riparian vegetation can contribute to channel migration. A relatively smooth, but resistant treatment (including riprap) will only pass the stream energy to the next downstream unprotected bank, and likely exacerbate the problem. The following techniques attempt to work with stream energy and alter stream dynamics around the site.

The Pacific Northwest and northern California have used these techniques successfully. It is a holistic approach, but the techniques are still experimental and the practices are evolving.

They appear best suited for wide, degrading river systems that move significant bedload. They also are applicable to moderate gradient mountain streams with low-to-moderate sinuosity and where whole-tree jams are common (Benoit, personal communication).

Floating Log Weirs

Many streambank protection treatments involve a rigid, massive structure designed to deflect flow away from the treatment site, such as riprap armored banks, gabions, and rock or log deflectors. Those structures can withstand the maximum expected drag forces and scour at the site and are built to a height equal to the highest design flow, plus some freeboard. Often these structures increase the scour at the structure due to how the structure interacts with the flow. A structure with a rigid uniform surface, including a riprap streambank, reduces channel roughness and increases water velocities. The result is an increase in local and downstream scour, which can contribute to the failure of the structure itself.

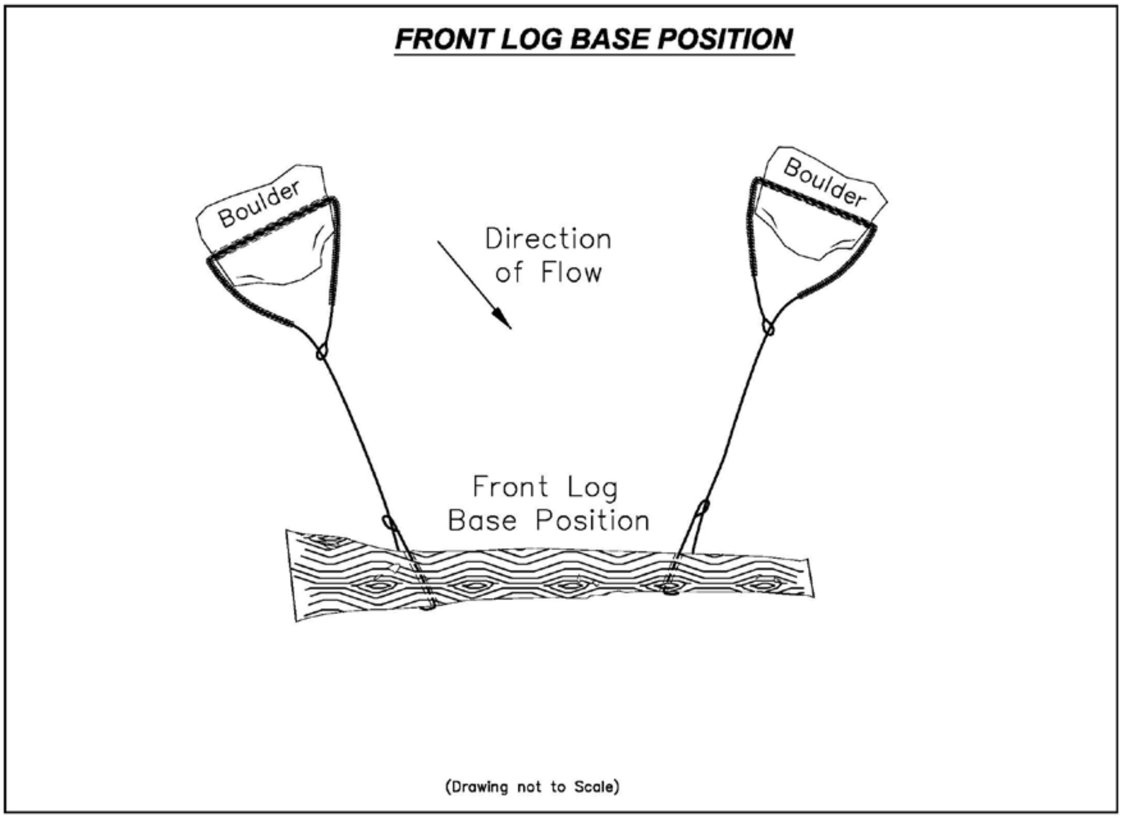
Natural wood jams form on key features or logs and capture floating debris on the falling limb of the hydrograph. During a runoff event, the collected buoyant debris expands as it floats up in the water column. As the flow recedes, the debris settles and compacts. This process is repeated many times on varying sized storm events resulting in the debris jam increasing in size until the channel shifts or the river reacts by cutting a new channel. Secondary processes that accompany this dynamic jam flexing are continual renewal by debris collecting and disruption of the water column, which results in localized eddy formation. The backwaters and eddies trigger sediment deposition. Constructed structures that utilize these traits of natural wood jams can be utilized to slow the water velocities along the eroding bank and slowly increase the bed elevation through sediment deposition downstream. The eventual result is a channel shift away from the eroding bank.

Ballasted log structures are a flexible design, which attempt to mimic the natural flexing of a wood debris jam with similar local scour and deposition characteristics. The technique has been employed successfully at a number of sites and minimizes the impact on fisheries resources. Monitoring has shown improvement in aquatic habitat over the project life.

Ballasted long-line log weirs

For long-line cabled log weirs, logs are placed perpendicular to the streambank and cabled to boulders (figures 118 and 119) that help maintain the log positions. The cables are slack so that the logs float up as the flow increases and interact with the upper velocity vectors in the water column. This does not increase the bed scour around the structure, but rather interrupts flow velocities and creates lower velocity eddies within the structure and near-bank area. At the same time, the floating logs have the potential to capture other logs floating downstream on the surface of the flow. The result is the deposition of sediment within the structure and a shift in the stream thalweg away from the bank being protected (figure 120).

Figure 118—Floating log weirs just after installation. These weirs are designed to move the river thalweg away from the near bank, Warnick Bluff, Nooksack River, Washington. (Courtesy of Roger Nichols.)



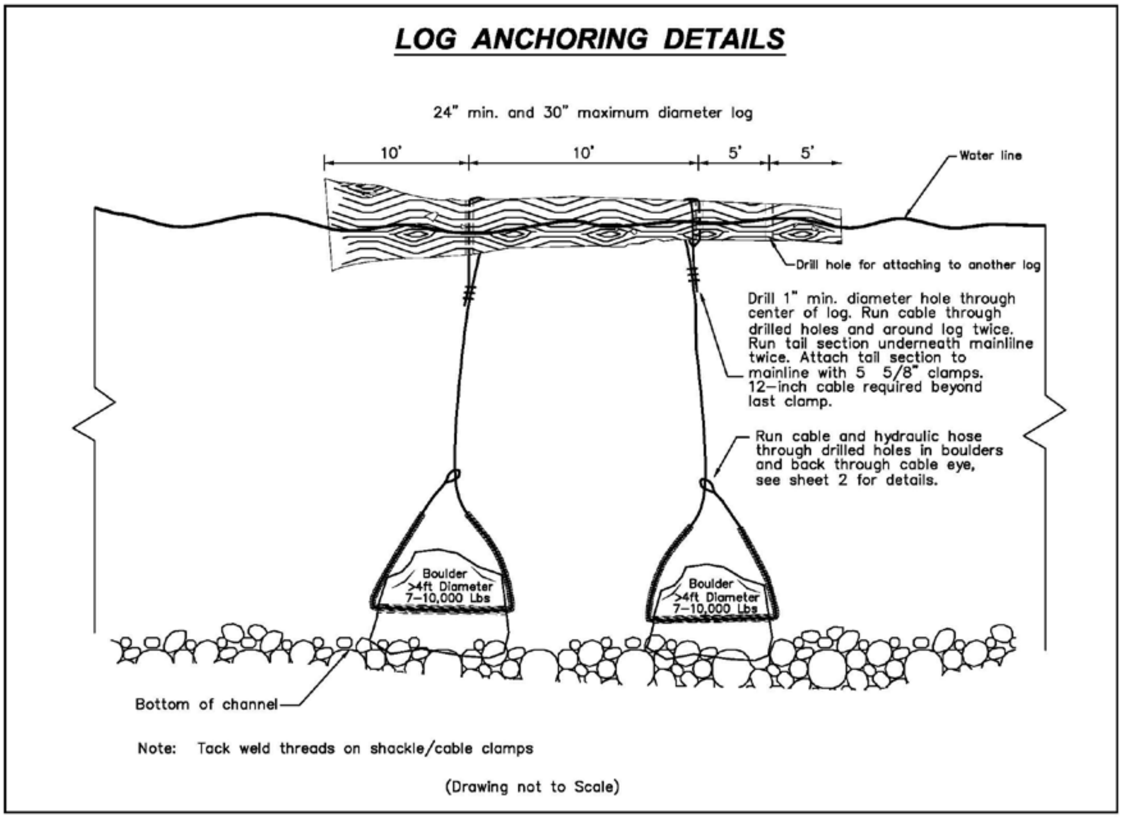


Figure 119—Floating log-weir design and anchor details.

Logs are held in place by two large boulders cabled to the ends of the log. Size these boulders to withstand the shear, buoyant, and drag forces expected at the site. Since the logs are on long cables, the shear force experienced by the boulders is reduced since the logs float up and do not exert a buoyant force directly on the boulders. The buoyant force is exerted at an angle instead of directly upward.

A discussion of this treatment can be found in the "Use of Long-Line Cabled Logs for Stream Bank Rehabilitation" (Nichols and Sprague 2003).

Figure 120—Warnick Bluff floating log weirs at high flow. Note the turbulent flow zone located outside the weir installation and slack water within the structure. (Courtesy of Roger Nichols.)

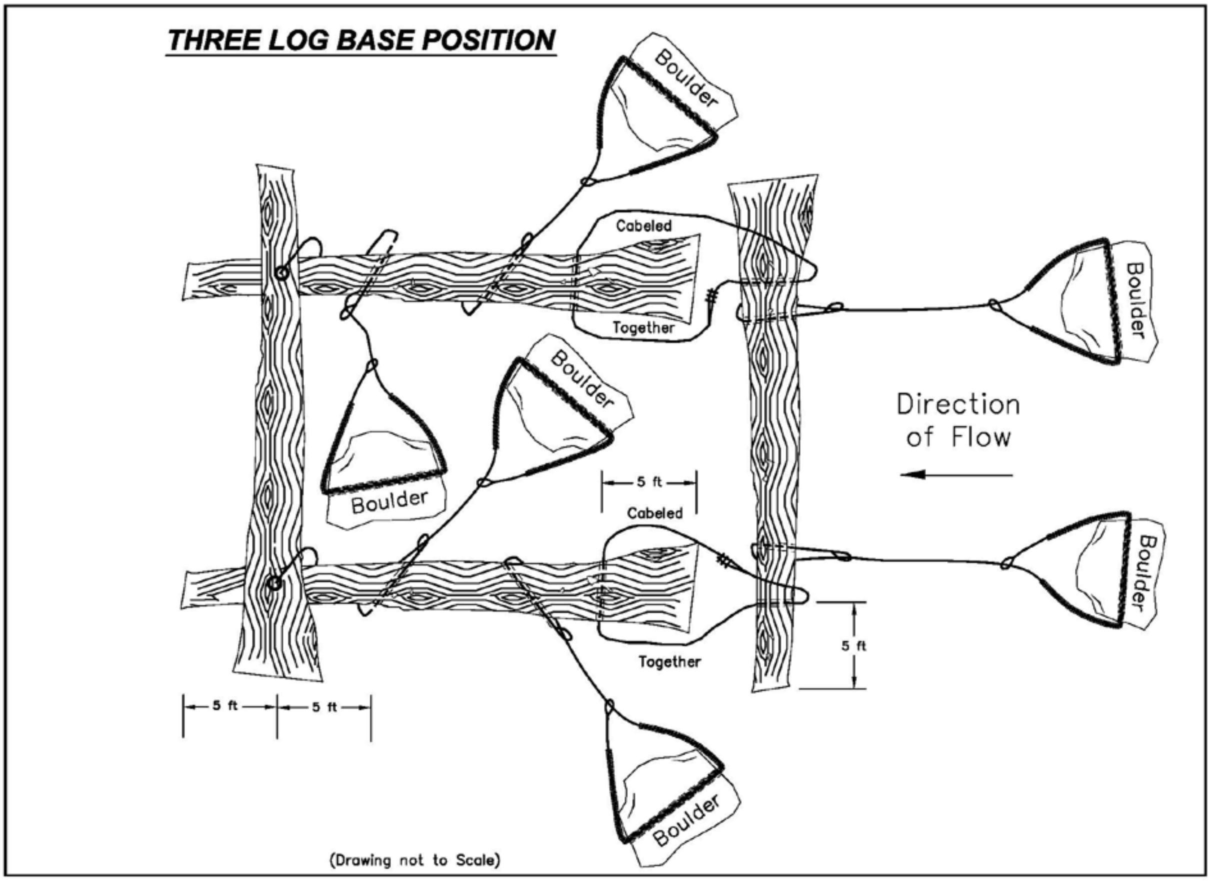
Four Log-Ballasted Long-Line Jams

Another long-line technique has been used to protect roads from damage. In this case, log jams are constructed within the river reach where the road-stream encroachment has become a problem. The log jams are designed and positioned to encourage the river to migrate or split flow energy around lateral or midchannel bars.

By combining three ballasted base logs and a rear top log (figure 121), an interactive log jam is formed, which amplifies debris capturing characteristics and additional local sedimentation and scour. By placing this type of structure in series of three, the top, middle, and bottom of lateral or medial gravel bars, it is possible to split flows and reduce river power significantly. This splitting of flows greatly reduces effective stream power and encourages localized deposition.

Figure 122 shows the application of the ballasted floating log weirs being used to slow the water velocity along the bank and protect the streambank along a highway, both after installation at high flow and after 7 years in service during a low-flow period. Riprap in this location had previously been inadequate and had allowed streambank erosion. These ballasted floating logs can be useful for streambank protection, as well as to encourage streambank revegetation.

Another option involves using whole trees cabled to the upper bank. The long-term objective is to move the center of flow away from the eroding bank while live vegetation takes over. Boulder vanes also can help redirect the flow away from the eroding bank, followed by sloping the eroding bank (usually to a 1:1 slope) and vegetating the area. Live vegetation is the key to long-term success.



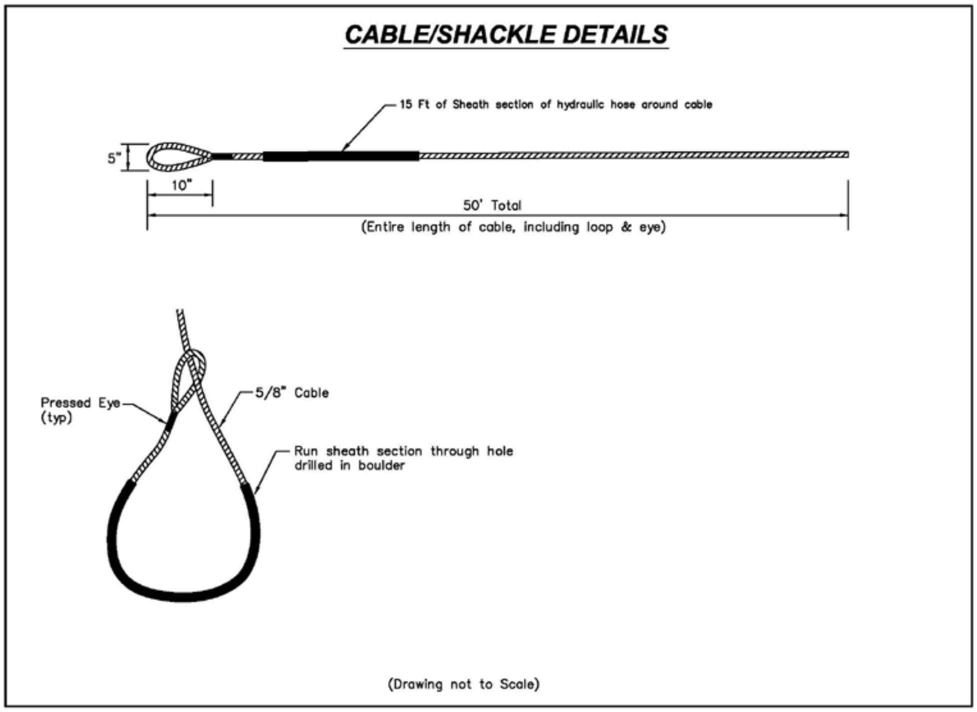


Figure 121—Design details for four log-ballasted long-line structure.

Figure 122—Ballested logs slowing the water along the bank during high flow in 2004 along State Route 542, Washington (a). Same location at low flow in 2011 (b). Note the streambank erosion in the riprap (in 2004) that took place before installing the ballested logs. (Courtesy of Roger Nichols.)

Other Channel Redirection and Bank Protection Measures (Spurs, Veins, Drop Structures, and Log Jams)

Floating log weirs were discussed in the previous section and some bank armor and hard and soft protection measures were discussed in section 6.2. In addition to these measures, other treatments have been developed to help protect structures and are used as river-training structures to confine, direct, or focus waterflow, as well as provide some armoring and energy dissipation. These include use of spurs, barbs, dikes, J-hooks, drop structures, guidebanks, vanes, and so forth. These treatments are useful when flow needs to be deflected or directed away from the streambank, a structure, or the road. Again, moving the road or structure may be the best long-term solution.

Flow redirection techniques include using spurs, dikes, jetties, vanes, groins, barbs, engineered log jams and large woody debris, boulder drop structures, and porous weirs. They are most commonly constructed with rock or boulders, and frequently used in conjunction with vegetation, but they also may be constructed using gabions, wood posts, fencing, concrete, or other materials. Rock cross veins, boulder drop structures, and stone weirs are used to focus the waterflow, prevent channel erosion and headcutting, as well as provide pool habitat. Examples are shown in figure 123.

Figure 123—Flow redirection or training measures used to protect streambanks and structures, such as spur dikes or rock vanes (a), and rock drop structures or weirs (b). (Photos courtesy of John McCullah.)

A textbook that addresses many considerations in river dynamics, channel morphology, assessment of stream condition, and effects of structures on the channel (and vice versa) is "Applied River Morphology" by David Rosgen (1996).

Four other references (previously mentioned) that contain information on streambank stabilization, channel control, and flow direction measures are:

- "Environmentally Sensitive Channel and Bank Protection Measures" (McCullah and Gray 2005).
- HEC 23 "Bridge Scour and Stream Instability Countermeasures" (Lagasse et al. 2009).
- "Streambank and Shoreline Protection, Chapter 16" (NRCS 1996).
- "Integrated Streambank Protection Guidelines" (Cramer et al. 2003).

6.5 Erosion Control

Erosion control on roads and disturbed areas is fundamental for the protection of water quality, particularly during major storms. The two main causes of erosion are concentration of flowing water and lack of ground cover over the soil. Many erosion control treatments are low cost, effective, and commonly applied. Vegetative ground cover is the primary long-term defense against surface erosion. Section 5.5 discussed a number of basic erosion control and protection measures.

Some erosion situations and treatments are more complicated and costly to implement, but have great long-term benefits in environmental protection. Some soil bioengineering and biotechnical slope stabilization measures can offer excellent and aesthetic slope treatments, but most are labor-intensive to install. Gullies, as mentioned previously, are a particularly severe form of erosion, and efforts should be made to prevent their formation, particularly those caused by concentrated runoff from roads. Section 5.5 discussed prevention criteria. However, once a gully has formed, various measures exist to help stabilize the area or prevent it from getting larger.

Gully Stabilization

Stabilization of gullies typically begins with removing or reducing the source of water flowing through the gully. The following information also applies to gully formation caused by road drainage features or poor land-use practices. Typically, gully stabilization structures are not desirable on natural stream channels. Only use these structures in natural drainages to correct some severe problems, and then only after careful study, examining a range of alternative solutions. For gullying of ditches or gully formation below the road, the best solution is prevention by adding more frequent drainage features (ditch-relief culverts) to reduce the concentrated water volume (as discussed in section 5.5).

If a gully already exists, stabilization measures help, but the first step is to remove as much of the source of the water as possible. With time and the source of water removed, a gully may tend to stabilize itself, particularly if the area can be revegetated. However, as a common practice, the gully can be stabilized with vegetation or refilled with dikes, or small dams, built at intervals along the gully. Reshaping and stabilizing the over-steepened gully sides also may be needed, as well as some treatment on the headcut area. Gully stabilization can require a lot of work and expense.

Typical gully stabilization check-dam structures are constructed from materials including rock, gabions, logs, wood stakes with wire or brush, rock and brush, bamboo, vegetative barriers, and so forth. Each has its advantages and disadvantages. Loose rock structures are somewhat forgiving and can deform a bit and still function. The rock should be well graded, but it will still be porous so it detains water temporarily and then attenuates the runoff. Gabions commonly are used but can be problematic and need extra care in installation. They are subject to settlement, piping through the rock, and flow diversion around or under the structure. Place a geosynthetic filter material behind and under the structure to minimize piping. Examples of log and loose-rock structures are shown in figure 124. Biotechnical methods offer a combination of physical structure and vegetative measures for physical protection, as well as additional long-term root support and aesthetics. Typically, a headcut structure is needed to stabilize the upslope, or top-most portion of the gully and prevent additional headward movement.

Figure 124—Gully stabilization structures made of logs (a) and of loose rock (b).

Important design details for gully stabilization structures are shown on figure 125. They include:

- ❑ Have a weir, notched, or U-shaped spillway that is constructed for the design peak flow capacity to keep the water flow concentrated in the middle of the channel.
- ❑ Key the structure into the adjacent banks tightly and far enough to prevent erosion around the ends of the structures.
- ❑ Bury the structures deep enough in the channel to prevent flow under the structure.
- ❑ Spill the water over the structure onto a splash apron, protective layer of rock, or into a pool of water to prevent scour and undermining of the structure.
- ❑ Space the structures close enough so that the flow over the structure spills into backwater caused by the next structure downstream (figure 126).
- ❑ Use of well-graded rock is important if rock check dams are used so that the structure is relatively impermeable. Use of vegetation with the rock will add integrity to the structure.

The recommended spacing for structures depends on the slope of the terrain or gully channel, and the height of each structure, as presented in figure 126a. This physical relationship between structure height and spacing in a sloped channel is so that water and material stored behind the lower structure is level with the toe of the upper structure. This allows water from the upper structure to spill into the pool above the lower structure, thus minimizing toe scour at the upper structure (figures 125 and 126b). Figure 126c shows the arrangement of a series of rock check-dam structures in a channel (as well as installation details).

Another consideration is height of the structures. Occasionally, one large dam is built in an area to fill and stabilize an entire gully system. Also, large structures typically are built as debris-retention dams where massive quantities of sediment and debris are moving in a canyon, such as some steep Southwest arroyos. Generally, a series of small, well-built structures is more desirable than one or a few large structures, particularly if grade control is the objective to keep a gully from eroding deeper and to reduce the effective gradient of the channel. Smaller structures are more versatile, easier to build using local materials, and have less fall at the outlet that can cause erosion. Also, there is less risk of a catastrophic failure of just one structure. Structures typically are less than 5 feet (1.6 m) high.

In gully prevention proper erosion control measures result in less sediment and erosion caused damage. Take action to prevent

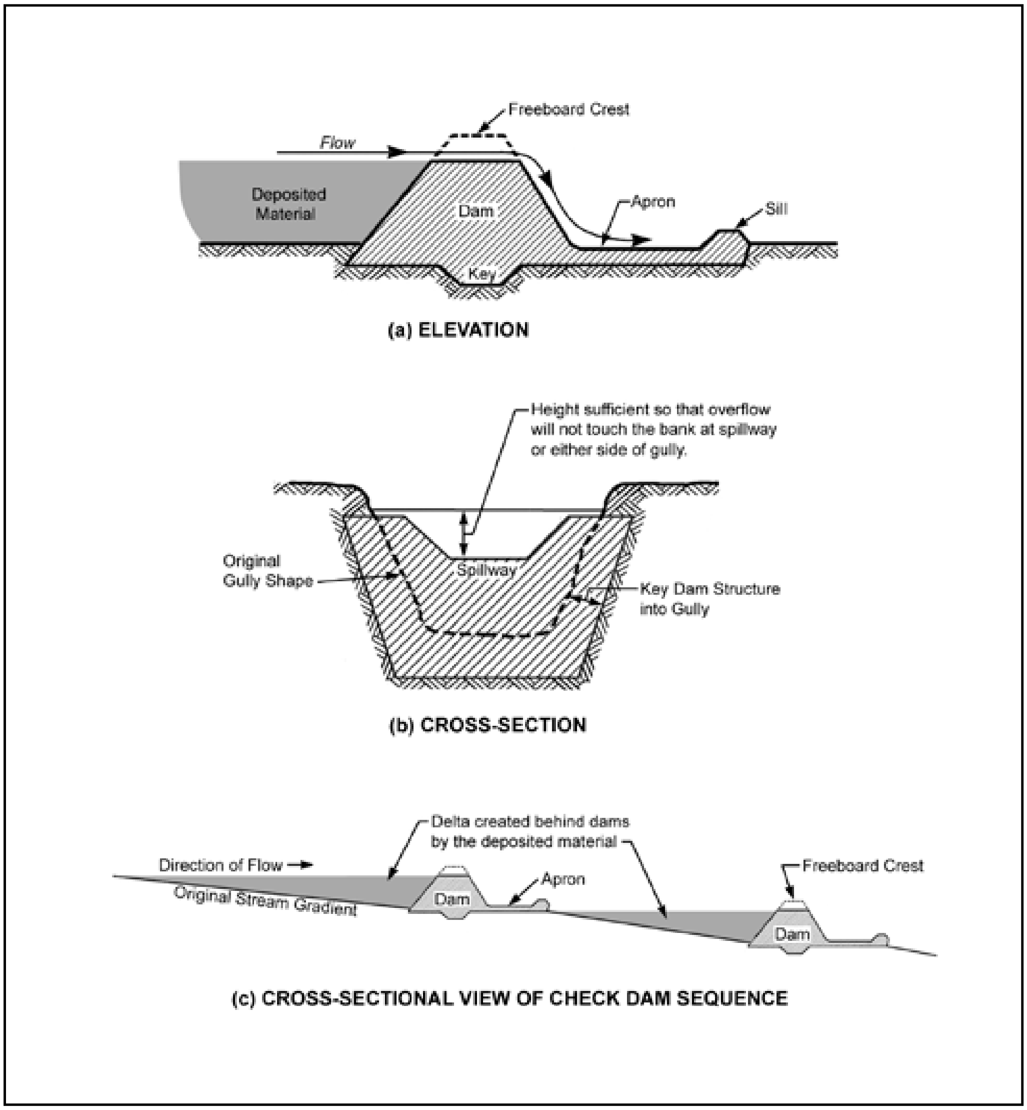


Figure 125—Check dams used to control or stabilize a gully. Note the details for keying the structure into the gully, having a U-shaped weir, and protecting the toe area against scour and with other downslope structures.

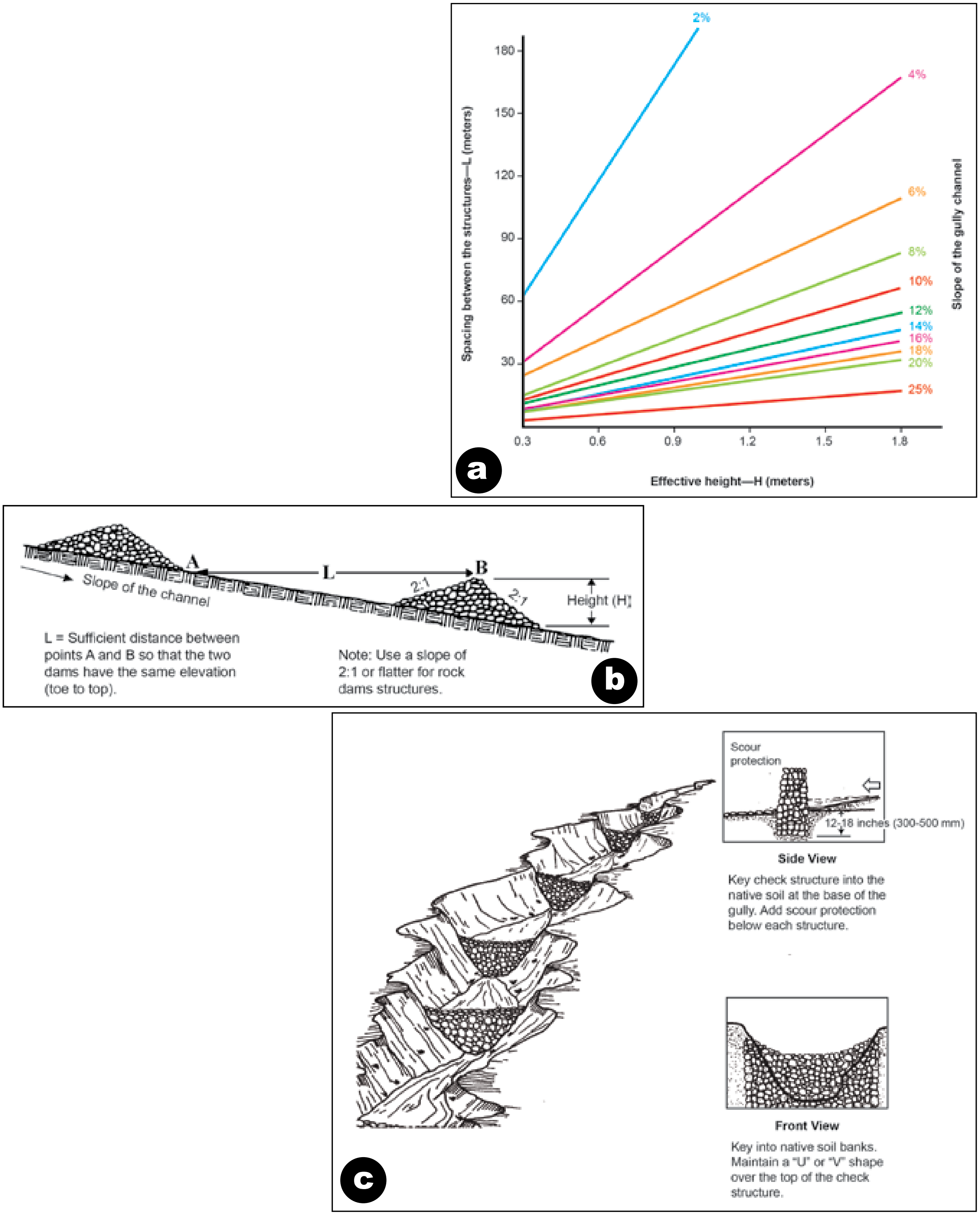


Figure 126—Ideal gully control check-dam spacing criteria (a) and installation details for loose rock-check dams (b and c). Note that water from the upper structure should spill into the pool above the lower structure (adapted from Gray and Leiser 1982). Note: 1 meter = 3.28 feet.

the formation of gullies, remove or divide the source of water, and stabilize existing gullies before they grow larger. Once large, gully stabilization measures can be very expensive.

Other Gully Control Considerations

In addition to removing the source of water, and building gully control structures (check dams), several other concepts are important and may be useful for controlling gullies.

Zeedyk et al. (2006) discusses some healing principles for gullies including:

- ❑ Disperse upland flow to prevent water concentration and increase infiltration and percolation.
- ❑ Reduce channel slope to reduce runoff velocity.
- ❑ Widen the channel bottom to lessen erosion forces.
- ❑ Increase channel roughness.
- ❑ Retain soil moisture to improve conditions for plant growth.

Gully repair or stabilization projects should begin with an assessment of the scope of the problem, the severity of the conditions, and whether water control and revegetation treatments will be adequate or if structures are needed. Global climate change, wildfires, and intense rainstorms all contribute to more potential for severe gully problems. Also, clarify the objective concerning grade control or sediment retention check dams, or both.

Methods to minimize gully problems include reforestation in the watershed above a gully and planting vegetation to reduce the amount of runoff, as well as other erosion control measures. Treatments may include large gully plugs that provide both grade control and sediment storage. Adopt a pond-and-plug design to fill in parts of the gully and establish a new waterway. A variety of check-dam designs and materials have been used, as discussed above. Reshape and design the gully area as a waterway if the water cannot be diverted. Alternatively, reshape the entire gully area to eliminate the gully, but the area needs to include diversion ditches or waterways to accommodate any flows.

Treat headcut areas at the top of the gully specifically to prevent the gully from migrating further headward. Typically, the area must be reshaped and smoothed, and backfilled with rock to form a rock-filled basin that will resist erosion. Usually, there is a drop, or change in elevation from the natural ground level to the bottom of the gully. The armoring must accommodate this drop yet remain stable. Other designs have used logs, biotechnical meansures, or materials that form steps and break up or divide the fall of the water.

References on gully control and stabilization are: “Biotechnical Slope Protection and Erosion Control” (Gray and Leiser 1982) and “Gullies and Their Control” (U.S. Department of Agriculture, Natural Resources Conservation Service 2007). The Natural Resources Conservation Service document is available at <http://www.nae.usace.army.mil/reg/nrrbs/TECHNICALSUPPLEMENTS/TS14P.pdf>.

“Gully Development and Control: The Status of our Knowledge” (Heede 1976) is a classic document and basic primer on gully formation, gully stabilization techniques, and types of control structures.

“An Introduction to Erosion Control” (Zeedyk et al. 2006) offers an overall perspective and useful suggestions for erosion and gully control, particularly for semiarid conditions. Available at <http://www.comanchecreek.org/images/links/115-Erosion%2520Control%2520Field%2520Guide.pdf>.

Roadway Surfacing Materials

Roadway surfacing materials, such as gravel, crushed aggregate, or even a rocky soil, can be useful to reduce road surface erosion. An aggregate surfacing also can make the road more resistant to washing and damage during major storm events. Roads that have had a dense surfacing material have withstood severe storm events much better than unsurfaced roads or roads with a loose, poorly graded material (Copstead and Johansen 1998). Over time, roadway surfacing is displaced or worn out and is ineffective at protecting the road surface from erosion and traffic damage. Therefore, road surface material replacement often becomes an important SDRR treatment. Fortunately many main collector roads in the Forest Service currently are surfaced with aggregate, particularly in the Pacific Northwest. However, many roads need surface replacement and many lower standard roads would benefit from armoring with a surfacing aggregate.

Key characteristics of the aggregate to be most resistant to flowing water are to have a dense gradation, be well compacted, have angular rock particles, and have adequate plasticity to resist ravel, particularly in arid to semiarid regions of the West. In high rainfall areas, such as the East, plasticity may not be desirable since it can be a source of sediment. Thus, a dense gradation with adequate fines and good compaction are all the more important.

A dense graded 1- to 2-inch (25 to 50 mm) maximum size aggregate is ideal. Coarser aggregate may seem better than a small aggregate to resist erosion, but the coarser aggregate also tends to ravel more during normal road use, likely leaving the road surface loose if a storm hits. Figure 127 shows a dense, well-graded aggregate on a forest road, with minimal ravel.

Information on use and properties of roadway materials, both for structural support and erosion control, is found in “Stabilization and Rehabilitation Measures for Low-Volume Forest Roads” (Keller et al. 2011). This document is available by chapters at <http://www.fs.fed.us/eng/php/library_card.php?p_num=1177%20 1801P>. Also see the FHWA/LTAP publication “Gravel Roads Maintenance and Design Manual” (Skorseth and Selim 2000). It is available at <http://water.epa.gov/polwaste/nps/gravelroads_index.cfm> and <http://www.mnltap.umn.edu/publications/videos/gravelroadmaintenance/documents/manual.pdf>.

Figure 127—A dense, compact, well-graded roadway aggregate that is making the road surface more resistant to erosion and washing.

6.6 General Slope Stabilization Measures

Achieving Stable Cut and Fillslopes

Cut and fillslopes are routinely constructed in new construction or road reconstruction and repair projects. Over-steep cut and fillslopes are a hazard during storm events and risk failure. Failed slopes typically need to be repaired or removed. They usually do not involve analysis, but rather are constructed at slope angles thought to be stable based on local experience and general guidelines. Guidelines are meant to produce stable slopes in most soils most of the time. If a specific problematic, unstable, or wet area is encountered, the road can be realigned around this area or the slope can be flattened, drained, or a retaining structure or a buttress built. Designs typically are site specific and may require input from geotechnical engineers and engineering geologists. Figure 128 shows the typical range of stable cut and fillslopes. Slopes steeper than those presented in the figure have a high risk of failure during a major storm event. Table 6 also presents common stable slope ratios for cuts and fills in a variety of soil and rock types. Existing slopes steeper than these values again have a risk of failure during storms.

Add simple rock buttresses, gabions, or geosynthetic reinforced soil or mechanically stabilized earth walls to improve site stability. Drainage improvements might include ditches, cutoff trenches, or horizontal drains. The use of deep-rooted vegetation is always desirable on marginally stable slopes, and it is fairly inexpensive. Live stakes, brush layers, and various soil bioengineering or biotechnical treatments with vegetation are common to improve slopes and the stability of structures.

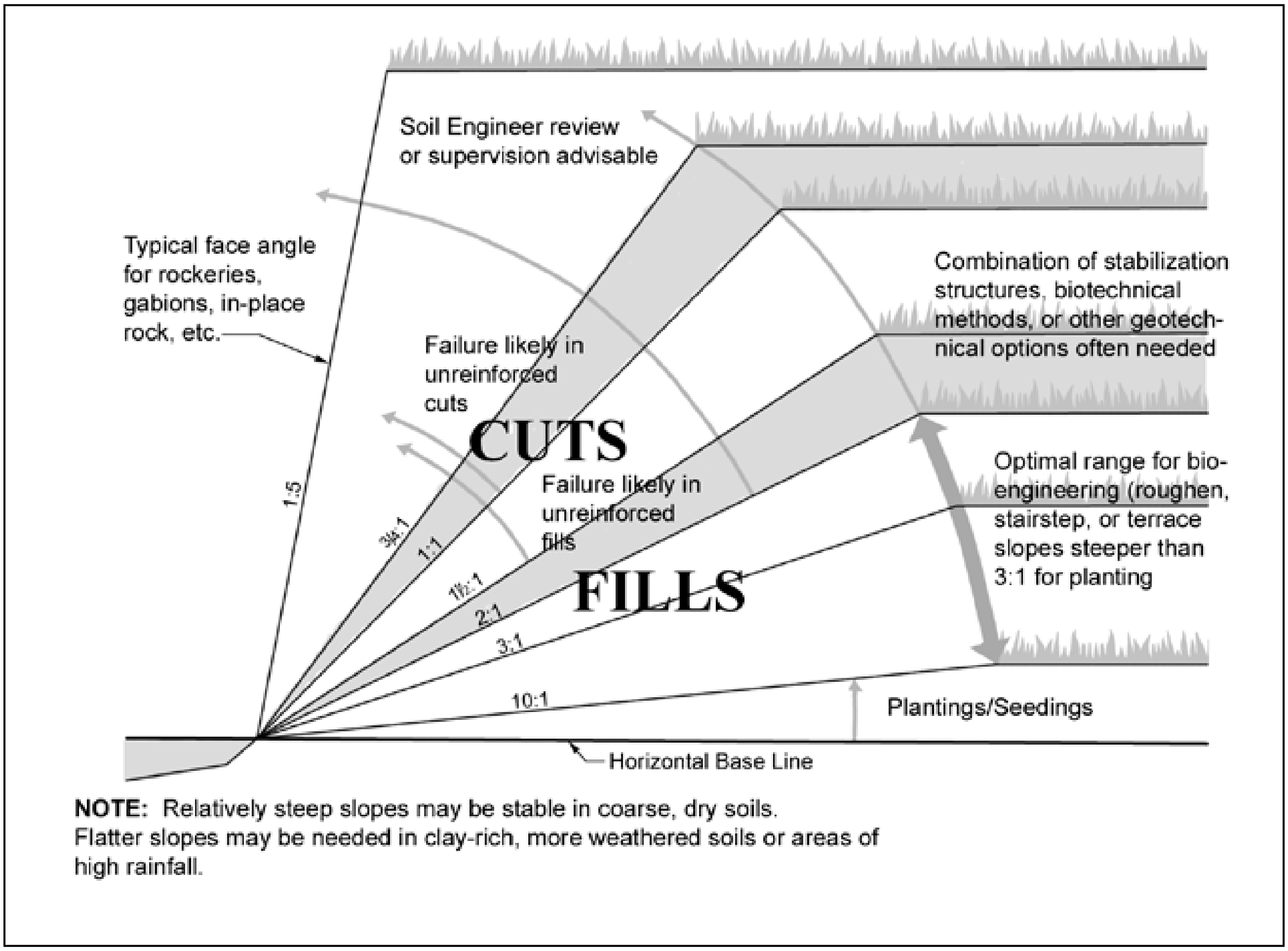


Figure 128—Typical conditions and treatments for stable cut and fillslopes. Figure is adapted from "Stream Corridor Restoration," by the U.S. Department of Transportation, Federal Interagency Stream Restoration Working Group (1998).

Table 6—Common stable slope ratios for varying soil/rock conditions

	Soil/Rock Condition	Slope Ratio (Horizontal:Vertical)
CUTS	Most rock	1/4:1 to 1/2:1
	Very well cemented soils	1/4:1 to 1/2:1
	Most in-place soils	3/4:1 to 1:1
	Very fractured rock	1:1 to 1 1/2:1
	Loose coarse granular soils	1 1/2:1
	Heavy clay soils, volcanic ash	2:1 to 3:1
	Soft clay rich zones or wet seepage areas	2:1 to 3:1
FILL	Fills of most soils	1 1/2:1 to 2:1
	Fills of hard, angular rock	1 1/3:1
	Low cuts and fills (<7-10 ft) (<2-3 m.)	2:1 or flatter (for revegetation)

Note: All slope references are shown as Horizontal:Vertical (H:V). However, current Federal Highway Administration-FP03 Specifications use a designation of Vertical:Horizontal (V:H).

Two general references on slope stability assessment, slide recognition, investigation, risk analysis, and slope stabilization treatments are:

- ❑ Transportation Research Board Special Report No. 247, "Landslides-Investigation and Mitigation" (Turner and Schuster 1996).
- ❑ The three-volume Forest Service publication "Slope Stability Reference Guide for National Forests in the United States" (Prellwitz and Steward 1994).

Links to the Forest Service documents: <http://www.fs.fed.us/rm/pubs_other/wo_em7170_13/wo_em7170_13_vol1.pdf>.

<http://www.fs.fed.us/rm/pubs_other/wo_em7170_13/wo_em7170_13_vol2.pdf>.

<http://www.fs.fed.us/rm/pubs_other/wo_em7170_13/wo_em7170_13_vol3.pdf>.

The National Cooperative Highway Research Program Synthesis 430, "Cost-Effective and Sustainable Road Slope Stabilization and Erosion Control" (Fay et al. 2012), addresses a variety of relatively low-cost solutions for slope stabilization, including vegetative, biotechnical, and structural solutions.

Cutslopes

For most cutslopes, typical slope angles are prescribed based upon the general soil or rock type found in that area and field observations. For most rocky, silty-to-sandy soils in the Western United States, cutslopes of 1:1 or 3/4:1 (H:V) are used. In rock cuts and rocky or cemented soils, use near vertical cutslopes, or use a 1/4:1 slope, as shown in figure 129. In clay rich, fine-grain soils or zones of saturation, flatter slopes such as 2:1 or 3:1 may be required for stability.

A balanced cut-and-fill design is used in gentle terrain with slopes less steep than 50 percent where material excavated from the cutslope is placed into the adjacent roadway fill embankment. On slopes in the 50- to 65-percent range, the suitability and stability of balancing the cut-and-fill material should be evaluated carefully, depending on local soil conditions. On steeper slopes, a steep full-bench cutslope is used with no fillslope. Note that stable cutslope angles are very particular to local soil, weather, and groundwater conditions. Local experience is invaluable. Values presented in this publication should be adapted for your local conditions and based upon local observations.

Fillslopes

A slope of 1 1/2:1 to 2:1 is recommended for fillslopes constructed with the majority of common soils. Rock fills can be stable on slopes as steep as 1 1/3:1 or even 1:1 with angular rock and careful placement. To achieve good vegetative stabilization on a constructed fillslope, the slope should be 2:1 or flatter, especially for low fills.

Figure 130 shows the construction of typical fills under a variety of conditions and natural ground slopes. Routine fills or through fills placed upon relatively flat ground, with a slope less than 30 percent, are commonly built with a

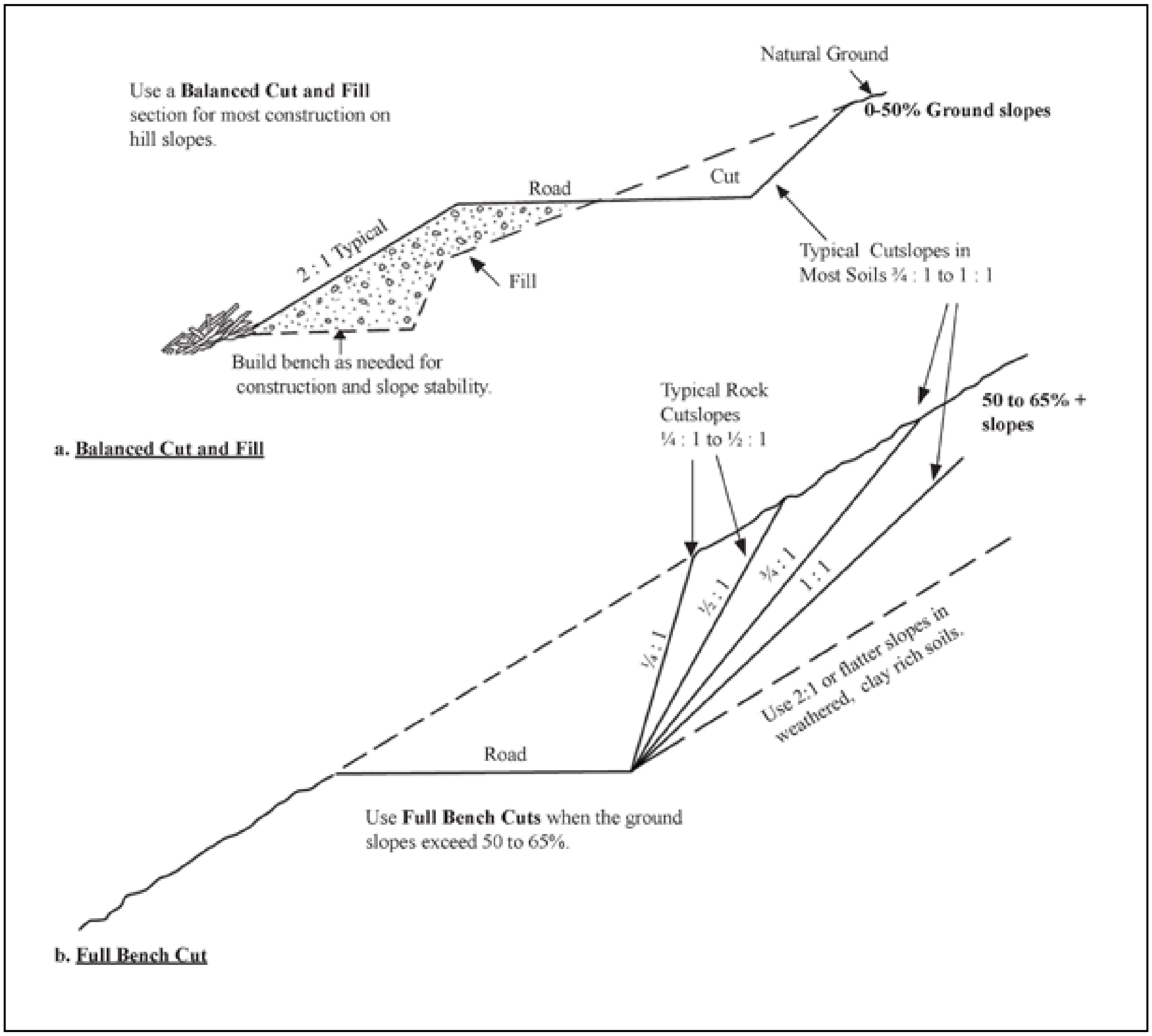


Figure 129—Commonly used stable cutslope angles.

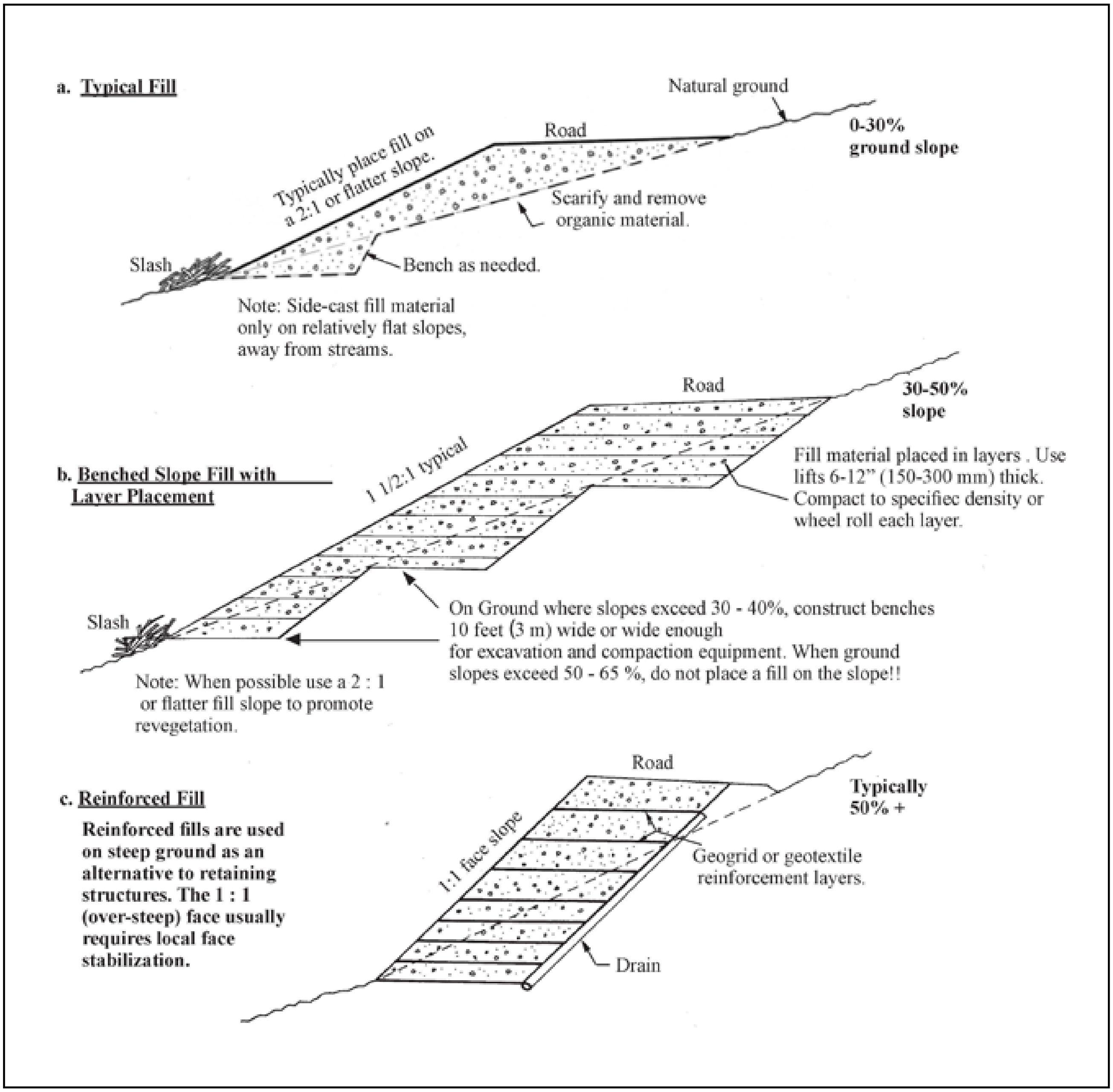


Figure 130—Common fillslope design requirements and slope angles.

1 1/2:1 slope. If the ground is relatively flat and a fillslope will easily catch and not be excessively long, a 2:1 or flatter fillslope is used to help promote the growth of vegetation. On ground slopes steeper than 30 to 40 percent, place the base of the fill upon a terraced surface to key the fill into the slope and prevent a failure along the plane of contact between the fill and natural ground. The foundation is critical to the fill's stability. On slopes over 50 to 65 percent, construct a full-bench road and no fill. Alternatively, design and construct a reinforced soil fill, using layers of geosynthetic reinforcement. End-haul excavated cutslope material to a designated stable disposal area or fillslope area on flatter ground.

Thin sliver fills are a common problem on old roads where construction was done by sidecasting the fill material on steep slopes. The material may only be 2 to 4 feet (0.6 to 1.2 meters) wide at the road surface elevation. These slopes commonly have failures or problems with settlement, particularly during major storms. Repair of these sites by pulling back the fill material was described in section 5.6. Also, using relatively flat fillslopes or avoiding fillslopes and using full-bench construction might be considered at the approach to stream channel crossings, particularly if the stream channel or sideslopes are deeply incised or steep. This will minimize sidecast material getting into the stream channel.

Increasing Stability with Structures

Retaining structures are used in many applications with roads. Their primary use is to resolve a space constraint in steep ground, where a wall is needed to support the roadway in a tight location and to avoid a large cut or fill. They also are used to rebuild the roadway where fills fail to avoid cutting into a hillside in a slide area, to support a roadway across a steep, narrow saddle, to buttress a marginally stable slope, and to provide vertical, low-profile abutments for bridges. The Forest Service publication "Retaining Wall Design Guide" (Mohney 1994) offers a comprehensive coverage of basic retaining walls, their use, selection, design details for a variety of wall types, and sample calculations. It is available on the Association of Environmental and Engineering Geologists, Geoscience Library Web site under section 5, Transportation Geology, Low-Volume Roads Collection, Slope Stability Issues. (To access this site, you must register initially with GeoSci Library at <http://www.geoscilibrary.org>.)

Retaining walls are relatively expensive structures so they are not routinely used for SDRR work. They should not be used without looking at other options, such as road relocation, cutting into the hillside to place the road prism on a full bench, using a reinforced or rock fill, and so forth. However, when needed, walls offer a positive solution to support the roadway. Their use can avoid creating additional slope stability problems, avoid long fillslopes that may be erodible or unstable, and keep the toe of fills out of drainages (all of which can have adverse environmental impacts). Walls constructed into cutslopes need to be designed and constructed to allow ditch cleaning without undermining the wall or damaging its facing.

Design and construct walls considering the existing or potential failure plane of any slide and the depth of failure. Determine the size and height of the wall based upon slope stability analysis to ensure that the structure will have enough mass to resist the driving forces of the slide or slope. A wall needs to be deep (tall) enough to have its base placed upon firm, in-place material (ideally bedrock) below the depth of slide movement or a slide plane. Build walls with a subsurface drain behind the structure. In some cases a lightweight structure, constructed with sawdust, shredded tires, or geofoam, can be designed to minimize the driving forces if the wall is placed on a slide or has a marginal foundation material.

Several basic types of retaining structures exist, with a variety of wall options within each type. The fundamental types are:

- ❑ Gravity retaining structures where the mass of the structure resists sliding and overturning, such as gabions, cantilever concrete, concrete blocks, or cribwalls.
- ❑ Earth reinforced systems where the backfill material is actually reinforced with reinforcing layers of material, such as welded wire, geogrids, or geotextiles, to form a composite unit, which becomes the wall.

- ❑ Special types, such as cantilever H-piles or tieback walls, which are used in special applications, such as high walls on very steep slopes or bedrock areas to avoid excavation.
- ❑ Simple rock buttresses also are used in many small slump repairs.

Figure 131 shows two simple retaining structures, a rock buttress (a) and a gabion retaining wall (b).

Alternatively, less expensive soil bioengineering or biotechnical measures, such as live crib structures, vegetated rock walls or vegetated gabions, which rely both on the engineered structure and the anchoring effects of roots from vegetation, may be appropriate for small slopes. Consult a geotechnical or geological engineer when selecting and designing retaining structures.

Figure 131—Commonly used retaining structures, such as a rock buttress (a) and a gabion wall (b).

Gravity Structures. The most common gravity structures are those made of reinforced concrete, cellular bins, gabions, masonry, dry rock walls, or large rocks. The size of the structure depends on the height of the wall needed to fit the site and provide the desired roadway width and elevation, loading conditions on the wall, and allowable foundation conditions. Common heights for gravity structures are a few feet (a meter) to 25 feet (8 meters). Above this height, gravity structures become relatively difficult and expensive to build. For simple gravity structures, the base width typically is about 0.6 to 0.7 times the height to achieve a stable design for simple loading conditions. With traffic loading, the base-to-height ratio ranges from 0.6 to 0.8. For a hillslope immediately above the wall, the base-to-height ratio ranges from 0.7 to 1.0. A wider base may be needed for unusual conditions, such as a soft foundation, high lateral loads, or seismic loads. Set any structure onto firm, in-place materials.

Also, use gabions in stream channels to buttress the toe of a fillslope and prevent scour of the fill, or for streambank protection, particularly on the outside bend of a stream near a structure. They are an alternative to loose rock riprap or other bank stabilization measures. However, with time, the wire baskets will corrode or wear through from abrasion. After 20 to 30 years, many gabion structures in a stream environment begin to fail. Their life can be maximized by use of galvanized or plastic-coated wire. Gabions also are susceptible to piping of soil under or behind the basket, so install them on a filter blanket, such as a geotextile.

Earth Reinforced Systems. Today, use of earth reinforced systems, reinforced soils, geosynthetic confined soils, or mechanically stabilized earth (MSE) walls, as they are commonly called, offers an economical and effective alternative to traditional gravity type structures for most wall heights and applications. Actually, the use of reinforcement fibers to strengthen soil has been a concept used since biblical times. For walls over 25 feet (8 m) high, MSE walls offer significant cost advantages over gravity structures. In the case of rural or forest low-volume roads, where the access may be very difficult and when the budget is limited, the use of prefabricated or lightweight materials, combined with local or onsite soils, as used in MSE technology, generally is recommended.

Soil reinforced gabion designs also have been developed where typical gabion baskets form the face and gabion wire mats are used to reinforce the backfill. Reinforcing spacing is typically 3 feet (1 m) (the height of a basket). The length of reinforcement is a function of the wall height and loading conditions, similar to other MSE designs. Advantages of this design are the comfort people have using traditional gabion baskets, combined with reinforced soil technology. Fewer baskets go into any moderately high wall compared to a conventional gravity structure and use of a reinforced soil backfill reduces cost. Figure 132 depicts the construction process of a reinforced soil wall with a gabion face.

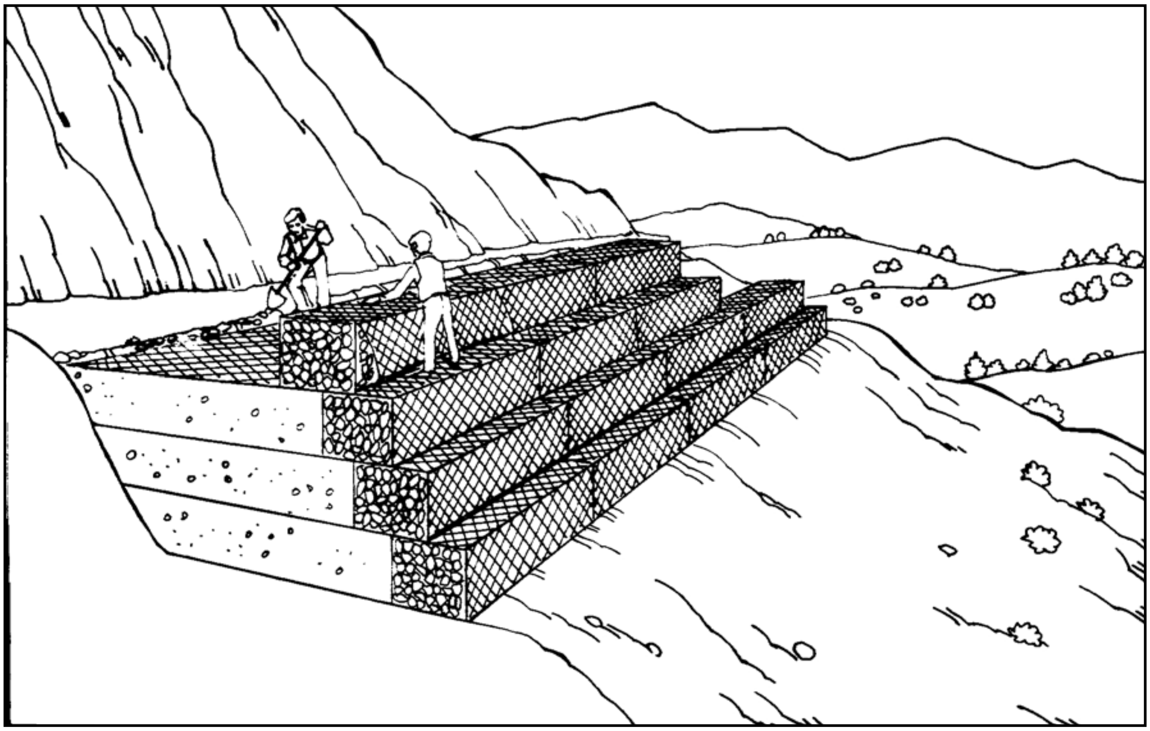


Figure 132—A soil reinforced gabion design. (Terramesh, courtesy of Maccaferri Gabions Inc.) Note that this design could easily be improved by incorporating layers of vegetation between the baskets.

Reinforced soil or mechanically stabilized earth retaining structures use strength properties of wire or geosynthetics and soil reinforcement concepts. MSE structures include welded wire walls, geotextile reinforced walls, modular block walls, lightweight wood or sawdust walls reinforced with geosynthetics, and so forth. MSE walls use a variety of facing materials, including tires, wood beams, straw bales, modular concrete blocks, gabions, concrete panels, geotextile or turf reinforcing mats, and other facings. Soil reinforcement commonly is achieved using geotextile and geogrid reinforcing layers, though welded wire, chain link fencing, metal bars, and metal strips have been used. MSE structures are most commonly constructed today because of their flexibility, minimal foundation pressure, ease of construction, and relatively low cost. Figure 133 shows two earth reinforced (MSE) types of retaining structures commonly used on forest roads. Note that the geotextile reinforcing and facing shown on the photo on the right will degrade with time, often a few years, when exposed to the sun. Thus, at a minimum, add some ultraviolet protection, such as an application of asphalt emulsion, and ideally a durable permanent facing, such as shotcrete or concrete.

Figure 134 shows a typical drawing for a relatively simple MSE wall using geotextile for reinforcement and a geotextile-wrapped face. Note that the face does need to be protected in some way against damage from ultraviolet light (the sun) and possibly vandalism. Note again that layers of vegetation could easily be introduced between the layers of geosynthetic reinforcement to improve both the long-term stability and the aesthetics of the structure.

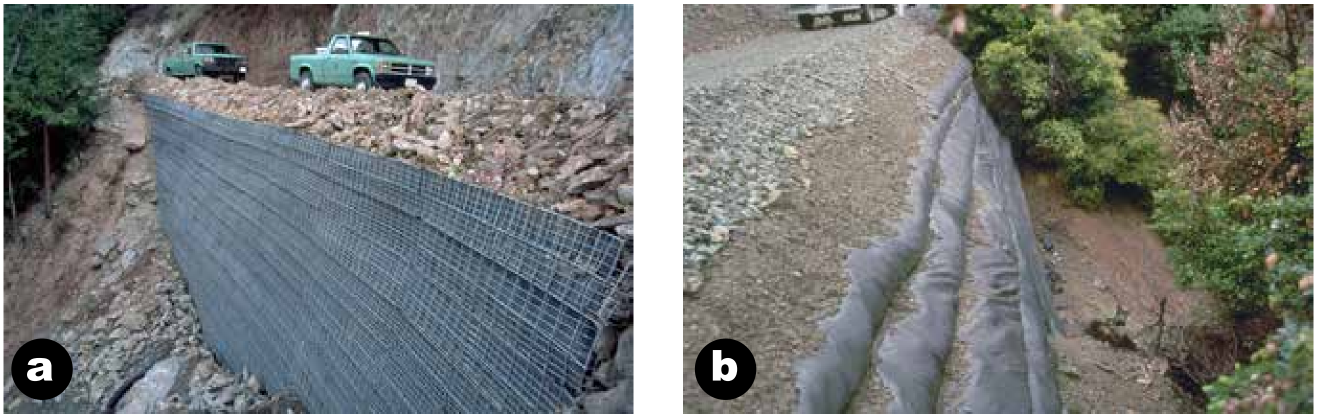


Figure 133—A welded wire MSE wall (a) and a geotextile wall (b), both used because of their relatively low cost and ease of construction.

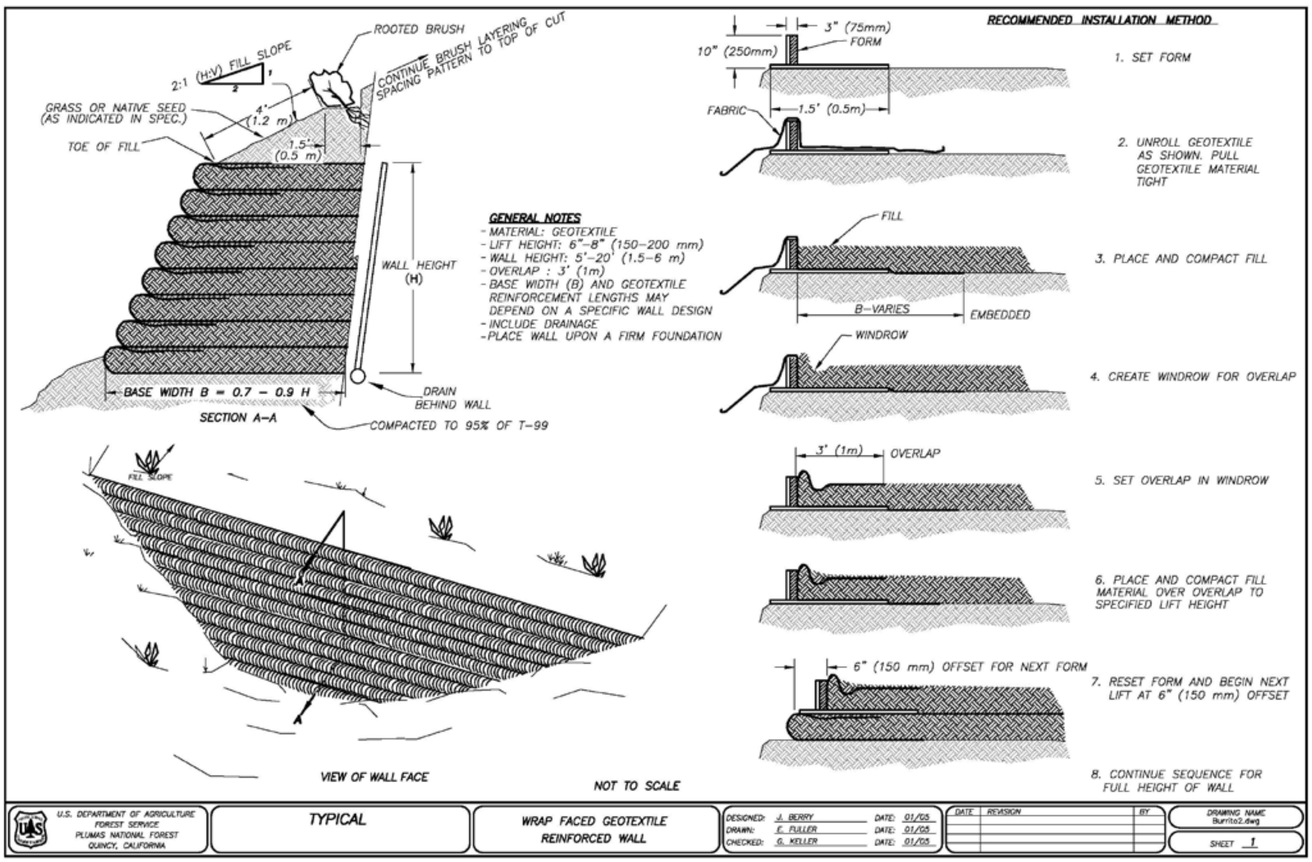


Figure 134—Typical drawing for a simple geotextile faced retaining wall.

Comprehensive information on MSE wall design and construction is found in the FHWA publication titled "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes," Volume 1 and 2 (Berg et al. 2009). Additionally comprehensive information on general use of geosynthetics is found in the FHWA publication "Geosynthetic Design and Construction Guidelines – Reference Manual" FHWA-NHI-07-092 (Holtz et al. 2008).

Drainage Improvements

Localized wet areas, clay-rich or deeply weathered soil pockets, and shear or fault zones require relatively flat cutslopes to reduce the risk of failure. Seeps, springs, or wet areas, often recognized by water-loving vegetation, almost always require special consideration and drainage. In any excavation, the water table should be below the exposed surface (where practical) to prevent instability. If an excavation opens a wet area, or a fill is placed on a wet area, take extra measures to drain the slope, flatten the slope more than normal, or buttress the toe of the slope. A stable wet slope angle may be roughly half the angle of the same stable dry slope. Drain slopes using surface ditches, cutoff trenches, collection galleries, horizontal drains, and so forth as discussed below.

Use drainage measures, including cutoff trenches or underdrains (figure 135), toe drains, drainage blankets or filter blankets (figure 136), or horizontal drains to remove the water and lower pore-water pressures within the slope. Any reduction in the water table or pore pressures in the slope will improve slope stability. Place underdrains, as seen in figure

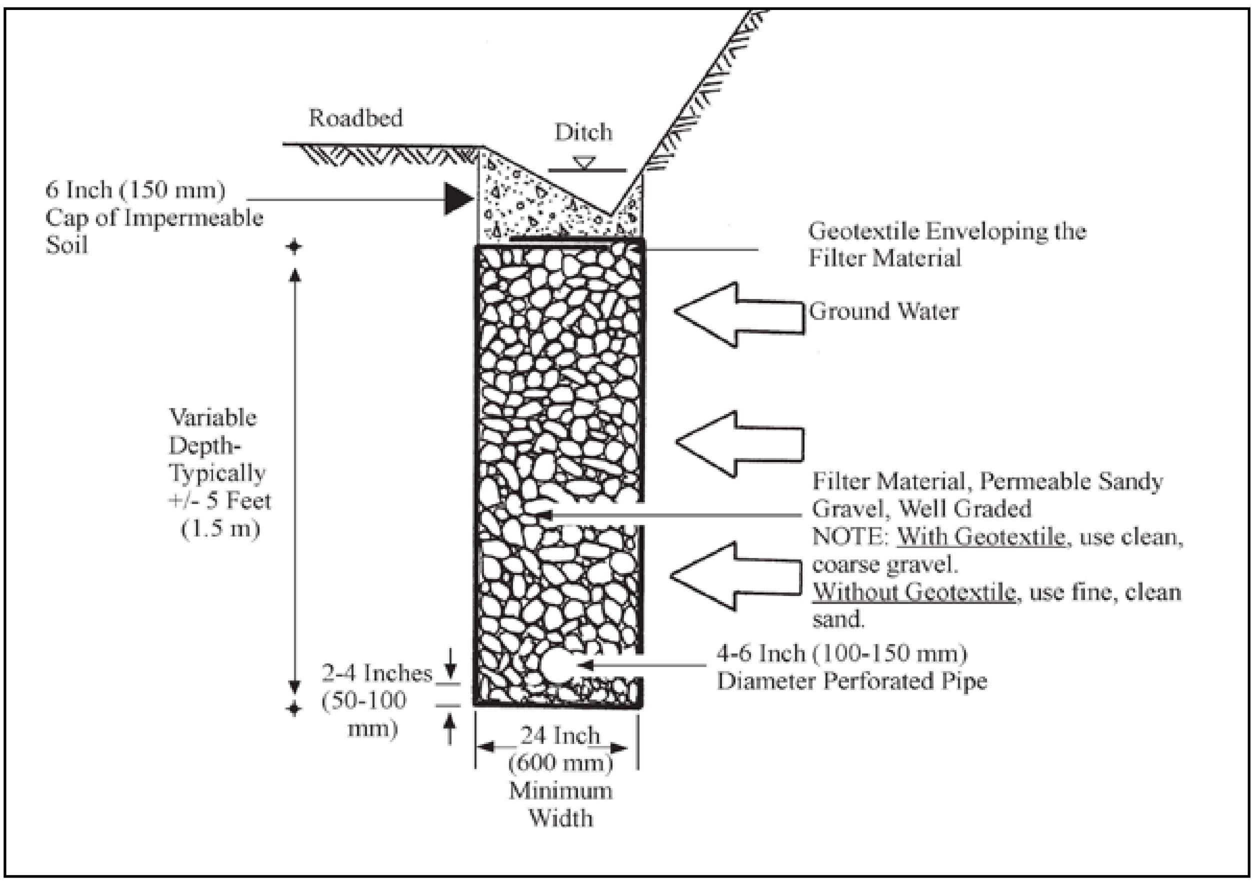


Figure 135—Typical road underdrain or trench drain, enveloped in a geotextile, used to remove subsurface water.

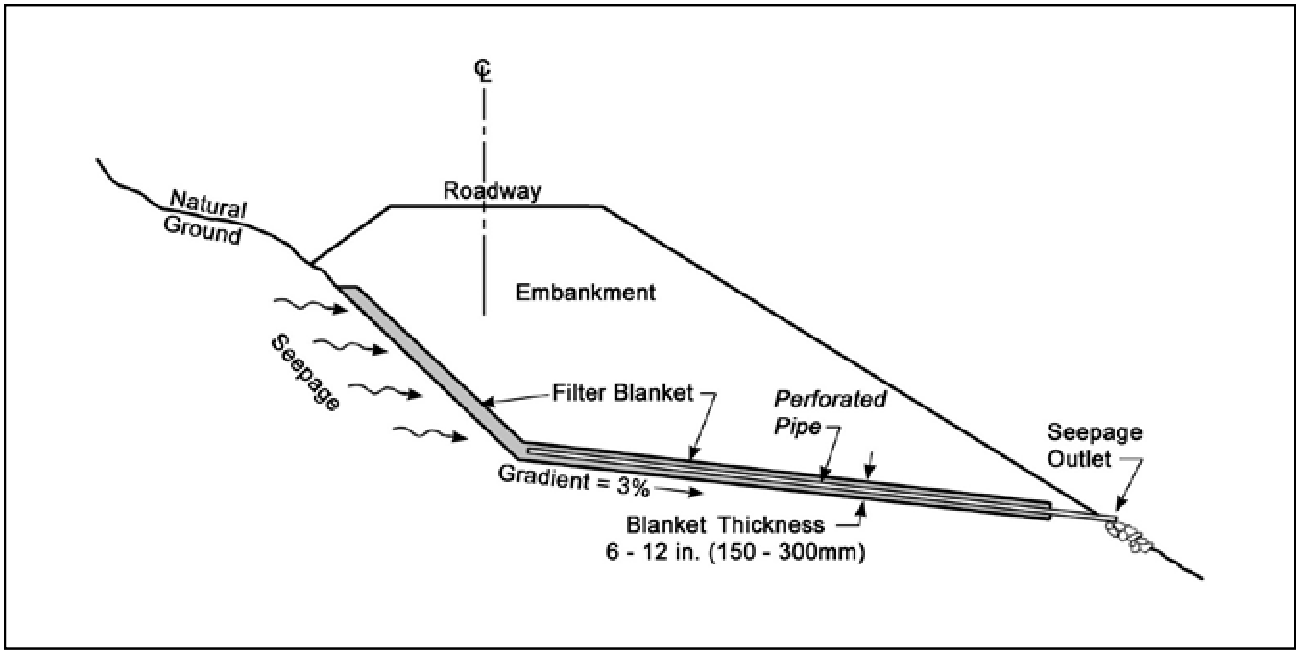


Figure 136—A filter blanket drain used under a fill to provide subsurface drainage for the fill placed upon a wet or spring area.

135, along roads in wet cutslope and seepage areas. They typically are constructed with a filter aggregate and perforated pipe wrapped in a geotextile, or with a geocomposite drain comprised of a core material and geotextile wrapped around the core to serve as a filter.

Drainage measures typically are less expensive than walls, buttresses, slide removal, and so forth, and can greatly improve the slope's factor of safety. However, drainage measures often are difficult to predict in terms of effectiveness and reliability. Install piezometers (water level monitoring or observation wells) if necessary to measure the groundwater level and the effectiveness of drainage measures.

Install deep internal drains, such as the horizontal drains being drilled in figure 137, to lower the groundwater table and to intercept groundwater before it reaches the face of the slope. A road cut may intercept groundwater that creates high pore pressures within the cutslope. This increases the risk of a cutslope failure. Horizontal drains change the direction of the groundwater flow, remove water, and reduce the water pressure before water reaches the face of the slope. The Washington State Department of Transportation has a publication that offers a comprehensive treatment of groundwater issues and horizontal drain designs, "Design Guidelines for Horizontal Drains Used for Slope Stabilization." The publication is available at <http://www.wsdot.wa.gov/research/reports/fullreports/787.1.pdf>

Figure 137—Horizontal drains being drilled to drain groundwater and stabilize a large landslide.

Use of Deep-Rooted Vegetation or Soil Bioengineering/Biotechnology

Vegetative slope stabilization is achieved using soil bioengineering methods or biotechnical methods, particularly for shallow failures. Vegetation use is encouraged since it is relatively inexpensive, though labor-intensive, and it improves slope stability. Advantages of soil bioengineering are low initial cost; a visually pleasing result using natural, biological systems; and minimum long-term maintenance.

Vegetative stabilization works well on most projects (as mentioned in section 5.5). Vegetation as a slope treatment and the benefits of root strength are shown in figure 138. Vegetative and soil bioengineering measures are appropriate for surface erosion control and shallow slope failures, such as debris slides and small cutslope failures. Do not use vegetative stabilization by itself for stabilizing large and deep-seated slides. Use deep-rooted shrub and tree species rather than shallow-rooted grasses for most slope stabilization applications. Conservation of topsoil is encouraged for later placement on slopes to aid in the process of slope revegetation. Also, vegetation and slash placed at the toe of any slope or fill will help control erosion and trap sediment coming off that slope. Figure 139 shows photos of cutslopes stabilized with vegetation.

Live stakes for slope stabilization are shown in figure 140 as a drawing and a photo. Brush layering (figure 141) also is a very effective vegetative soil bioengineering technique for slope stabilization. Figure 142 shows an entire hillslope being stabilized using brush layering. Ground cover with grasses, ideally mixed with deep-rooted shrubs and trees, also is effective for erosion control and preventing surface instability.

As also discussed in section 5.5, biotechnical stabilization is a combination of vegetation and conventional structures used for slope stabilization. Some of the more common types of biotechnical slope stabilization measures include live cribwalls, vegetated rock walls and gabions, and vegetated reinforced soil slopes. These treatments depend on the strength and design of the traditional structure combined with the supplemental benefits of root strength and the long-term durability and aesthetics of vegetation. Figure 143 shows photos of two vegetated live cribwall designs, as well as sketches of a vegetated rock wall and a vegetated reinforced soil slope. In vegetated reinforced soil structures, the roots of the woody vegetation have a very real and important stabilizing role as they knit the system together. Root penetration through the geosynthetic is anticipated to provide a composite root/geosynthetic structure with a net gain in reinforcement strength.

Strengthening Existing Structures

Soil Nails

Launched soil nails are a rapid, economical alternative to recurring maintenance or other reconstruction solutions, particularly for road-shoulder failures. Often workers can fix several small fill failures in one day without any excavation. They can move the launcher easily between trees and shrubs with little or no vegetation removal and little need for environmental or visual mitigation. The launcher, which is mounted on a tracked excavator, uses suddenly released high-pressure air to project steel nails up to 1.5 inches (37 mm) in diameter and up to 20 feet (7 m) in length into the soil to depths ranging from 5 to 20 feet (1.5 to 7 m). Fiberglass bars are now available that can be launched into corrosive soils. Hollow bars with drilled holes also can be launched that serve as

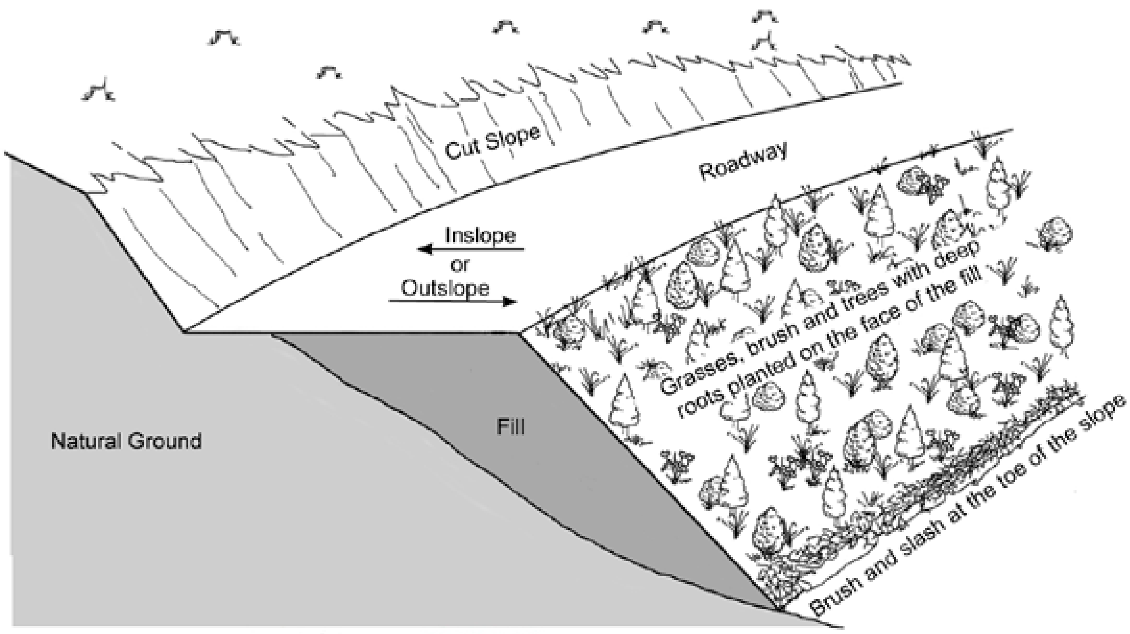


Figure A - Use of vegetation (grasses, shrubs and trees) on the face of a fill slope.

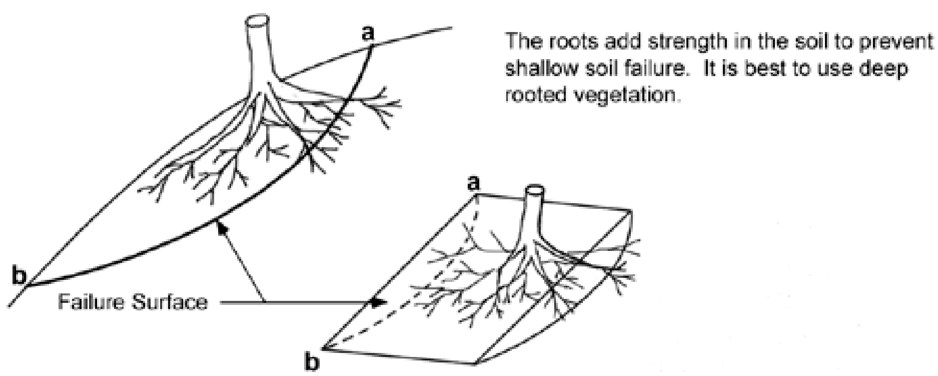


Figure B - Use of vegetation with root strength to help stabilize a slope.

Figure 138—Use of deep-rooted vegetation to stabilize slopes (A) and the benefits of root strength (B) to help stabilize a slope.

Figure 139—A variety of vegetation used to stabilize cutslopes. Selection of vegetation type depends a great deal on the local climate and environment, but deep-rooted species are critical to achieve slope stabilization. (Right photo courtesy of the Pennsylvania State University Center for Dirt and Gravel Road Studies.)

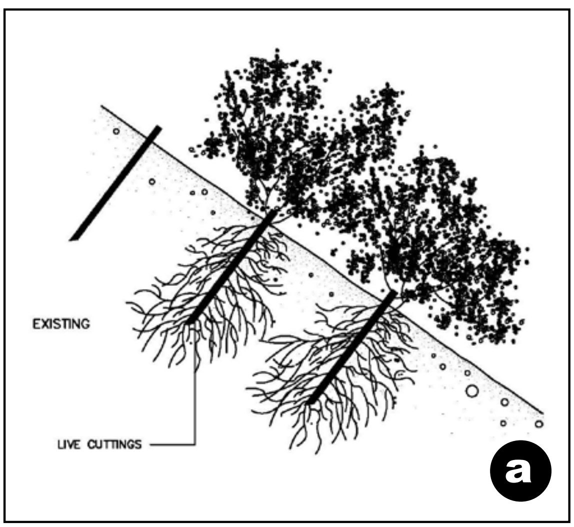


Figure 140—Use of live stakes for slope stabilization. (Sketch (a) courtesy of Robbin B. Sotir & Associates, Inc.)

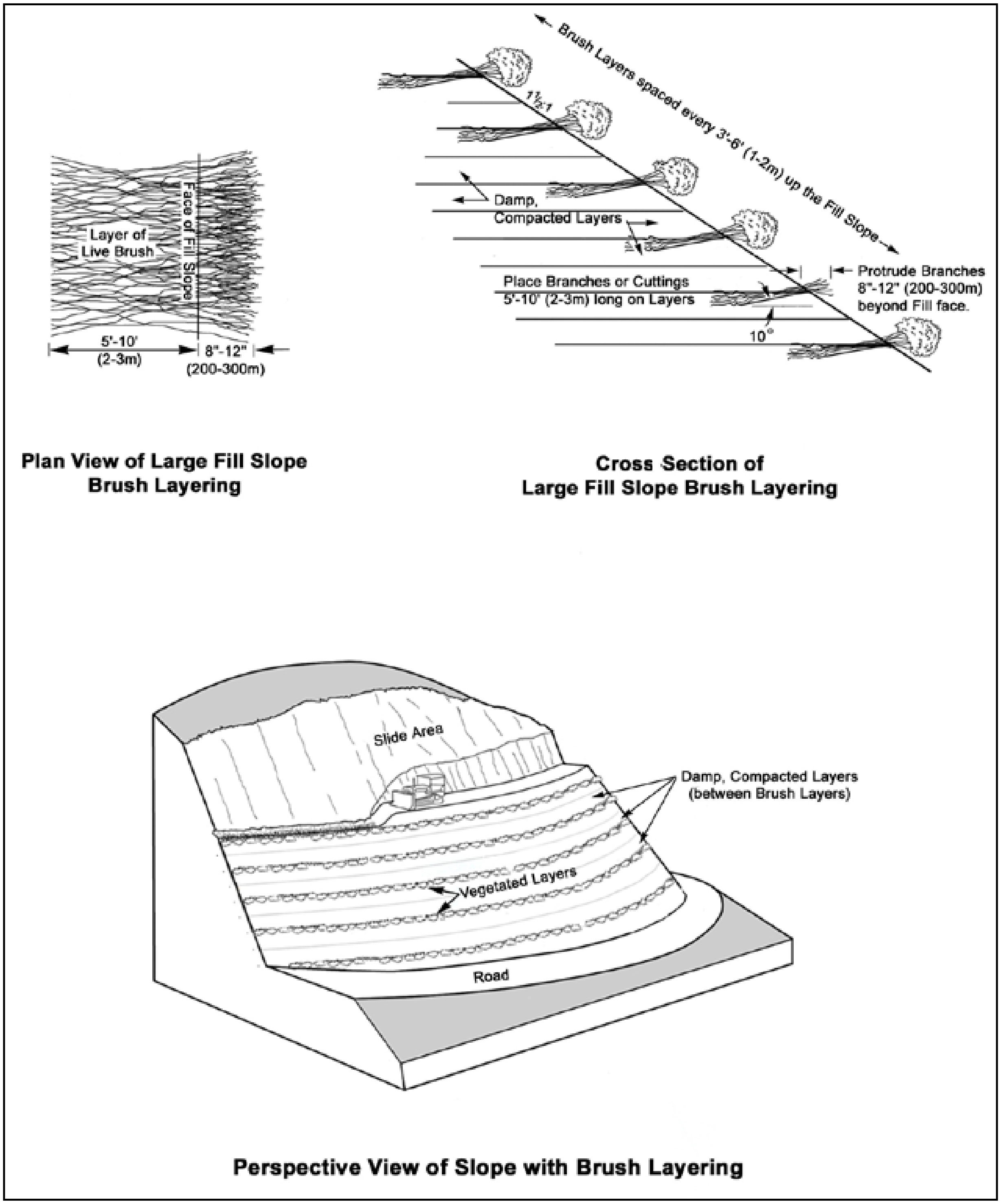


Figure 141—Brush layering used for slope stabilization and erosion control on large or small slopes. Brush layers are labor intensive but very effective, particularly for shallow slope stability and erosion control. (Adapted from NRCS Engineering Field Handbook, Chapter 18, 1992.)

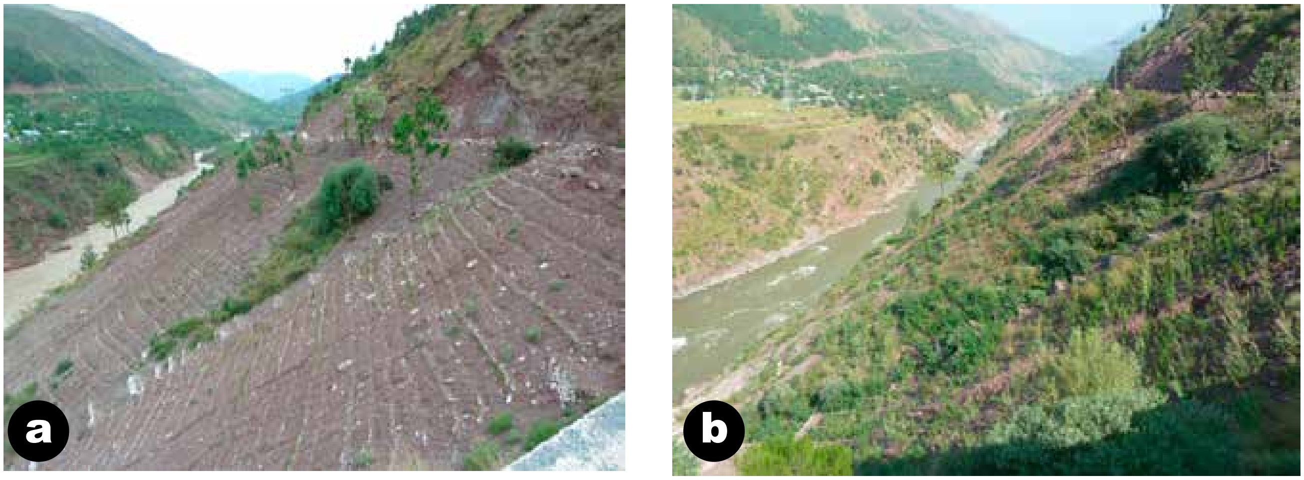


Figure 142—Before (a) and after one season (b) photos of brush layering used to stabilize an entire hillside after storm damage in Pakistan. (Photos courtesy of Asif Faiz, World Bank.)

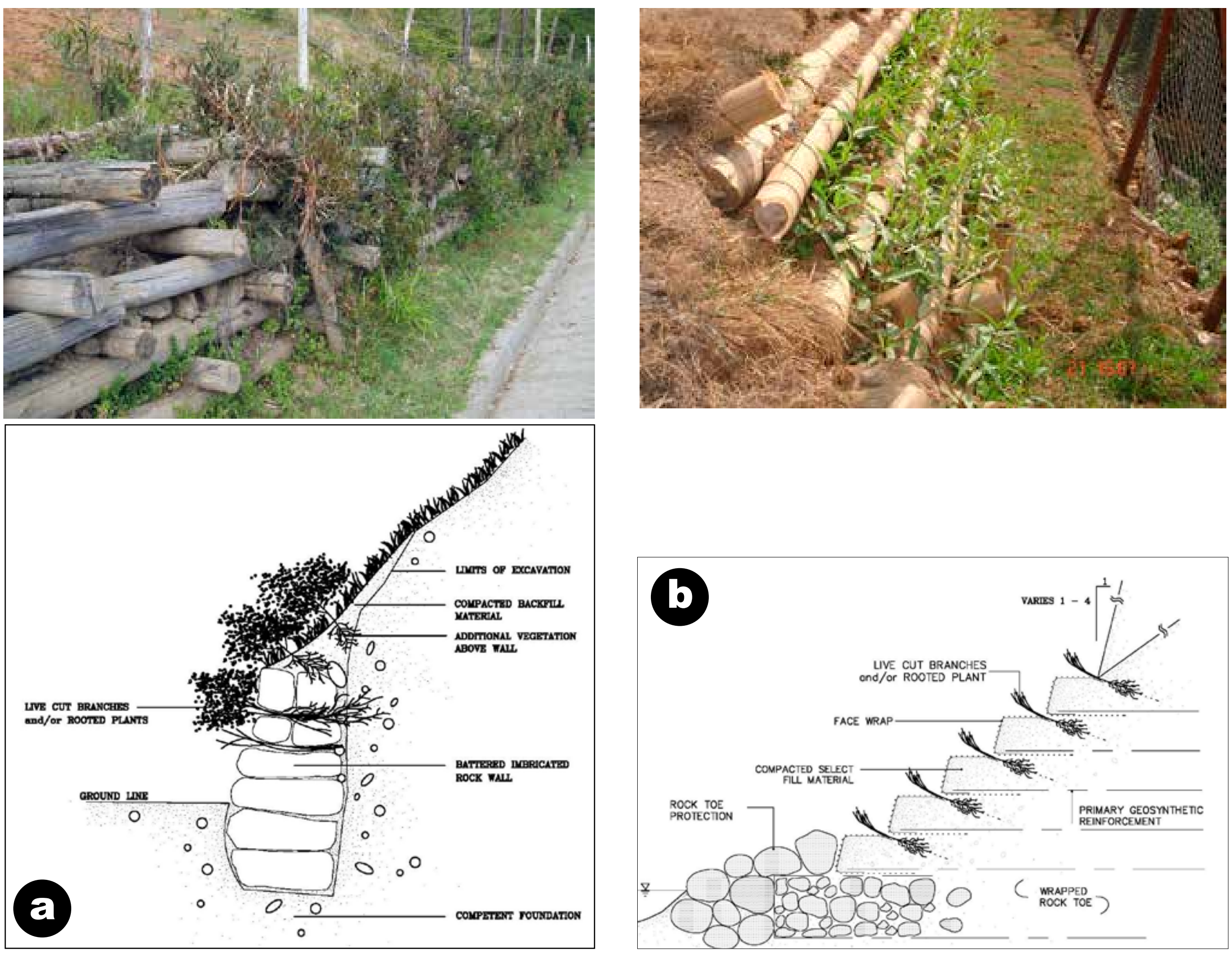


Figure 143—Biotechnical treatments using vegetation to strengthen timber cribwalls (upper photos), a rock retaining wall (a), and a geosynthetic reinforced fillslope (b). (Right photo courtesy of Neha Vyas, India.) (Lower sketches courtesy of Robbin B. Sotir & Associates, Inc.)

tensile inclusions and horizontal or vertical drains. Threaded bars can be used as well for tie downs and micropiles. The number, depth, and spacing of the nails depend on the slide geometry and loading conditions. Site investigation and analysis are needed to develop a soil-nail design.

The launcher, because it is mounted on a tracked excavator, can reach very remote locations to install nails and drains. One of its most useful applications is to stabilize roadway shoulder fill failures and shallow slides rapidly and without needing excavation for a wall that can result in long traffic delays. Figure 144 shows a sketch of a roadway shoulder failure stabilized with launched soil nails. Also use soil nails to stabilize a toe zone for the foundation of a retaining wall or launch them through some failing walls.

For additional technical information about the launched soil nails, consult U.S. Department of Agriculture, Forest Service (1994 a, b). Link to volume 1 <http://www.fs.fed.us/eng/pubs/pdf/em7170_12a.pdf>. Link to volume 2 <http://www.fs.fed.us/eng/pubs/pdf/em7170_12b.pdf>.

Currently launched soil nails is a proprietary method used by Soil Nail Launcher, Inc. Link to its Web site at <http://soilnaillauncher.com/dnn/>.

Deep Patch Shoulder Strengthening

Uncompacted sliver fills (as discussed in the previous section) often settle progressively, are a maintenance problem, and are at risk of failure. Certain maintenance approaches are considered inexpensive methods of dealing with settlement because road maintenance crews can do the work as part of their normal routine. These methods usually consist of grading over the areas of settlement and cracks (aggregate-surfaced roadway) or filling cracks and adding asphalt (paved roadway) to level the road surface. While these approaches temporarily restore the road's driving surface, the cause of the cracking and continual settlement in the road remains untreated. Grading does not stop

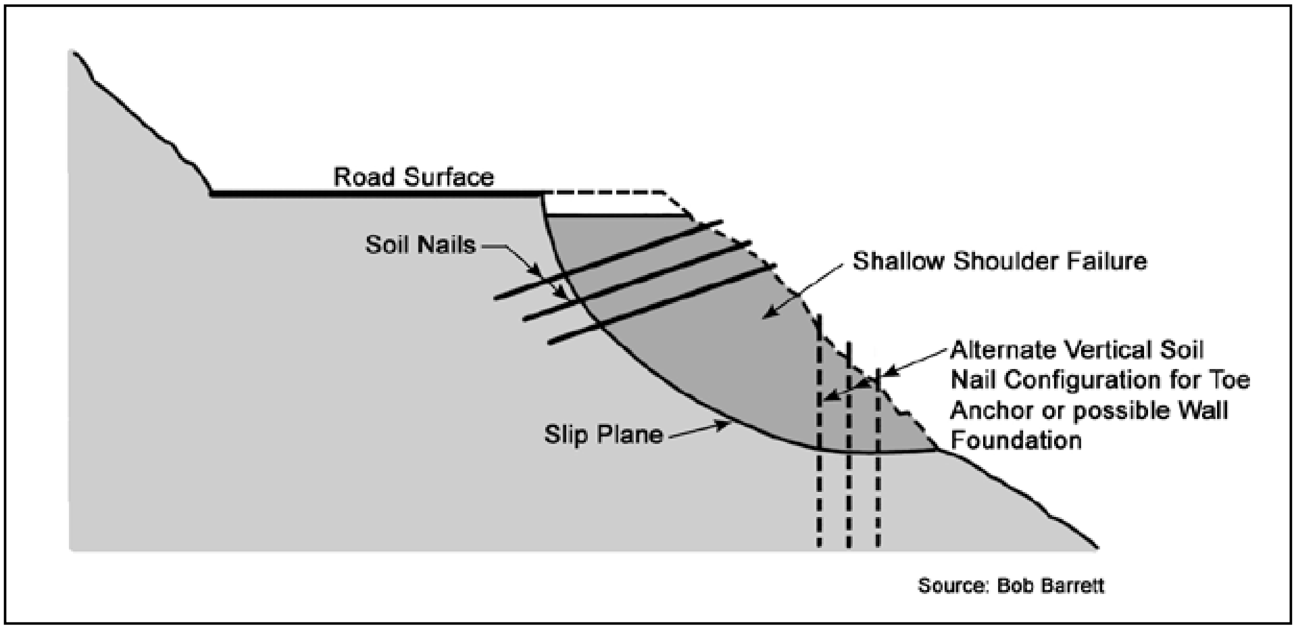


Figure 144—A roadway shoulder failure stabilized with launched soil nails. (Courtesy of Bob Barrett.)

the settlement either, but begins a long-term commitment to continual roadway repair. Deep patch, as a maintenance technique, reduces or stops the continual settlement. Deep patches have slowed, but not stopped slope surface movement on sections of roads crossing areas of large-scale slope movement. Road settlement and road maintenance costs have been reduced using deep patch repair.

The deep patch design is a shallow road-fillslope repair where the upper 3 to 6 feet (1 to 2 meters) of the subsiding section of roadway is excavated; the fill material is replaced with compacted select backfill, and several layers of geogrid or other reinforcing material are installed, as shown in figure 145. Geogrid has been the most used type of reinforcement. However, multiple layers of closely spaced geotextile (every 6 to 8 inches (150 to 200 mm)) might offer additional cost savings to this technique for road shoulder fill stabilization. Figure 146 shows a typical cross section of a deep patch design.

The cost of repairing a road embankment failure with the deep patch method depends on backfill material (type and source), type and number of reinforcement layers, and drainage (if needed). However, when compared to other methods, such as road realignment or reconstruction, or retaining structures, the deep patch generally is the least expensive option.

For additional technical information about deep patch, consult the "Deep Patch Road Embankment Repair Application Guide" (Wilson-Musser and Denning 2005). The guide describes the background, performance, design, and construction details of the deep patch technique. Link to the document <http://www.fs.fed.us/eng/pubs/pdf/05771204.pdf>.

Additionally the Federal Highway Administration and Western Transportation Institute have published "Deep Patch Repair, Phase 1: Analysis and Design" (Cuelho et al. 2012) that updates the design methodology.

Figure 145—Over-steep settling fillslope before deep patch repair (a) and a geosynthetic reinforcing material (a geogrid) being placed in a deep patch shoulder repair (b).

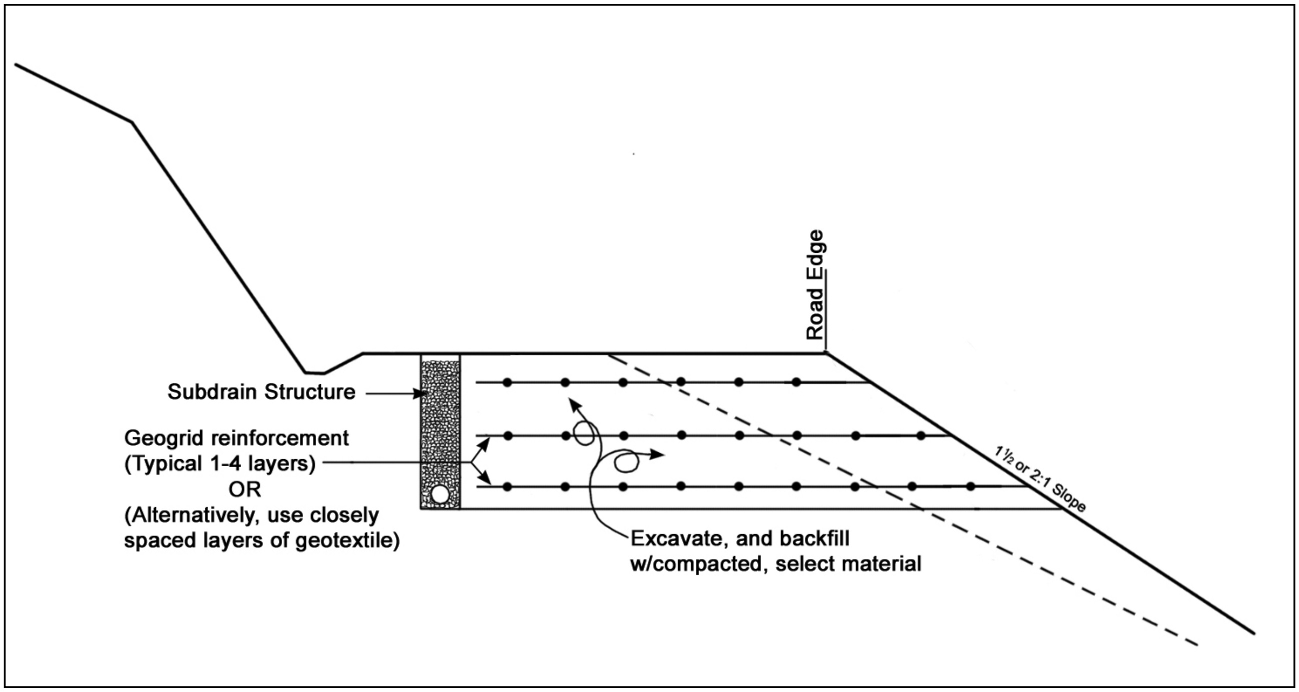


Figure 146—Cross section of typical deep patch road embankment repair.

Changing Road Grade, Alignment, and Width

The first question to be asked in cases of roads adjacent to streams is: "Can the road be relocated?" If the answer is no, or only at too great a cost, then employ onsite measures. Road realignment or narrowing a section of the road may be ways to deal with slope instability and erosion at the toe of a slope, especially if that slope toe ends at a stream. Shifting and widening into the cutbank gains space in a narrow canyon or steep area, which is often caused by a stream channel eroding and over-steepening the roadway fill. Figure 147 demonstrates this situation where a roadway fill toe was originally in the stream. After reconstruction, the road level is raised and the template shifted into the cutbank, away from the creek. Also the toe of the fill is armored with riprap along the creek. Additional discussion of this topic is found in section 6.4.

Raising or lowering the road grade may be effective for stabilizing unstable fill or cutslopes. Where a shallow fill failure surface is present at the shoulder of the road section, lowering the road grade below the failure zone can eliminate the problem (figure 148, top). Also if the cutslope is steeper than the fillslope (typically it is), lowering the grade will gain some road width. If a low cutslope chronically is unstable, raise the road bed using compacted backfill such that the added backfill buttresses the cutslope and reduces the failure potential (figure 148, bottom). If the cutslope is weeping subsurface water or surface water is present, provide drainage, such as a trench drain (underdrain) behind the new compacted backfill, or a surface ditch drain (or both).

Figure 147—Road centerline is shifted away from the river after reconstruction, with a flatter, stable fillslope and riprap armor along the river. (Courtesy of Mike Balen.)

Narrowing the road can add stability to the roadway prism either by removing part of the fill, particularly the uppermost material (as discussed in section 5.6), or by placing material at the toe of the cut, thus buttressing the cut. In either case, the slopes can gain some improvement in stability, but part of the roadway is removed or filled, narrowing the road. In some cases, an inside ditch can be eliminated by outsloping the road and some road width can be gained back. Depending on the road use, closure status, or maintenance level, this can be an acceptable, relatively expensive SDRR treatment and a viable alternative to improve marginally stable slopes and reduce the road surface area subject to erosion.

6.7 Cold Regions Storm Issues

Whether attributed to latitude or altitude, more than half the road network maintained by the Forest Service lies within what is categorized as a "seasonal frost area." Problems caused by this severe environment present a set of unique challenges for road managers. While preventive and mitigating measures from noncold regions all still apply, it also is recommended that they be supplemented by additional mitigation measures designed to deal with cold regions' storm issues. A full treatment of this subject is beyond the scope of this document. However, some of the key issues are mentioned below, along with some references on the issues.

Since problems in cold regions span the spectrum from solely temperature-induced to solely winter-storm induced, problems/damages of both types occur. Problems, such as ice weighing down and breaking trees and limbs are almost exclusively winter-storm induced. On the other end of the spectrum, problems with the pavement structure itself, such as frost heaving or thaw weakening, are caused almost exclusively by cold temperatures (although damage does not occur from cold temperatures alone; freezing temperatures must be accompanied by the presence of water, which can originate from storms/rain, groundwater, or meltwater, and frost-susceptible soils). Although this temperature-induced category falls outside the scope of this publication, frost heave and thaw weakening are major problems for roads. Most cold-regions' problems are some combination of storm impacts and cold temperature. Problems, such as ice-blocked culverts, are caused primarily by cold temperatures, but they can be exacerbated by winter storms. Another category of problems that are indirect results of winter storms include roads that are treated with salt in response to snowstorms; however, salt, itself, is the cause of other problems, such as tenting of pavements and browning of roadside trees. Problems occuring with low-volume roads in cold climates are often caused by changes in temperature from thawed to freezing, or freezing to thawed conditions. Storm events with heavy precipitation add to the problems.

Thawed-to-Frozen Condition

Sudden drops in temperature can lead to the freezing of water flowing overland, or underground. Bigger problems occur if the

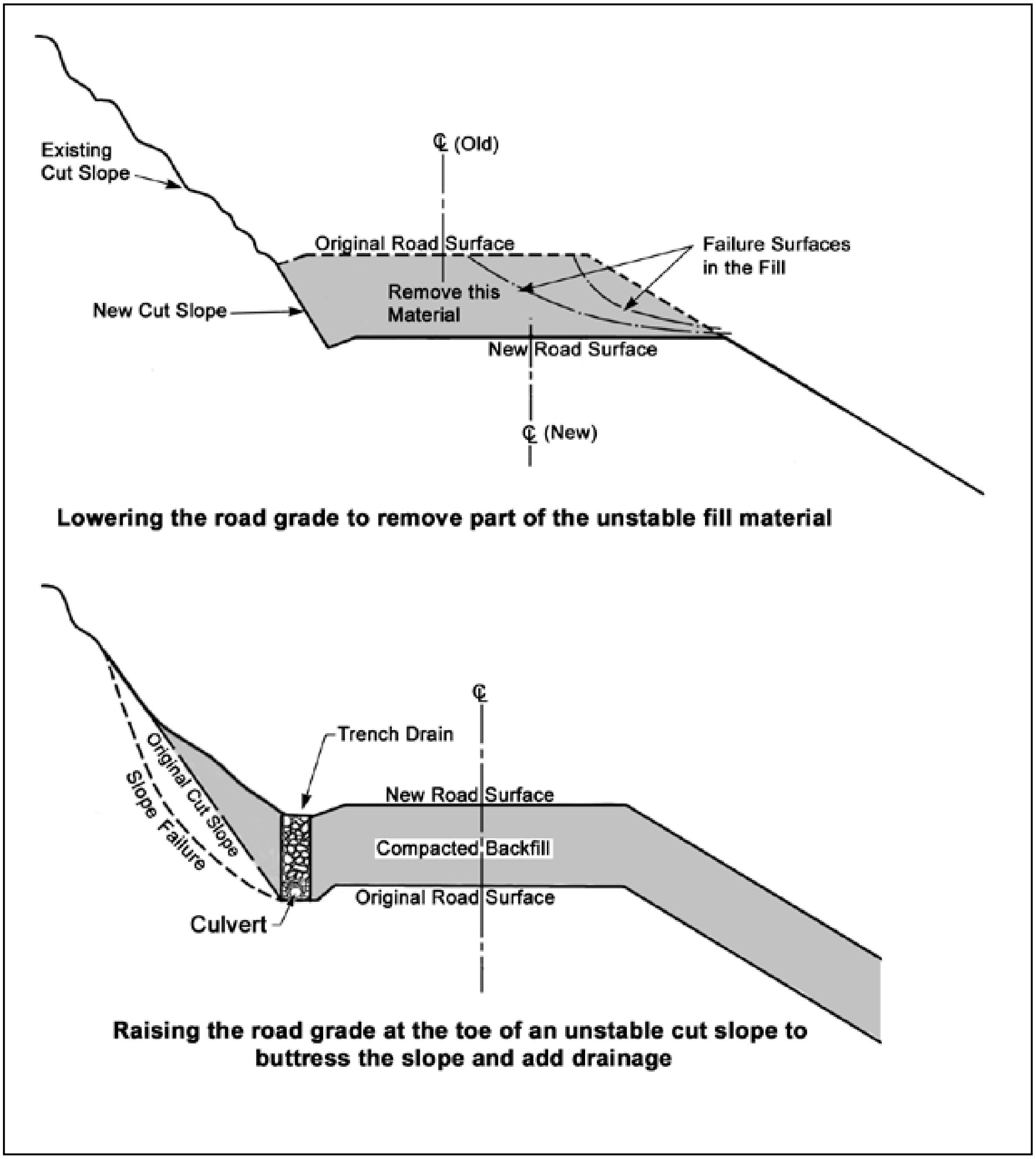


Figure 148—Raising or lowering road grade to improve slope stability. (Adapted from "Landslide Remedial Measures" Royster 1982.)

drop in temperature is followed by rain while the ground is still frozen. Freezing can cause a buildup of ice on streams, which subsequently breaks up and flows downstream. The ice floes plug culverts and jam up at bridges. Large floes also may scour the streambed. If a particular site, such as a culvert is prone to repeated jams, install ramped trash racks upstream to protect the culvert. Construct in-stream bridge piers with ramped cutwaters, which are protected with steel leading edges. When a floe encounters the cutwater, it is lifted up. Being weak in tension, the lifted, bending ice floe breaks and passes in halves either side of the pier.

The freezing of flowing groundwater may lead to icings—thick sheets of ice developing over the road surface. Construction details may be responsible for the problem. For example, groundwater, flowing laterally, encounters the relatively impermeable consolidated soils under a road embankment. With enough pressure, the groundwater is driven upwards and over the road surface. The cold temperatures freeze the water at the surface, and a thick slab of ice grows across the road, with the accretion of more and more water, freezing in place, just as it does on an icicle. Solutions include finding a better location for the road, away from the site of the groundwater flow, and directing the groundwater flow away from the road.

Frozen-to-Thawed Condition

A sharp rise in temperature can lead to rapid thawing of frozen soil or permafrost, causing a loss of bearing capacity and large settlements. Thawing permafrost can release water, which starts a progressive degradation cycle with the released water melting more permafrost, releasing more water, which melts more permafrost, cutting deeply into the permafrost and moving substantial amounts of soil.

One solution is to be careful of drainage, preventing water from contacting frozen soil or permafrost. Another is to insulate the soil or permafrost, so it does not melt in the first place. Place soil or aggregate blankets over the frozen soil or permafrost, to a sufficient depth that it never melts. Place rigid foam insulation on the frozen soil or permafrost, and cover to protect the foam. In extreme cases, install thermopiles, keeping the soil or permafrost frozen.

Imposing seasonal load restrictions, i.e., either reducing allowable load or completely prohibiting truck traffic during the damage-susceptible period, is the most common, and the most widely accepted road-usage technique to reduce damage in seasonal frost areas. Technical information on simple diagnostic techniques for determining when to place and remove seasonal load restrictions is provided in Kestler et al. (2003, 2011), and number of models are reviewed in Miller et al. (2015). Also using trucks with reduced tire pressure is not widely practiced, but serves as a viable alternative road-usage technique during the spring thaw period.

Frozen, Plugged Culverts and Ditches

Culverts that are plugged with ice can be a significant problem for road managers (figure 149). There are several techniques to address this problem. Some are after-the-fact (after the ice blockage has already occurred), and others are more preventive, but may require action or a site visit to be effective.

Figure 149—Iced culvert at milepost 2.5 on Mt. Washington Auto Road, NH. (Photo courtesy of the Mt. Washington Auto Road.)

Mitigating measures include:

1. Push a steam point through the culvert after the blockage has occurred. This works well, but uses an expensive steam boiler mounted on a truck. It also requires special training.
2. Use steam pipes permanently mounted in the culvert. There is some variation and debate on whether the steam pipe should be on the top or bottom of the culvert. Outlets typically are drilled at intervals along the pipe.
3. Use electrical thaw wires, but they must meet electrical code. (Note, a person was killed when a system failed and the water was electrified.) The system is efficient, but can only be used where there is power.
4. Use solar-powered thawing systems (which have had limited success). These systems circulate hot water through a pipe. The power to run the pumps uses solar panels. The water is also heated by the sun. These systems require a bit of maintenance and are subject to vandalism.
5. Dislodge ice with jets of water; then vacuum the ice and debris with a vacuum truck.
6. Ensure a smooth flow into the inlet. This is perhaps the most natural way to eliminate the likelihood of freezing, as ideally the flow will continue and never freeze solid. However, this is generally outside the road manager's control.
7. Preinstall electric heat tapes.

Ice-blocked ditches also can cause significant problems, as seen in figure 150. Water flowing over the road typically is most problematic in the spring. Water in ditches and culverts typically freezes due to cold winter temperatures. In the spring, ice in the culvers melts more slowly than snow on the ground surface. Meltwater running down ditches cannot pass through frozen culverts, and overflows the road. Preventive and mitigation methods are similar to those of frozen culverts.

Figure 150—Culvert clogged with ice causing water to flow across the road. (Courtesy of Dale Higgins, Chequamegon-Nicolet National Forest.)

River Ice Jams

The Army Corps of Engineers, Engineering Research and Development Center, Cold Regions Research and Engineering Laboratory (CRREL) maintains a comprehensive Web site and database of reported ice jams. Also, it provides a wealth of publications and presentations on case studies and preventive measures (figure 151).

Figure 151—Photos of ramifications of ice jams from presentation on the Cold Regions Research and Engineering Laboratory Web site.

Consultation with the Web site and publications is recommended for details. Some mitigations include the following suggestions:

1. Winter flow control can reduce ice jam flooding. (But it should also be noted, winter reservoir operation influences the natural ice regime on rivers, and affects downstream ice cover, which may, in turn, affect fish survival.)
2. Dark materials can be distributed on river ice, since they absorb heat faster, to accelerate melting. Leaves were shown to perform in a similar manner to the traditionally used dusting materials, such as fly ash and coal slag. However, unlike the latter, leaves are not believed to adversely affect aquatic organisms when applied in small quantities.
3. Tuthill (1995) reviews ice control structures. The purpose of ice control structures are either for sheet ice retention, breakup ice control, or ice diversion.
4. Haehnel (1998) discusses several additional nonstructural methods to reduce ice jams and subsequent damage. These include a variety of mechanical, thermal, chemical, and physical methods.

Other Cold Regions Problems

Other cold region storm and temperature impacts on roads include:

- ❑ Culvert differential heaving and washout.
- ❑ Longitudinal cracking in pavements.
- ❑ Localized puddling and ice buildup on roads.
- ❑ Snow drifts across roads.
- ❑ Impacts to roadside vegetation.
- ❑ Road distress from frost heaving or thaw weakening, and associated road cracking and damage.

6.8 Road Storage and Closure

The post-World War II era brought a high demand for wood products for home construction and rebuilding war damaged areas. The baby boom and increased prosperity fueled an expanding economy with an appetite for wood and places for recreation. Road systems on private and public lands expanded rapidly to access forests and keep pace with demand. The environmental movement of the 1970s clashed with the expansion of industrial forestry into undeveloped forests. By the 1980s, the pace of construction slowed as more public lands were set aside and environmental impacts from development and habitat alteration were identified. The result is a large transportation system on public lands that is no longer used as intensively. Federal road maintenance budgets were never large because maintenance was performed by the activity using the road, mostly timber management. Inadequate maintenance can result in environmental and access problems and storm damage risks increase.

A critical need now exists to bring road maintenance costs in line with budgets. One of the benefits to SDRR treatments is that general maintenance and storm damage repair costs will decrease. But the reduced costs will not be sufficient to close the gap between maintenance need and budget levels. So, as mentioned throughout this guide, when a road needs repair, the first question that should be asked is "Is this road needed?"

National forests have been directed to define a minimum road system (36 CFR (Code of Federal Regulations) 212.5(b) through a science-based process to identify the necessary transportation system and those roads no longer needed. With this mandate, managers are looking hard at road closure and decommissioning.

In the introduction to this guide, we stated that the road decommissioning is outside the scope of the document, but it may be the best management decision for a road. In the context of this guide, decommissioning is in a separate category specific to roads that will not be used again. Storage applies to roads that will be used in the future. Road decommissioning applies to roads that are no longer needed and results in the removal of the road from the maintained transportation system. Selection of appropriate decommissioning treatments is similar to that of SDRR, but is not discussed in detail in this document. Decommissioned roads are permanently blocked to traffic, drainage structures are removed, and a series of earth and rock berms or waterbars may be added that will revegetate and obscure the existence of the road. Structural barriers also may be used. In some sensitive areas, full road obliteration may be undertaken, where the entire roadway template is removed and the terrain is returned to its natural shape.

Road closure is discussed here because closed roads are expected to be used again in the future. Risks from storm damage and impacts to resources need to be considered and managed just as on open roads. Closed roads, or maintenance level 1 roads (see Forest Service Handbook 7709.59, U.S. Department of Agriculture, Forest Service 2009), are closed to vehicular traffic or stored until access needs are required again.

Road closure may be for one or more purposes and for varying periods of time. A road may be closed if it will not be used for some period of time, or if the road is causing unacceptably high maintenance costs or environmental damage. Closure may be annual, may be for a short period of time, or may last a few decades. A clear understanding of the purpose and expected duration of closure is key to determining the appropriate SDRR treatment.

Use short-term road closures (less than a year) to prevent traffic use that may damage surface drainage structures, to prevent use during wet periods or the rainy season, to protect them from erosion, or when use must be prevented for safety concerns. In most cases, short-term closure does not change the selection of SDRR treatments because the road is used at least part of the year. The same evaluation and decisionmaking process for open roads should be used in these instances. Treatments should be those that are effective at preventing erosion and other failure hazards that may occur during the time of closure. Road closure typically is a barricade or berm.

Consider long-term road closure as a way to reduce road maintenance costs. Although the long-term cost savings are less than for road decommissioning, substantial savings and reduced damage often results from proper road storage. However, the implementation costs for storage may be significant, especially for roads with high storm damage risk, and involves a more complex evaluation to select appropriate SDRR treatments. Road closure often involves input from the public and other affected road users, and may be controversial. The main reality of long-term closures is that road maintenance will be limited or lacking during the period of closure. Thus, confidence is needed in any SDRR treatments that are used.

Figure 152 shows the range of options commonly considered in road closure and decommissioning. The figure includes road decommissioning as a closure treatment. Road obliteration is the most extensive decommissioning treatment where all road features are removed. In other, less extensive decommissioning treatments, only high-risk features are removed. Figure 153 shows various road closure treatments. Block closed roads with a barricade or berm to keep traffic off the road.

Consider a number of factors when selecting treatments for long-term storage:

- ❑ Term of closure (5, 10, 30 years).
- ❑ On and offsite risk factors.
- ❑ Road age.

The term of storage and the current age of the road act in combination to suggest the susceptibility of the road to storm damage during closure. The longer the road is stored the more deterioration of road features will occur. Deterioration includes loss of ditch capacity (infilling by cutslope ravel, erosion, slope failure, or vegetation growth), settling or cracking of fill material, loss of culvert capacity (partial or complete plugging by sediment and/or debris), and degradation of surface drainage shape and features. If road drainage structures, such as culverts, are already nearing their useful life, they are at high risk of failure during a long storage period. It is prudent to remove those features since they will need to be replaced when the road is reopened and they represent a real risk of failure and environmental impact during the time of storage.

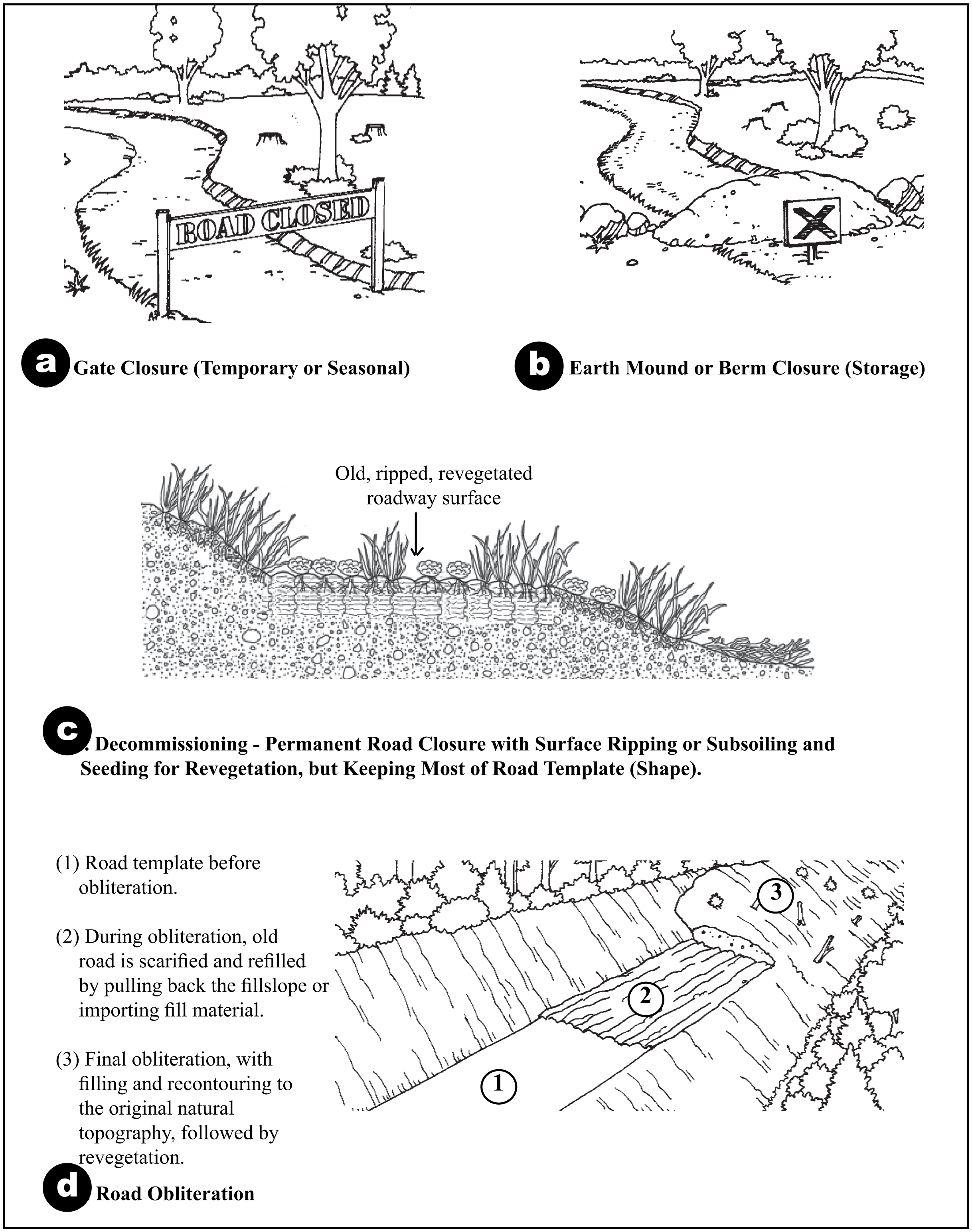


Figure 152—Road closure options, including temporary or seasonal closure, storage, decommissioning (permanent closure), and obliteration. In the context of this guide, decommissioning is in a separate category specific to roads that will not be used again. Closure and storage apply to roads that will be used in the future. Road obliteration is the most extensive decommissioning treatment where all road features are permanently removed.

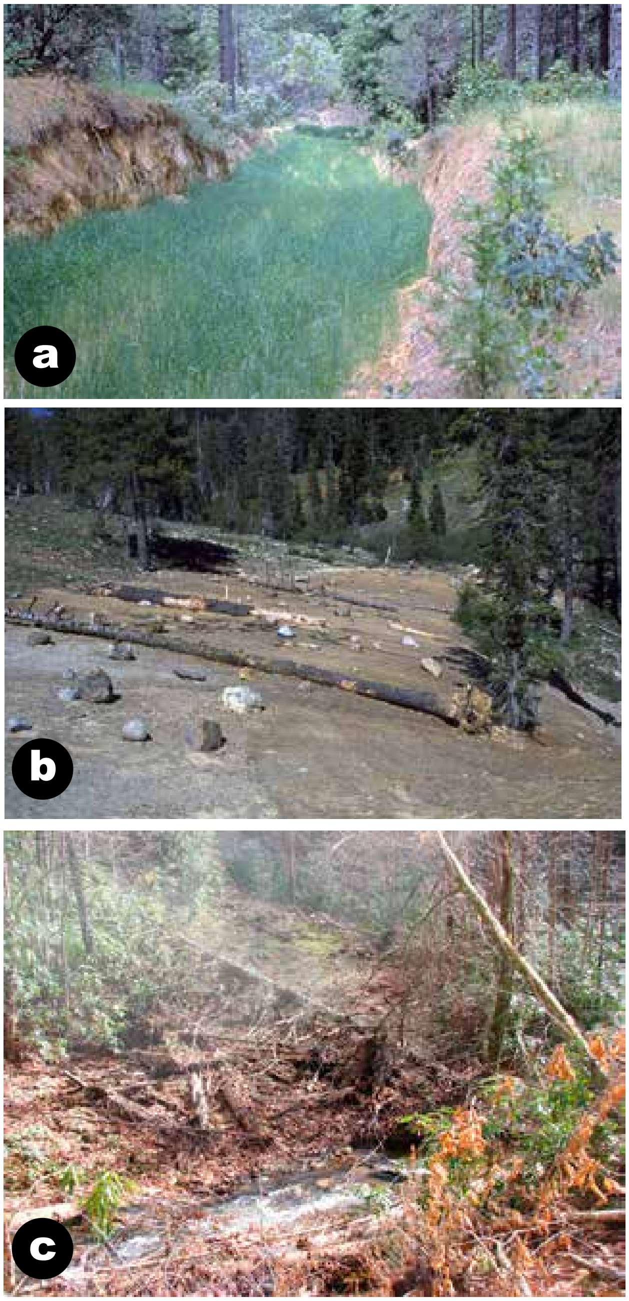


Figure 153—Examples of road closure treatments including a decommissioned road (a), an obliterated road and recontoured area (b), and closure of a road-stream crossing (c). (Lower photo courtesy of James Jones.)

Roads stored for long periods of time may require extensive reconstruction to reopen, especially in wet climates with lush vegetation. Organic litter fall will cover road surfacing and retain moisture that will seep into the subgrade, requiring substantial removal and resurfacing. Figure 154 shows examples of roads that have been placed into storage, using waterbars or berms and logs to close the road.

Figure 154—Examples of roads that have been placed into storage. Photo (a) shows a road that has been closed using a waterbar. (Courtesy of Ken McCall/Karen Bennett.) Photo (b) shows the road has been closed with a log and berm, plus some vegetation. (Courtesy of Greg Napper.)

Although the probability of a given sized storm is the same for a given year, the probability of a road suffering storm damage by a large storm is greater the longer the road is in storage. Roads that are to be stored for long periods should receive treatments that build in a factor of safety to allow for the degradation of drainage features. Schedule periodic inspections to assure all features are functioning, but realize this may not happen. Thus, a factor of safety can be achieved through sizing ditches and other features larger than would be done for an open road receiving regular maintenance, or using redundant or backup features like waterbars and dips in case of individual failures. The more factors that contribute to higher risk, the more extensive treatment will be required to assure the stored road does not contribute to environmental degradation during storage.

Roads with a number of high-risk factors and older roads that will be stored for many years will need treatments that will appear similar to those of road decommissioning. Drainage structures (culverts) will be removed; ideally, the ditch removed and the road bed outsloped; high-risk fills pulled up and the material stored in stable locations; and frequent waterbars added for backup drainage or to replace removed ditch-relief culverts.

Roads that will be stored for just a few years may only need to be waterbarred. Consider unstable fills for removal. Remove and replace high-risk stream-crossing structures when use is resumed; consider temporary (portable) bridges that do not require the replacement of large volumes of fill.

There are just as many considerations, if not more, for closed roads as open roads as they relate to SDRR. Do not skimp on the analysis for a closed road since impacts may be as important as for an open road. The analysis must look more long term to factor in the uncertainty of how long the road will stay in storage and not receive maintenance. Should all culverts be pulled or just stream crossings? That may depend on the age of the culverts as much as the risk factors. If a portable bridge will be used in the future, how should the crossing be left upon closure? If some structures are left that may need maintenance, can they be accessed? It is important to understand the landscape and watershed above a crossing, and how the terrain will perform over time.

Economics will enter into the decision on SDRR treatments for stored roads as well. The initial direct costs of storage may be high, but if the road will be stored for a long time, annual maintenance costs will be saved. Over a number of years, the savings may be substantial. Roads stored long term will need considerable work to reopen, including replacement of culverts that were removed or that have rusted, reconstruction of settled or sagging fills, reconstruction of the subgrade, reshaping the surface, and likely addition of new surfacing materials.

CHAPTER SEVEN
SUMMARY AND CONCLUSIONS

7. SUMMARY AND CONCLUSIONS

Closure or damage to forest and rural roads can present a significant hardship to rural populations and economies, particularly during a time of disaster. Considerable experience has been gained in the assessment of storm damage to low-volume roads, subsequent repairs, and implementing measures to reduce the risk of the road system to future events and associated damage and environmental impacts caused by road failures during storms. These measures are an instrumental part of storm damage risk reduction (SDRR).

SDRR assessment for both assessing vulnerability and determining needed preventative measures or repairs should involve a process of working with local land managers, engineers, specialists, and local road agencies to identify their highest priority sites. Work should include an objective inventory of the transportation system, an evaluation of on-the-ground conditions and risks, an understanding of landscape and channel geomorphic processes, and identification of SDRR options. Specify needed work on work lists and with site-specific designs. Appendix A4 is an example of a road condition form that can be useful to identify, assess, and document needed SDRR work.

Many planning, location, design, and maintenance measures exist that can greatly reduce the risk and vulnerability of low-volume roads to major storm events. Most measures involve avoiding problematic areas, having adequate designs, or controlling drainage in a positive manner. A key factor is the value of practical, cost-effective, and preferably simple measures to reduce the risk of storm damage.

Table 2 presents a summary of most of the SDRR measures used to protect roads. The most commonly used treatments are identified, as well as a list of less common or more expansive, yet useful treatments used at times.

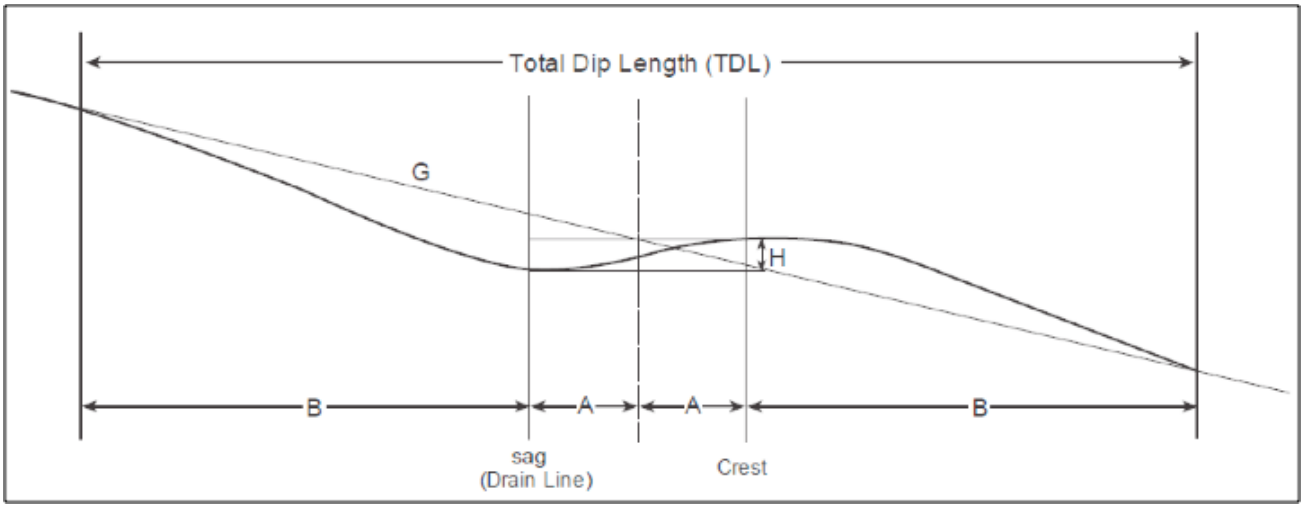
These measures include minimum road widths, frequent and well disbursed road surface drainage, use of rolling dips and fords, use of relatively flat cutslopes that will not fail, bridge and culvert scour protection, having adequately sized culverts with diversion protection, and well vegetated areas for both slope stabilization and erosion control.

Proper selection and implementation of SDRR treatments will reduce annual maintenance costs and catastrophic storm repairs. SDRR treatments can be approached on a systematic basis, following an assessment of risk and treating the highest risk sites first. Watersheds where SDRR treatments are complete are expected to show improvements in watershed condition and less damage suffered during storm events.

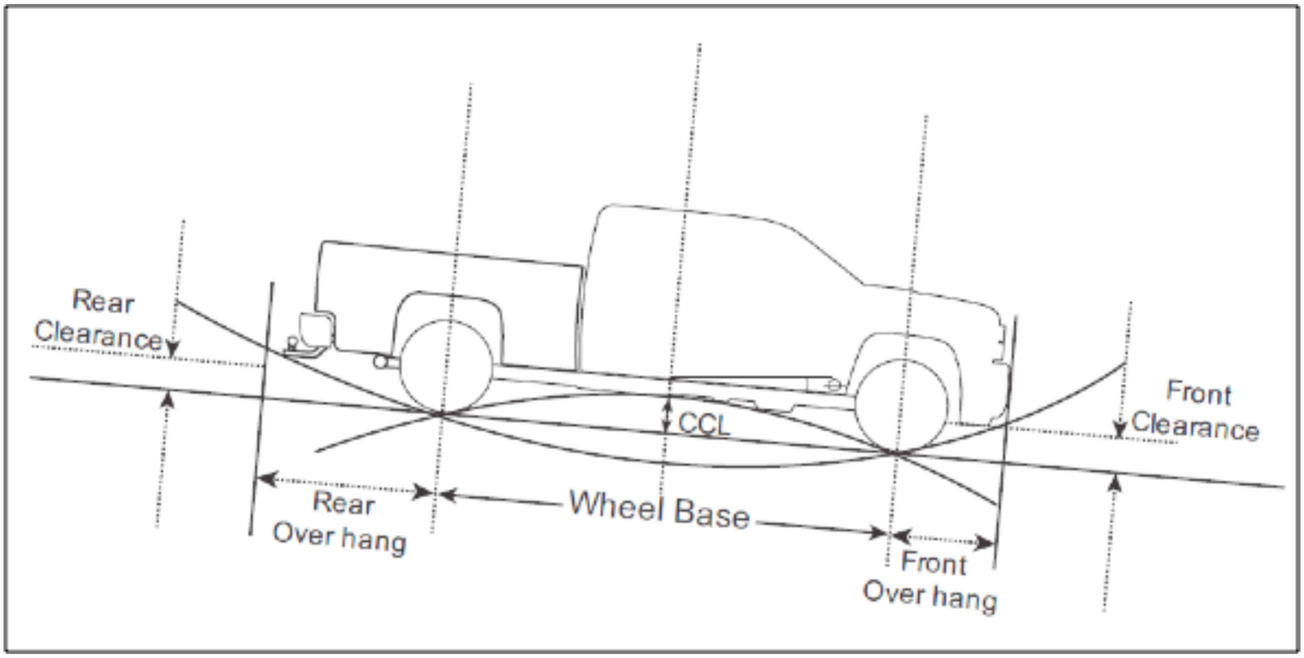
CHAPTER EIGHT
APPENDIXES

APPENDIX—A1. DESIGN AND CONSTRUCTION DRAWINGS/NOTES

A1a—Dip design information and details for common vehicles (adapted from Russell, et al., in preparation)



Dimensions of a drain dip for design (Note: vertical scale is exaggerated).



Schematic of vehicle clearance dimensions on vertical curves.

Table A1a—Common drain dip dimensions for various design vehicles

Road Grade (G) %	Length (feet)		Total Dip Length (TDL)	Depth, H (feet)		Approach Grade %	Dip (reverse) Grade %
Vehicle: Passenger Cars, wheelbase = 10 feet, center clearance on flat ground = 6 inches							
	A	B		Outside Edge	Inside Edge		
0–4	14	46	120	1.1	0.7	7	6
5–8	11	75	172	1.0	0.6	10	8
9–12	8	110	236	0.9	0.5	14	10
Vehicle: RV with low trailer hitch, wheelbase = 16 feet, center clearance on flat ground = 8 inches; rear overhang = 6 feet, rear clearance = 5 inches							
Road Grade (G) %	**Length (feet)**		**Total Dip Length (TDL)**	**Depth, H (feet)**		**Approach Grade %**	**Dip (reverse) Grade %**
	A	**B**		**Outside Edge**	**Inside Edge**		
0–4	16	65	162	0.8	0.4	7	4
5–8	10	90	200	0.6	0.2	11	3
9–12	4	112	232	0.3	0.1	13	2
Vehicle: Fire Truck/4-by-4 Truck, wheelbase = 18 feet, center clearance on flat ground = 18 inches							
Road Grade (G) %	**Length (feet)**		**Total Dip Length (TDL)**	**Depth, H (feet)**		**Approach Grade %**	**Dip (reverse) Grade %**
	A	**B**		**Outside Edge**	**Inside Edge**		
0–4	12	48	120	0.8	0.4	8	4
5–8	10	66	152	0.7	0.3	12	5
9–12	5	75	160	0.6	0.2	14	6
Vehicle: Log Truck, wheelbase = 50 feet, center clearance on flat ground = 12 inches							
Road Grade (G) %	**Length (feet)**		**Total Dip Length (TDL)**	**Depth, H (feet)**		**Approach Grade %**	**Dip (reverse) Grade %**
	A	**B**		**Outside Edge**	**Inside Edge**		
0–4	14	30	88	1.0	0.6	11	4
5–8	14	45	118	1.0	0.5	15	5
9–12	13	58	142	0.8	0.4	20	3
Vehicle: Lowboy, wheelbase = 38 feet, center clearance on flat ground = 5 inches							
Road Grade (G) %	**Length (feet)**		**Total Dip Length (TDL)**	**Depth, H (feet)**		**Approach Grade %**	**Dip (reverse) Grade %**
	A	**B**		**Outside Edge**	**Inside Edge**		
0–4	18	54	144	0.8	0.5	8	4
5–8	Not recommended without special analysis						
9–12							

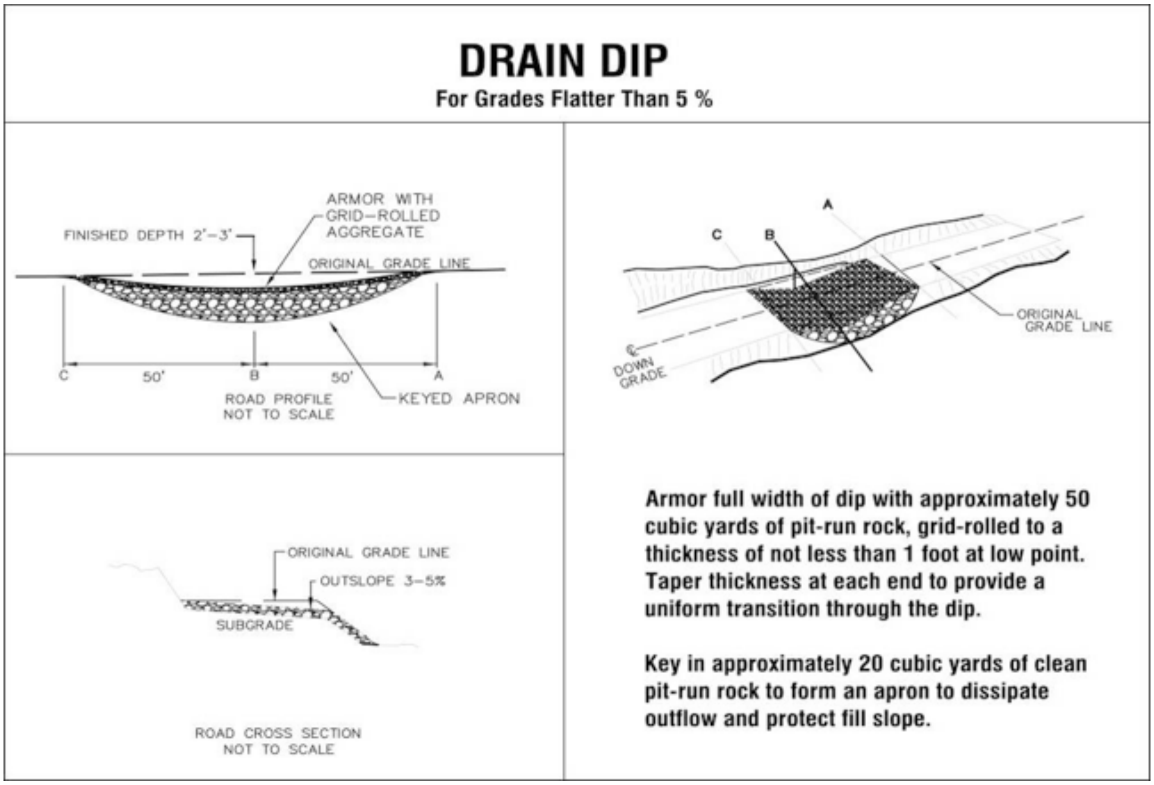
Notes:
1. Values for H are based on 3-percent drain-line pitch and 14 feet lateral distance between inside and outside edges of road.
2. The values in this table are based on calculations and some field experience assuming generic vehicle dimensions. Local conditions and vehicle types may vary.

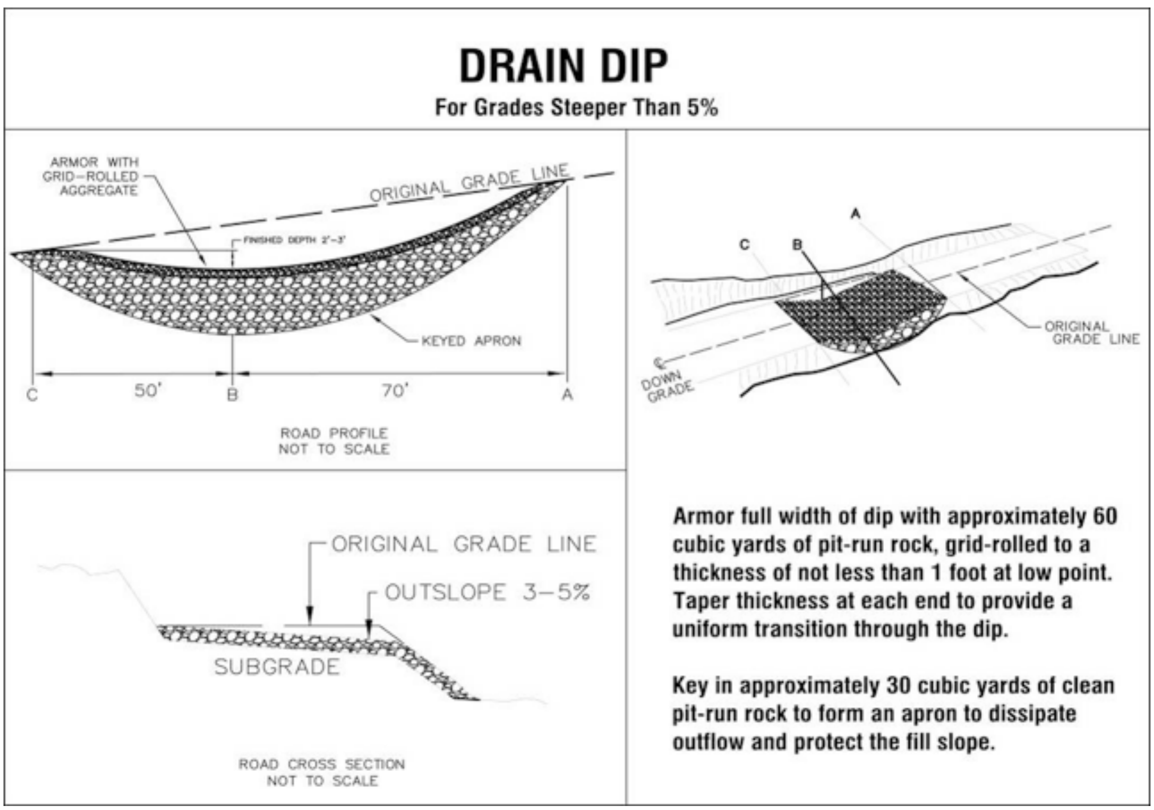
The values in table A1a are based on the dip dimensions and the physical geometric clearance between the vehicle and the road surface or the vehicle and its load (i.e., bottoming out, tail dragging, front scraping, stinger-log contact, and so forth) (the figures above). These values do not account for dynamic issues, such as vehicle speed and acceleration, vehicle jounce or dive, or driver comfort. See Hafterson (1973) for an evaluation of vehicle acceleration through drain dips.

Complete discussions and calculations for geometric design of drain dips for vehicle passage are given by Hafterson (1973), French et al. (2002), and Ohmstede (1976). Detailed spreadsheets for geometric drain-dip design (Cummings 2002 and Russell and Messerlie 2013a) are available on the Forest Service Intranet, which is available only to Forest Service and Bureau of Land Management employees at: <http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/Applications/dips.xls> and <http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/drain_dip_spreadsheet/Drain%20Dip%20Vehicle%20Pass_v8-30-13.xlsx>

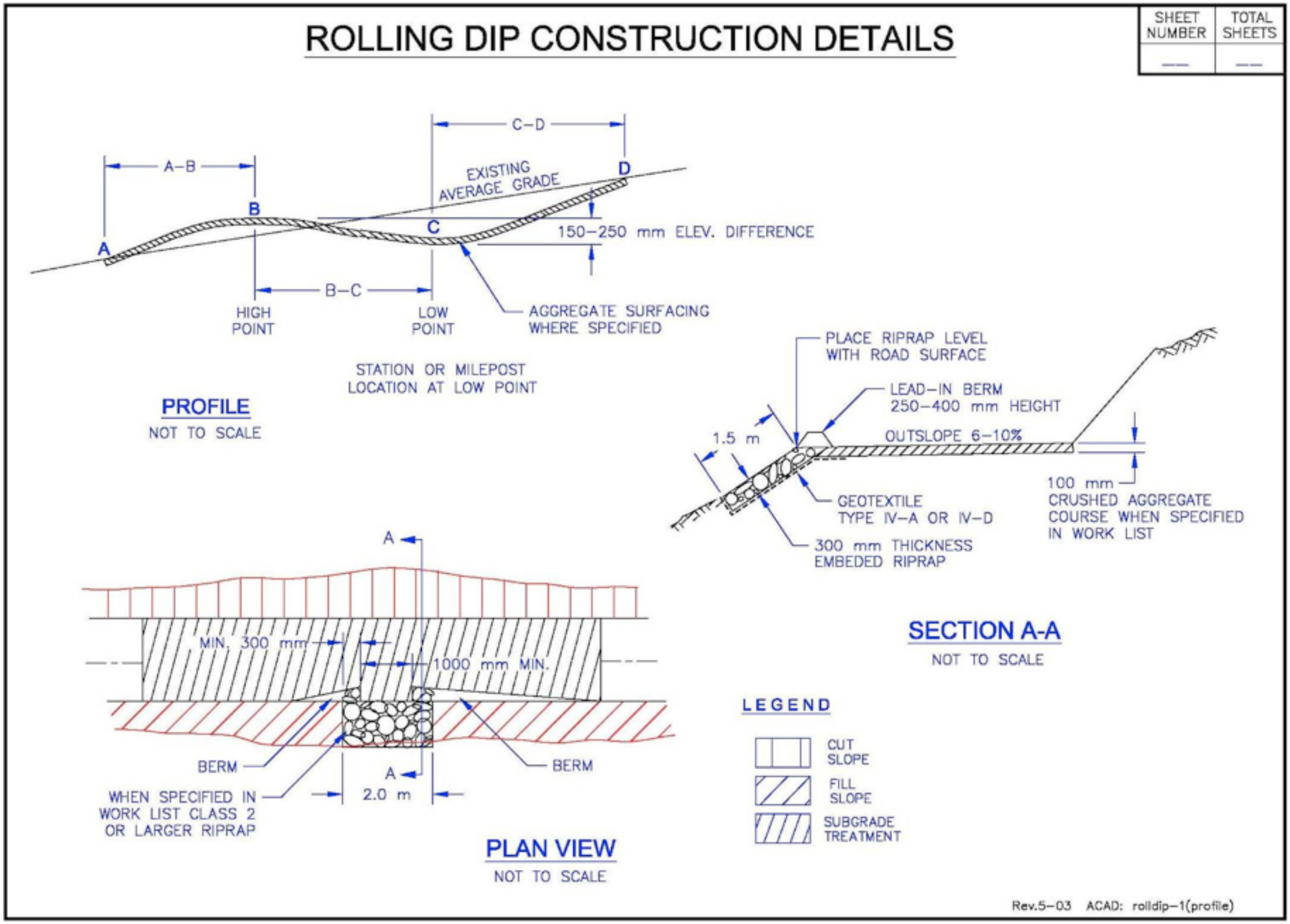
A similar, but less detailed, online calculator for drain dips may be found at: <http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/ENG_1/sample-project/sample-project/index.html> on the right sidebar of the Web page.

A1b—Drain Dip Typical Examples and Information





Drain Dip Typical—Flat and Steep Grades Umatilla National Forest


ROLLING DIP CONSTRUCTION DETAILS
SHEET NUMBER
TOTAL SHEETS
A–B
C–D
EXISTING AVERAGE GRADE
A
B
C
D
150–250 mm ELEV. DIFFERENCE
B–C
HIGH POINT
LOW POINT
AGGREGATE SURFACING WHERE SPECIFIED
STATION OR MILEPOST LOCATION AT LOW POINT
PROFILE
NOT TO SCALE
PLACE RIPRAP LEVEL WITH ROAD SURFACE
LEAD–IN BERM 250–400 mm HEIGHT
1.5 m
OUTSLOPE 6–10%
100 mm
CRUSHED AGGREGATE COURSE WHEN SPECIFIED IN WORK LIST
GEOTEXTILE TYPE IV–A OR IV–D
300 mm THICKNESS EMBEDED RIPRAP
SECTION A-A
NOT TO SCALE
A
MIN. 300 mm
1000 mm MIN.
BERM
WHEN SPECIFIED IN WORK LIST CLASS 2 OR LARGER RIPRAP
A
2.0 m
BERM
PLAN VIEW
NOT TO SCALE
LEGEND
CUT SLOPE
FILL SLOPE
SUBGRADE TREATMENT
Rev.5–03 ACAD: rolldip–1(profile)

ROLLING DIP CONSTRUCTION DATA

SHEET NUMBER	TOTAL SHEETS
—	—

All distances are metric system of measurement.

Construction tolerance is 0% to +20% of the dips overall length (combined distances: A–B, B–C, C–D).

CRITICAL VEHICLE: **FIRE ENGINE**				ROUNDING THROUGHOUT DIP	
% ROAD GRADE	MINIMUM DIST. A–B	MINUMUM DIST. B–C	MINIMUM DIST. C–D	CHORD LENGTH	MAX. CHANGE PER CHORD LENGTH
0–9	6	3	6	2	15%
10–12	9	3	9	2	15%
13–15	12	3	12	2	15%
16–18	15	3	15	2	15%

CRITICAL VEHICLE: **LOG TRUCK**				ROUNDING THROUGHOUT DIP	
% ROAD GRADE	MINIMUM DIST. A–B	MINUMUM DIST. B–C	MINIMUM DIST. C–D	CHORD LENGTH	MAX. CHANGE PER CHORD LENGTH
0–5	8	5	8	4	8%
6–7	11	5	11	4	8%
8–10	15	5	15	4	8%
11–13	18	5	18	4	8%
14–15	21	5	21	4	8%
16–17	29	5	29	4	8%

CRITICAL VEHICLE: **LOWBOY TRAILER**				ROUNDING THROUGHOUT DIP	
% ROAD GRADE	MINIMUM DIST. A–B	MINUMUM DIST. B–C	MINIMUM DIST. C–D	CHORD LENGTH	MAX. CHANGE PER CHORD LENGTH
0–5	17	7	17	4	7%
6–7	20	7	20	4	7%
8–9	23	7	23	4	7%
10–11	26	7	26	4	7%
12–13	29	7	29	4	7%
14–16	33	7	33	4	7%

Rev. 5-03 ACAD: rolldip-2(charts)

SHEET NUMBER	TOTAL SHEETS
——	——

ROLLING DIP GENERAL NOTES

Horizontal Alignment. Dip construction shall include provisions (e.g. elevating ditch dam, shifting berm or back slope alignment, etc.) to satisfactorily guide driver away from any blind approach into a ditch or other unsafe condition within the dip.

Constructed Slopes. All excavated back slopes shall be 1:1 or flatter, unless otherwise SHOWN ON DRAWINGS. All embanked fill slopes and berms shall be 1;3 or flatter. Utilize all excavated material and side casting shall not be allowed.

Compaction Unless otherwise SHOWN ON DRAWING, compact each part of the dip by operating spreading and hauling equipment uniformly over the full width at a moisture content suitable for compaction.

Traveled Way Width. The finished traveled way width through the dip shall be no narrower than 900 mm less than the adjoining travel width, but not less than 3.5 m, unless otherwise SHOWN ON DRAWINGS.

Drain Line. The drain line of the dip shall be shaped smooth and free draining. Skew of drain line shall be 80-100 degrees.

Lead-in Berm. Outside edge of roadbed shall be retained as berm leading into the outlet ditch. Riprap shall be incorporated into 300 mm of the lower end of each berm.

Outlet Ditch Elevation. The elevation of the outlet ditch through the berm, or upper edge of the riprap, shall closely match that of the finished drain line of the dip where they join. Outlet ditch and dip drainline shall be constructed at similar' grade.

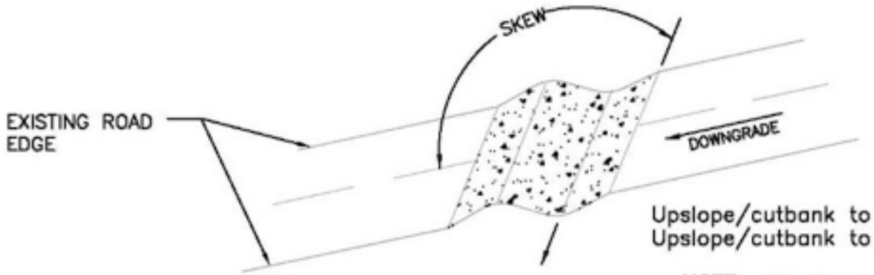
Outlet Riprap. Place riprap at drainage outlet when SHOWN ON DRAWINGS. Excavated oversize rocky material which meets gradation requirements may be used as riprap below drainage outlet. Alignment of riprap placement and opening through the berms shall be centered to the low point of the dip.

Aggregate Surfacing. Salvage and reuse existing aggregate surfacing when SHOWN ON DRAWINGS. Import crushed aggregate surfacing and place to designated depth when SHOWN ON DRAWINGS. Aggregate from commercial source shall be Forest Service certified as free of POC disease. Material shall meet requirements of Specification 304, type base, grading E, compaction A. Savaged or imported surfacing shall be spread against the inside bank, or native shoulder material at same elevation, in a manner that facilitates water drainage away fro inside edge of the traveled way.

Rev. 5-03 ACAD rolldip-3(notes)

A1c—Drivable and Non-Drivable Waterbars

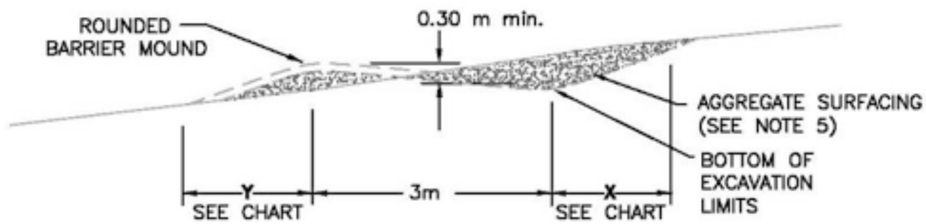
833A & 838 Driveable Waterbar



Upslope/cutbank to left – skew 120
Upslope/cutbank to right – skew 70

NOTE: All skews are based on 90° to left perpendicular to centerline progressing up road.

PERSPECTIVE VIEW



PROFILE VIEW
(NOT TO SCALE)

Design Variable for X and Y

ROAD GRADE % (PERCENT)	Distance (m) X	Distance (m) Y	# / km Z
0 – 4%	2	2	0–3
4 – 6%	3	2	2–4
6 – 8%	4	3	3–5
8 – 10%	5	4	4–6
10 – 12%	6	5	5–7
12 – 14%	8	7	6–7
14 – 16%	11	9	6–7

NOTES:

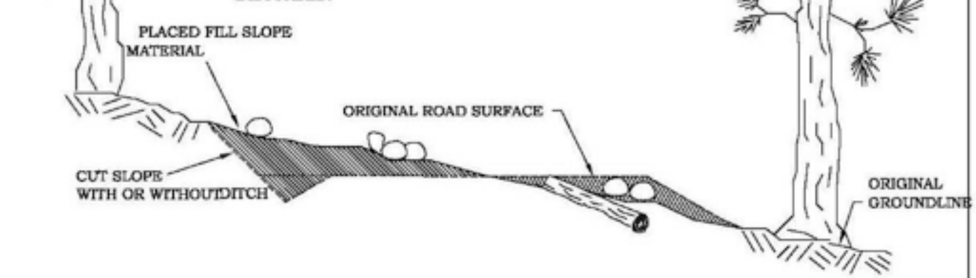
1. Excavation and barrier mound shall be constructed across entire traveled way.
2. Driveability of waterbar to be determined and approved in the field by the Forest Service.
3. Waterbar grade will match or exceed existing road grade.
4. Subgrade shall be compacted.
5. Existing aggregate shall be conserved and utilized to surface waterbar to a depth of 4". Surfacing shall be compacted.
6. Z= Average # of Waterbars/Km
7. Cross ditch is same dimensions as Drivable Waterbars.

OLYMPIC NATIONAL FOREST
HOOD CANAL R.D.
Fall Road Maintenance 2001
DRIVEABLE WATERBAR PERSPECTIVE AND PROFILE VIEW
SHEET 13 OF 15

FILL SLOPE PULLBACK

NOTES

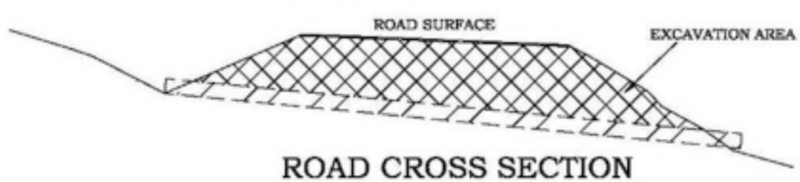
1. REMOVE MATERIAL FROM FILL SLOPES AND PLACE ON CUT SLOPES AND SHAPE TO A 1-1/2 : 1 SLOPE OR FLATTER.
2. PLACE LOGS, ROCKS OR OTHER MATERIALS ON DISTURBED AREAS TO MATCH THE NATURAL SURROUNDINGS.
3. TREES LARGER THAN 6" GROWING IN FILL SHALL NOT BE DISTURBED.



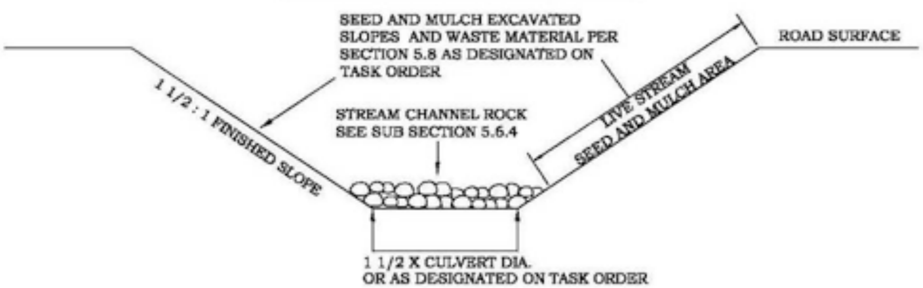
CULVERT REMOVAL

NOTES

EXCAVATED MATERIAL SHALL BE PLACED AND SLOPED TO DRAIN PER SECTION 5.6



ROAD CROSS SECTION



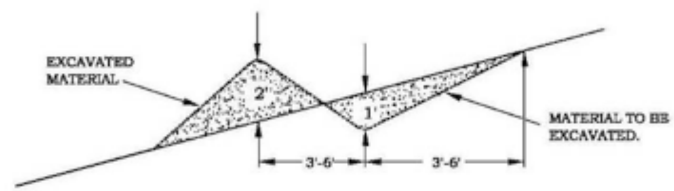
STREAM CROSS SECTION

NOT TO SCALE

WATERBAR(NON-DRIVEABLE)

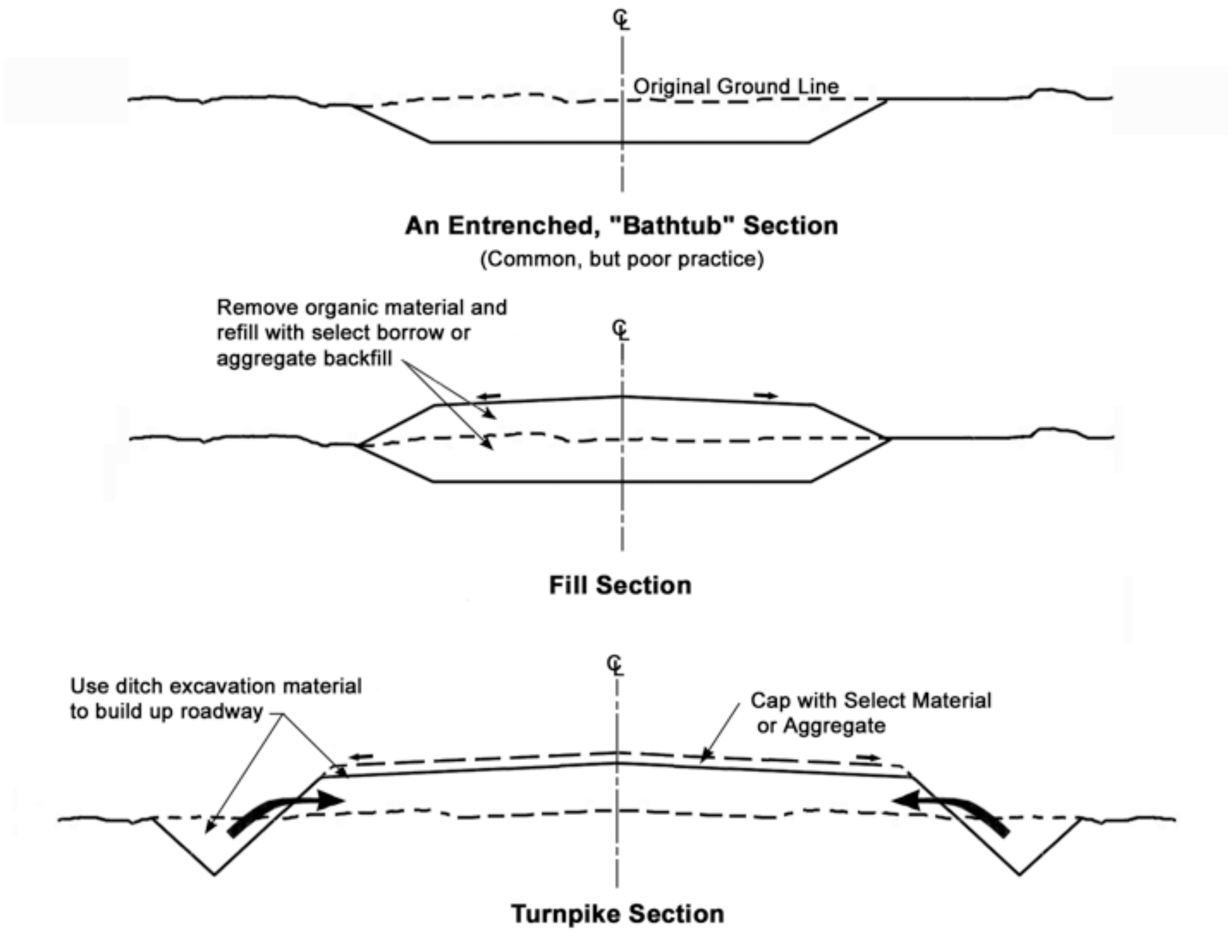
NOTES

1. CONSERVE ANY 6" TO 18" ROCK ENCOUNTERED IN THE EXCAVATION AND PLACE AT THE OUTLET OF WATER BAR TO ACT AS ENERGY DISSIPATIOR
2. WATER BARS SHALL BE SKEWED TO FACILITATE DRAINAGE, 30 TO 60 DEGREE ANGLE FROM ROAD CENTERLINE.
3. INTERCEPT DITCH WATER BY INCLUDING A DITCH BLOCK DURING CONSTRUCTION OF WATER BARS.
4. SPACE WATER BARS PER SECTION 5.1 OR AS DESIGNATED ON TASK ORDER.



ATTACHMENT #2

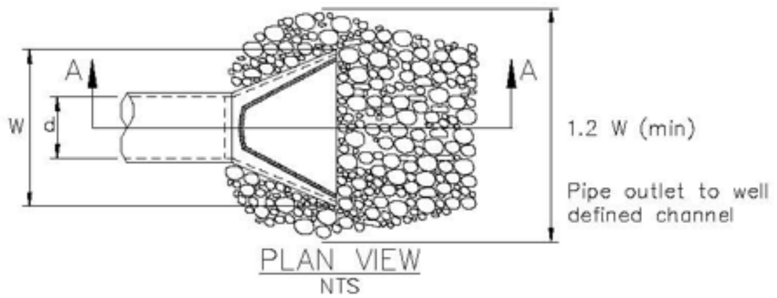
ROAD DECOMMISSIONING TYPICALS				
STATE	FOREST	PROJECT	SHEET NUMBER	TOTAL SHEETS
OREGON	MULTI-AGENCY	ROAD DECOMMISSIONING	2	7

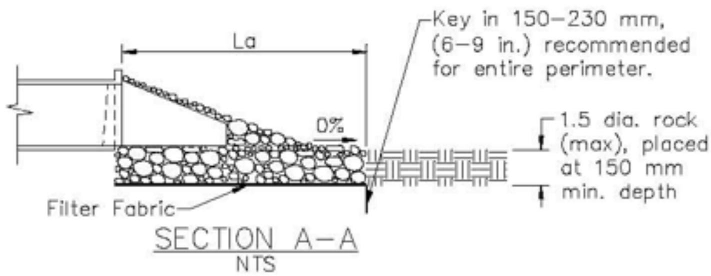


ROAD OPTIONS IN WET, VERY FLAT TERRAIN

Outlet Protection/Velocity Dissipation Devices

SS-10





Pipe Diameter mm	Discharge m^3/s	Apron Length, La m	Rip Rap D_{50} Diameter Min mm
300	0.14	3	100
	0.28	4	150
450	0.28	3	150
	0.57	5	200
	0.85	7	300
	1.13	8	400
600	0.85	5	200
	1.13	8	200
	1.42	8	300
	1.70	9	400
For larger or higher flows, consult a Registered Civil Engineer			

Source: USDA – SCS

APPENDIX—A4. ROAD STORM DAMAGE RISK REDUCTION ASSESSMENT—FIELD EVALUATION/ROAD CONDITION FORM

Adapted from Karen Bennett, regional soil scientist, Pacific Northwest Region

Road Name ________________________________ **Date** __________________________________

Surveyor(s) Names ____

Road Segment Information

Mile Post: From ______ To_____ GPS: From ____________________To_____________________

Total Segment Length: _______________________

Road Width:________________________________ Road Gradient:________________________

Topographic position: Ridgetop _____ Midslope ______ Valley Bottom _____ Vertical ______

Traffic Use Intensity: Low _____ Moderate _____ High _____

Reason for Segment Break: ____

Road Surface Condition Assessment

Road Surface Material: Paved ______ Gravel ______ Native Soil ______

Road Prism Cross Section: Insloped ________ with ditch ________ without ditch ________

Crowned ________ with ditch ________ without ditch ________

Outsloped ________ with ditch ________ without ditch ________

Flat ___________ Entrenched ___________

Surface Condition: Good _________ Corrugated _________ Potholes _________

Ruts __________ Gully ______________ Rough___________

Condition Severity: (H,M,L) _________ _________ _________ _________ _________

RECOMMENDED TREATMENT____

____

Slope Stability

Cutbank Height __________ Cutbank angle __________ Stable: Yes______ No______

Fillslope Length ___________ Fillslope Angle _________ Stable: Yes______ No______

Evidence of landslides? (movement?) Yes______ No______ Erosion: Yes______ No______

Seeps and springs in cutbank? Yes______ No______

Retaining Structures: Functioning _________ Needing Repairs _________

Add problem description?: ____

RECOMMENDED TREATMENT____

____

Road Surface Drainage

Drainage type: Cross-Drain Culvert _________ Rolling Dip __________ Water Bar_________

Number of cross drains ____________ _____________ ______________

Average Spacing ____________ _____________ ______________

Length to drain more important that spacing (needs to consider divides, etc.)

Need road grade paired w/ assessment of spacing and # to adequately assess.

Plugged Cross drain with location ____

Erosion at cross drain outlet with location ____

Ditch Condition: scoured: Y/N Scour length: Depth: (max & ave?)

RECOMMENDED TREATMENT____

____

Sediment Transport Assessment

Ditch delivers sediment to stream: Yes______ No______ Ditch length_____ Ditch width ___

Road delivers sediment to stream: Yes______ No______

Distance from road to bankfull channel _________________

Other sources of sediment __________________________

RECOMMENDED TREATMENT____

____

Stream / Wetland Crossing Assessment

Number of Stream/Wetland Crossings___________

Is flow or drainage being backed up? Yes______ No______

Stream Crossing type: Open channel ____ Ford ____ Vented Ford ____ Culvert ____ Bridge ____

Dimensions: ____

RECOMMENDED TREATMENT____

____

Culvert Assessment

Shape/Size: Circular _________ Eliptical ________ Recrangular ________

Squash _________ Arch __________

Single or Multiple Pipes: _______________ Number ______________

Are all pipes functioning?: Yes______ No______ Explain: ____________________________

____

Stream Gradient: ____________ Bankfull Width ___________ or active channel width

Culvert Grade: _______________ Culvert Length ___________

Inlet Blocked: Yes______ No______ Depth of sediment _______________

Outlet Eroded: _________ Height of drop__________ Length of erosion __________

Piping along culvert: Yes______ No______ ; through bottom of pipe (holes) Y/N

RECOMMENDED TREATMENT____

____

Consider adding: Evidence of recent flood or disturbance: Y/N (would provide context or validate width rating if condition = good after experiencing recent flood)

Description: (or damage/effects of disturbance)

Bridge/Ford Assessment

Type____ Span____

Structure Concerns: Yes_______ No_______

Channel Constriction_________________________ Debris______________________________________

Scour Problems____

RECOMMENDED TREATMENT____

____

Photo Point #	Description

APPENDIX—A5. GLOSSARY

Road decommissioning—A permanent road closure treatment (including obliteration) applied to roads that are no longer needed or are undesirable. This removes the road from the maintained transportation system. Treatments range from simply blocking the road and allowing it to brush in, to removing all drainage structures and unstable sidecast fills. Decommissioning removes those elements of a road that reroute or impede hillslope drainage and present slope stability hazards. Decommissioning removes the road from the road system.

Road obliteration—A permanent road closure with full physical site restoration that attempts to re-contour slopes with the intent of completely removing the footprint of the road from the landscape. Natural drainage patterns are re-established as much as possible. The term is more frequently used by Washington Department of Natural Resources for private and State road treatment.

Storage—This treatment involves closing and stabilizing those roads that are not currently needed, but have been identified as having a future access purpose. The road may be closed for a year or many years, such as until the next forest management cycle, but it will be used again in the future. Treatment can involve wide ranges of options on a case-by-case basis. These roads, built using sidecast excavation methods and undersized drainage structures, require removal of drainage structures and sidecast fill material but leaves the road prism intact. The road becomes maintenance level 1.

Open roads—Roads that are to remain open for necessary access, either all year or for a portion of the year (i.e., seasonal wildlife restriction, snow, etc.). Depending on the technique of the original construction of the road and other factors such as number of streams crossed , need for fish passage and steepness of side slope involved, results in varying amounts of drainage correction work required. Correcting these drainage deficiencies is sometime referred to as an upgrade. Open roads are maintenance at maintenance level 2 to 5.

Forest Service nonsystem routes—These are road segments that are not system roads. These roads were frequently built under timber sales and never became part of the Forest Service maintained road transportation system due to their short-term need.

Road maintenance levels—one of five levels assigned based on the maintenance required to provide the desired type of access:

> **Level 1**—These are roads that have been placed in storage between intermittent uses. The period of storage must exceed 1 year. Basic custodial maintenance is performed to prevent damage to adjacent resources and to perpetuate the road for future resource management needs. Emphasis is normally given to maintaining drainage facilities and runoff patterns. Planned road deterioration may occur at this level.
>
> Roads receiving Level 1 maintenance may be of any type, class, or construction standard and may be managed at any other maintenance level during the time they are open for traffic.

Level 2—Assigned to roads open for use by high-clearance vehicles. Passenger car traffic, user comfort, and user convenience are not considerations. Warning signs and traffic control devices are not provided with the exception that some signing, such as W-18-1 “No Traffic Signs” may be posted at intersections. Motorists should have no expectations of being alerted to potential hazards while driving these roads. Traffic is normally minor, usually consisting of one or a combination of administrative, permitted, dispersed recreation, or other specialized uses. Log haul may occur at this level.

Level 3—Assigned to roads open and maintained for travel by a prudent driver in a standard passenger car. User comfort and convenience are not considered priorities. The “Manual on Uniform Traffic Control Devices” (FHWA 2009a) is applicable. Warning signs and traffic control devices are provided to alert motorists of situations that may violate expectations.

Roads in this maintenance level are typically low speed with single lanes and turnouts. Appropriate traffic management strategies are either "encourage" or "accept.” "Discourage" or "prohibit" strategies may be employed for certain classes of vehicles or users.

Level 4—Assigned to roads that provide a moderate degree of user comfort and convenience at moderate travel speeds. Most roads are double lane and aggregate surfaced. However, some roads may be single lane. Some roads may be paved and/or dust abated. “Manual on Uniform Traffic Control Devices” is applicable. The most appropriate traffic management strategy is "encourage." However, the "prohibit" strategy may apply to specific classes of vehicles or users at certain times.

Level 5—Assigned to roads that provide a high degree of user comfort and convenience. These roads are normally double lane, paved facilities. Some may be aggregate surfaced and dust abated. “Manual on Uniform Traffic Control Devices” is applicable. The appropriate traffic management strategy is "encourage."

Diversion potential—The possibility that streamflow will leave its established channel and flow down a road or roadway ditch that slopes away from a road-stream crossing. Stream diversion occurs when a culvert pipe capacity is exceeded or a culvert plugs with debris, causing the stream to overtop the culvert and follow the road rather than stay in its own stream channel.

Drivable waterbars—Low berms or barriers, typically of soil, that are constructed across roads or skid trails with the purpose of blocking the flow of water or directing it off the road surface. Drivable waterbars are constructed such that they can be driven over with high-clearance vehicles.

Hydrologically connected (hydraulic connectivity)—Hydraulic connectivity, or items that are hydraulically connected, refers to a circumstance, such as a roadway ditch or other drainage structure, that is directly connected to a watercourse, such that water, and any associated sediment it is carrying, is delivered directly to that watercourse or a natural channel network.

River engineering—A coined term, similar to "Natural River Rehabilitation," or "Geomorphologic Restoration" referring to work in channels to restore the natural or proper function of a stream. Work is commonly associated with repairs around structures such as bridges, or bank protection where a roadway encroaches upon a natural channel. Traditional work may have involved use of hard structures such as riprap and concrete, while current practice places emphasis on use of natural products such as logs and vegetation, as well as a better understanding of channel morphology and dynamics.

Rolling dip (drivable dip, broad-based dip)—A roadway surface drainage structure, with a constructed break in the road grade, specifically designed to drain water from an inside ditch as well as the roadway surface off the road. The dip, mound, and ditch outlet area are often reinforced or armored. Vehicle travel speed is typically somewhat reduced, and dips are used on low-volume, relatively low-speed roads.

.

Stormproofing—Measures taken to reduce the risk or amount of damage to roads from major storms. **Storm Damage Risk Reduction** pertains to similar storm proofing measures, but considers the fact that risk or probability of damage can be reduced, as well as actual amount of damage, but that low-volume roads can never afford to be built to prevent all damage.

CHAPTER NINE
REFERENCES

9. REFERENCES

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