

Handbook for Forest, Ranch & Rural ROADS

A Guide For
Planning,
Designing,
Constructing,
Reconstructing,
Upgrading,
Maintaining
And Closing
Wildland Roads

Prepared by

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PACIFIC WATERSHED ASSOCIATES



Authors' Notes

In this expanded Handbook, we have provided new and additional insight on how to achieve the sometimes conflicting goals of high quality roads and low environmental impacts. Our philosophy is that wildland roads can be environmentally friendly, if they are located, designed, constructed and maintained in a thoughtful manner. More is now known about how roads can be designed, constructed and reconstructed to minimize their adverse environmental effects, not only during normal wet weather conditions but also during severe storm events that have historically plagued low volume road systems.

Roads are already common across most of the wildland landscape. In this Handbook we provide guidance on how these older roads can be updated to achieve the same beneficial results of low impacts and reduced maintenance costs. It doesn't matter if you manage an entire network of roads, or you have a single road leading to your rural home, everyone can benefit by seeing the examples we present, and by employing the strategies described here. If you don't find precisely what you need, we have provided a listing of useful manuals, guidebooks and technical publications.

A great deal more technical information is now widely available and accessible to those who build and manage low volume roads and road systems in various geographies, climates and cultures from around the world. New science has been developed and new methods are being employed to make forest, ranch and rural roads more resilient and less impacting on the environment, while at the same time providing landowners with access roads that have lower long term costs and require less maintenance.



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ARCATA, CA

FOR:

THE MENDOCINO COUNTY RESOURCE CONSERVATION DISTRICT

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www.pacificwatershed.com/roadshandbook 707.839.5130

All programs and services of the Mendocino County Resource Conservation District, the California State Water Resources Control Board and the California Department of Forestry and Fire Protection, are offered on a non-discriminatory basis, without regard to race, color, national origin, religion, sex, age, marital status, or disability.

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Pete Cafferata, California Department of Forestry and Fire Protection; Jonathan Warmerdam, North Coast Regional Water Quality Control Board; Bill Short, Dave Longstreth, Don Lindsay and Gerald Marshall, California Geological Survey; Patty Madigan, Mendocino County Resource Conservation District and Gordon Keller, Plumas National Forest (retired) provided useful technical reviews of portions or all of the text.

Patty Madigan and Janet Olave, MCRCD, administered the contracts and grants that funded the project, provided overall project coordination, and helped make organizational decisions on both structure and style of the revised Handbook. Joan Grytness (Joan Grytness Graphic Design) prepared and designed the Handbook's layout. Many other individuals have reviewed portions of the text or provided comments, graphics or ideas on individual topics covered in the document. Invaluable ideas and discussions for updates since the original 1994 Handbook for Forest and Ranch Roads (1994 Handbook) came from staff of the California Department of Forestry and Fire Protection, California Department of Fish and Wildlife, North Coast Regional Water Quality Control Board, and the California Geological Survey, as well as geologists and hydrologists from U.S. Forest Service and Bureau of Land Management offices in the western USA. We are indebted to many discussions and reviews provided by the geologists and hydrologists at Pacific Watershed Associates who have been living and breathing the subject of forest, ranch and rural roads for the last 25 years.

A great deal of new information on these topics has been published in the 20 years since the original Handbook for Forest and Ranch Roads was published in 1994. This includes many general forest and rural road BMP handbooks that have been published by various states and organizations across the USA, as well as many technical guides and manuals from countries and international organizations around the world. Each focuses on the characteristic and universal road-related problems faced by landowners and road managers everywhere (e.g., how do you drain a road?), as well as potential users in those particular areas; including arid, tropical, frozen and temperate zones, among others. In addition, a great deal of new

1 NOTE: Local, County and State regulations in California cover many of the same subjects presented in this guide. However, this guide is intended to be more universally applicable than for just California or the Western USA. Regulations change quickly, as do the technical methods of roading and the standards for environmental protection. No matter where your road is located, be sure to follow applicable regulations covering private land road building and related activities for your area, whether it is in California, another state or in another country. We have provided a general description of the requirements and typical regulations of many (but not all) regulatory agencies found here and elsewhere, but you will need to be sure that your specific project meets all applicable standards and regulations before you begin work. The information presented in this guide is not an exact "mirror" of California's Forest Practice Rules. However, we have tried to be consistent in most terminology, in general content, and in spirit with the goals of the Z'berg-Nejedly Forest Practice Act and California's Forest Practice Rules. These rules are not inconsistent with forest regulations elsewhere.

Any errors in the text are those of the authors and not those of the agencies who funded this project or of the agencies or individuals who provided technical reviews of the text. Technical comments and suggestions related to future updates and revisions should be forwarded to Pacific Watershed Associates, P.O. Box 4433, Arcata, CA 95521. We will attempt to maintain additional reading material, useful technical documents, references and updates on our web site (www.pacificwatershed.com) as well as that of the Mendocino County Resource Conservation District (www.mcrcd.org).

road-related research has been accomplished in the last 20 years, and some (but not all) of that information has been converted to practical application.

A summary book like this necessarily draws from a wide variety of these sources for ideas and technical information. We drew heavily from guides and manuals produced by the States of Montana, Oregon, Washington and California, the U.S. Forest Service, the Soil Conservation Service, the National Park Service and the Ministry of Forests, British Columbia, Canada in the 1994 Handbook. Many figures were developed or modified from these sources, and remain as core components for the updated version. Special appreciation is extended to the Information and Extension Branch, Ministry of Forests, Province of British Columbia for permission to use graphics and ideas from their publication A Guide for Management of Landslide-Prone Terrain in the Pacific Northwest for use in the 1994 Handbook, as well as the updated version. For the revised handbook, we have drawn on a number of other, more recent publications from a wide variety of sources. Most of these are identified in the references and can either be downloaded from the Web or directly from Pacific Watershed Associates (www.pacific-watershed.com). We are especially appreciative of permission to freely use ideas and graphics from excellent, practical handbooks developed by both Brian Kramer (Forest Road Contracting, Construction, and Maintenance for Small Forest Woodland Owners) and Gordon Keller & James Sherar (Low Volume Roads Engineering: Best Management Practices Field Guide).

Special thanks is also extended to those forest, ranch and rural landowners whose roads have been analyzed, prescribed and treated with upgrading and decommissioning measures over the last 20 years and which are the subject of some of the photos contained in this handbook. We have learned a lot from those experiences and they have benefited from having much improved low impact, low maintenance forest, ranch and rural roads.

**MENDOCINO
COUNTY**



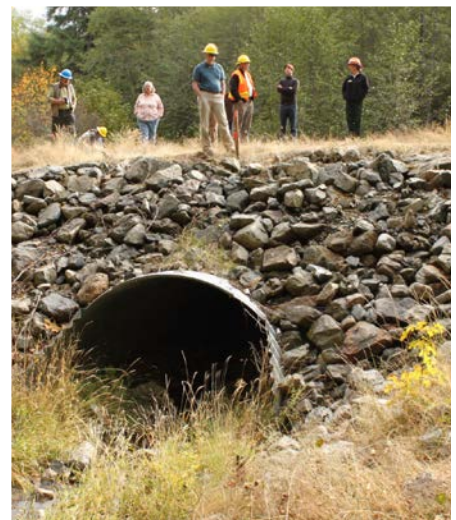
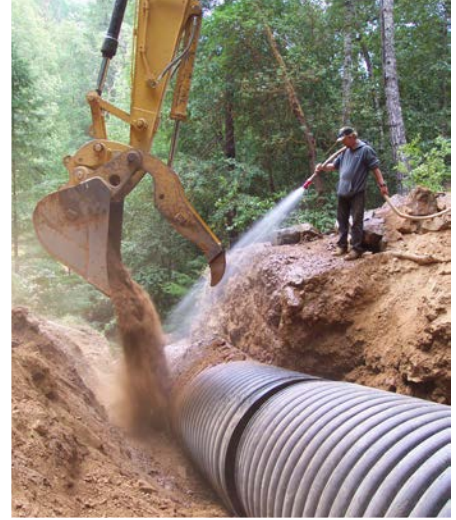
**RESOURCE
CONSERVATION
DISTRICT**

CONSERVING *wild and working* LANDSCAPES
since 1945

The Mendocino County Resource Conservation District (MCRCD) is a non regulatory, local agency supporting voluntary stewardship of natural resources on wild and working landscapes. Serving landowners since 1945, MCRCD is governed by a volunteer Board of Directors comprised of local landowners. The MCRCD staff collaborates with private and public landowners to address natural resource concerns on their property. Utilizing Best Management Practices, MCRCD develops projects and pursues funding to assist landowners with meeting conservation objectives and/or regulatory compliance.

'The real voyage of discovery consists not in seeking new landscapes but in having new eyes.'

Marcel Proust 1871 - 1922



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1 INTRODUCTION

A. PURPOSE

If you work in a wildland area, own forest, ranch or rural land, or are concerned about our natural resources, this book is for you. It contains guidelines for developing and maintaining a single forest, ranch or rural road or an entire wildland road-access system. It describes how to plan and design a stable road or road network in mountainous lands or gentle valley bottoms, and avoid many of the common pitfalls and environmental/pollution problems for which rural and forest roads are noted. Nearly everything discussed in this manual is aimed at producing efficient, low-cost, low-impact, low maintenance roads that have a minimal impact on the streams, water quality and aquatic resources of a watershed.

Reading and understanding this manual is not enough. It takes the commonsense, intelligent, practical application of the general principles described here for each “on-the-ground” situation you encounter. Correctly applying these “roading” concepts requires practice and personal judgment and, in certain situations, the expertise of a professional. The concepts presented in this handbook are not rules or regulations; rather, they are tools which should serve as one of your many sources of information and guidance. The success you achieve will be reflected not only in the stability of your roads, but also in the quality of the water and the health of the streams and watersheds through which they pass.

Forest, ranch and rural lands everywhere provide beauty, clean water, abundant wildlife, fish habitat, recreation, timber, livestock and jobs. They are great places to live and to work. This practical handbook is dedicated to the wise stewardship of these resources. It describes how we can and should protect our streams, water resources and productive soils, while at the same time provide recreational opportunities and natural resource jobs for our local communities.

B. CONTENTS AND ORGANIZATION

This is a practical guide and field manual, and therefore does not cover all topics in the same depth or detail as a textbook or a more focused

technical manual. It is designed to be descriptive and informative, yet cover the fundamentals of road planning, design, construction, reconstruction (upgrading), maintenance and closure. The handbook is organized under these basic topics, and they appear in the general order that they are encountered in the road-building and road management process. The text, figures and photos are designed to portray technical information in a readable and understandable way for people who work “on-the-ground” and who encounter and then solve road-related problems in the field.

The text of this manual contains both simple informational and instructional material, as well as more detailed discussions of specific practices. For the lay reader, some of the discussions may seem technical, or contain unfamiliar terms and concepts. Although it is useful for readers to have a basic understanding of commonly used road terms (such as fill slope, cutbank, roadbed, stream crossing, etc.) and road management practices (such as sidestepping, compacting and endhauling, to name a few), we have provided sufficient descriptions to help lay readers understand unfamiliar terms and concepts, while still providing the more technically savvy readers with new and useful information. Many of the more technical or uncommon terms have been defined in the text where they first appear, and/or in the glossary of defined terms included at the end of this handbook.

The following summary outlines the chapter contents of this handbook. Within each chapter, some of the more important principles of modern forest, ranch and rural low volume road practices have been highlighted in **bold print** to draw them to your attention.

Chapter 1 discusses how this handbook is organized and serves as an introduction to the concepts of what makes a good road, how a watershed works, and what naturally affects the quality of its water and stream resources.

It also reviews the main impacts roads typically have on watershed process, water quality and aquatic resources. It describes general permitting requirements and how landowners can benefit from using resource professionals to help solve their on-the-ground problems.

Chapter 2 describes the need for, and process of, planning for roads. It describes road standards and route planning, using maps and photographs, and how the components of a road system or an individual road need to be consistent with the types and volumes of traffic that it serves.

Included in **Chapter 3** are discussions of what on-the-ground obstacles to look for when you are scouting for a new road alignment or an alignment for rerouting an existing road, laying out curves and switchbacks, avoiding obstacles, and a description of the tools that are useful in locating a road in the field.

Chapter 4 covers the important topics of designing road prisms, road surfaces (drainage) and stream crossings. It describes the importance of designing road drainage to reduce the road’s impact on water quality, by reducing hydrologic connectivity and sediment delivery to nearby streams. Chapter 4 describes stream crossing designs, including bridges, culverts, arches, armored fills, fords and temporary stream crossings, which are used to carry flood flows, and introduces design considerations for fish passage. Because they are most common, the design of culverted crossings is described in detail. Finally, Chapter 4 covers a variety of special designs including stable road cuts and fills, operations on wet and unstable soils, through cuts and berms, as well as the most common uses of geotextiles and rock materials for armoring and road surfacing.

Chapter 5 covers the construction process, including clearing and grubbing, grading, stream crossing and bridge installation,

surfacing, erosion control and spoil disposal. Protecting water quality during construction and biotechnical measures for revegetation are also addressed. The special but increasingly common activity of road reconstruction (upgrading) is discussed in detail.

Chapter 6, reconstruction and upgrading describes the topics including road relocation, road redesign, drainage structure upgrading and replacement, road shape conversions, and erosion control. Road upgrading, often called storm-proofing, is conducted to make the road more resilient to storms and floods, and less impacting to downstream water quality and stream habitat during even the smallest runoff events.

Chapter 7, road maintenance, introduces the concept of identifying and addressing the various types of threats and road maintenance requirements that occur along existing and abandoned roads. It covers techniques for identifying hazards along road alignments, including potentially unstable road fills, high hazard stream crossings and culverts that are under-designed and likely to fail during storm events. It also reviews the topics of routine road surface maintenance, stream crossing maintenance, maintenance of fills and cuts and winterizing roads. A simple method for developing and prioritizing storm maintenance schedules is outlined.

Road decommissioning and road closure **Chapter 8** are now important components of proper transportation planning and road system management because of their potential long-term effects on water quality and aquatic resources. Chapter 8 describes techniques by which roads that are to be temporarily closed or permanently decommissioned (purposefully abandoned) can be “storm-proofed” to eliminate the risk of future failure, prevent subsequent soil loss, protect water quality and valuable aquatic resources, and put land back into timber or ranch production and other uses.

Finally, the **appendices** to this handbook contain information on specific topics, such as culvert sizing methods, methods for estimating stream crossing fill volumes, and curve layout, and regulatory requirements, as well as other sources of information you may find helpful.

C. CHANGES FROM THE 1994 HANDBOOK

Why revise the original Handbook? It's not that the original linkages between road construction, road management and water quality protection are no longer valid. They are still considered best management practices (BMPs). In fact, in the 20 years since the 1994 Handbook was originally published the importance of roads in watershed processes has been more widely described and uniformly affirmed, and many of the practices needed to reduce those impacts have become widespread, standard practices. Roads are now universally understood to be one of the most important human-caused contributors to degraded water quality and aquatic habitat conditions in managed watersheds. Environmentally protective road practices that were considered “new” and innovative in the 1990s now take front seat in road planning, design, construction and maintenance practices everywhere. New and newly described and adopted road construction and management practices have found their way not just across the U.S. but are increasingly found in international handbooks and guides written for developing areas elsewhere.

Changes that are incorporated into the 2014 Handbook edition include new science, new technology and expanded content on topics that were only broadly covered in 1994. A great deal more technical information is now widely available and accessible to those who build and manage low volume roads and road systems in various geographies, climates and cultures from around the world. New science has been developed on several topics, ranging from the impacts roads have on ecosystems

to the physical processes that link roads, drainage networks, and aquatic ecosystems together. More is now known about how roads can be designed, constructed, reconstructed, maintained and eventually closed to minimize their adverse environmental effects, not only during normal wet weather conditions but also during severe storm events that have historically plagued low volume road systems. Finally, there is a much greater wealth of road management literature available covering all aspects of road construction, road upgrading and road decommissioning that can reduce the environmental effects of roads while making them more resilient to storms and less costly to maintain.

It was clear to us when researching and preparing this revised, updated edition that a lot of new and expanded information was available, and that much of this material was now readily accessible on the internet. In fact, the amount of internet information on low volume roads can seem overwhelming. This

Handbook was developed as one way to sift through and focus on topics that may be of particular interest. In addition, and because the Handbook is a practical guide and not a comprehensive technical manual, we have included an expanded reference section and suggested reading materials on various topics.

D. WATERSHEDS

Wildlands act as the collectors of pure water. Watershed areas collect precipitation and funnel it to downslope and downstream areas across slopes and through a network of swales and stream channels carved into the landscape (Figure 1). Some water flows as surface runoff and some enters the soil as subsurface and groundwater flow. Logging, mining, road construction and other earthmoving and construction activities can disturb soils and drainage patterns, thereby displacing drainages, increasing surface runoff and causing erosion and the release of sediment into stream systems.

FIGURE 1.

Watersheds present a diversity of opportunities and challenges for water, land and resource management. Roads provide access to areas within a watershed and thoughtful planning, design, construction and maintenance of road systems are important to protect water quality, sensitive stream habitats and sensitive aquatic life.



Watershed hillslopes are carved into broad ridges and intermediate depressions called swales. **Swales** are sloping geologic depressions in which rainfall infiltrates into the soils and moves downslope through the soil mantle and along the axis of the swale. Swales may or may not show evidence of occasional surface runoff during extreme rainfall events and may go for decades without showing any evidence of channelization. Swales are not streams, but their subsurface flow eventually emerges lower in the swale to form a stream that displays evidence of more regular surface flow and channelization.

Although they do not generally carry surface runoff, swales are important features in a watershed and roads must be well planned, properly located and constructed in these areas so as to avoid future road failure. For example, if you cut into a swale to build a road you may intercept subsurface water and bring it to the surface, thereby causing increased maintenance problems. Alternatively, if you build a road on top of a steep swale, you will alter the subsurface hydrology and increase soil pore water pressures, thereby potentially triggering a damaging slope failure. **Care should be taken when constructing roads across steep hillslopes and swales and the advice of a qualified geologist may be needed.**

Streams are classified as **ephemeral** (flowing only during periods of extended rainfall), **intermittent** (flowing during and for an extended period following significant rainfall), or **perennial** (flowing most of the year, with base flow coming from emerging groundwater). Ephemeral streams often drain water into either intermittent and/or perennial watercourses as they flow downslope, collect additional runoff and intersect other streams. It should be noted that only the largest streams of a watershed are shown on a topographic map, and that many more watercourses, particularly intermittent and ephemeral streams, will be found on the ground. Those “unmapped” streams and

stream channels also transport sediment and can impact downstream water quality and habitat. ***Don't rely solely on map information to find and identify streams.***

Stream channels are landforms created by flowing water and having a bed and bank or showing evidence of, or capability for, sediment transport. Streams and stream channels are much like conveyor belts, inexorably transporting water and sediment downstream to larger and larger stream channels, where water quality is often more critical. The larger the stream and the more flow it carries, the faster the conveyor belt of sediment moves. Small streams may move sediment downstream more slowly, but the sediment still moves during runoff events and floods and it can pollute streams and damage habitat. Sediment impacts water quality and aquatic ecosystems regardless of how it got there or what size stream it came through. **Because streams of all types carry and deliver both water and sediment to downstream areas, care must be taken to minimize disturbance to *all* stream channels (regardless of their size) and the slopes which drain directly into them.**

For some forestry operations, the term “**watercourse**” or “**water**” is often used instead of stream. For example, California’s Forest Practice Rules (CFPR) describe watercourses as “any well-defined channel with distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel or soil, including manmade watercourses.” Here, watercourses are categorized into Class I, Class II, Class III or Class IV. Other states and countries may use different language, but this type of classification is sometimes used to describe the beneficial uses or ecological values of those waters; not just the frequency with which they flow. In California, **Class I** watercourses contain fish or provide domestic water supplies, **Class II** watercourses have fish present within

1000 feet downstream or contain habitat for non-fish aquatic species (e.g., vertebrates or aquatic invertebrates), **Class III** watercourses have no aquatic life present, but show evidence of being capable of sediment transport to downstream locations (and can therefore impact downstream resources) and **Class IV** are man-made watercourses (e.g., canals and diversion ditches). Class I (fish bearing) streams are usually perennial, but some may be intermittent and support fish during part of the year. Class II streams may be either perennial or intermittent. Class III streams are most often ephemeral, but can sometimes be intermittent.

Although not included in the definition of watercourses, road ruts, road-side ditches and gullies can sometimes act as man-made drainages which carry water and sediment into natural streams. **Care should be taken to disperse surface runoff so these “man-made” drainage ways do not impact water quality in natural stream channels.**

Wetlands are also ecologically valuable watershed features that, like streams, require environmental protection. Wetlands may occur wherever groundwater emerges onto the land’s surface, such as at a spring, a seep, a marsh or a bog, or where water ponds or pools for some time during the year. Even when dry, many wetlands can be recognized by the presence of certain water-loving plants. Wetlands are primary habitat for hundreds of species of waterfowl as well as many other birds, fish, mammals and insects. Some wetlands drain into streams, while others do not. They naturally filter and recharge water and act to slow the flow of surface water and reduce flooding. Wetlands can also buffer water bodies from potentially damaging land use activities.

Wetlands should be avoided during road construction and related activities, as they

result in special problems that often require expensive construction techniques and may cause continuing land stability problems. More importantly, wetlands require special protective measures and are highly sensitive to disturbance. Fish and wildlife agencies (e.g., the California Department of Fish and Wildlife or the US Army Corps of Engineers) can provide assistance on wetland delineation and protection measures, and can advise you concerning which agency to contact about applicable wetland regulations.

Roads need not threaten the biological productivity and water quality of lakes, streams and wetlands in a watershed if they are properly located, constructed and maintained. Poor road building and maintenance practices can cause excess runoff and erosion, leading to sedimentation in downstream areas. Sedimentation can pollute water supplies, increase flooding potential, accelerate stream bank erosion and trigger landsliding. Salmonid eggs laid in stream gravels can become buried and suffocate, fish habitat can be lost, and other aquatic life may be threatened or killed. Riparian and wetland vegetation may be impacted, resulting in increased summer water temperatures and loss of food and cover for fish and wildlife.

E. TYPICAL EROSION AND SEDIMENTATION PROBLEMS CAUSED BY ROADS

Roads are a major source of erosion and sedimentation on most managed forest and ranch lands. Compacted road surfaces increase the rate of runoff, and road cuts intercept and bring groundwater to the surface. Ditches concentrate storm runoff and can transport sediment to nearby stream channels. Culverted stream crossings can plug, causing erosion of the fill (**Figure 2**) or gullies where the diverted streamflow runs down nearby roads and hillslopes (**Figure 3**).



FIGURE 2. This stream crossing “washed out” (eroded) when the culvert plugged and streamflow overtopped and scoured through the road fill. Sediment was delivered directly to the stream system as the fill eroded. Stream crossings and culverts need to be properly designed, constructed and maintained to minimize the potential for such failures.



FIGURE 3. When a stream crossing culvert plugs, or its capacity is exceeded, flood waters can either buildup and flow over the road, washing out the stream crossing fill (see Figure 2), or it can be diverted down the adjacent road or road-side ditch, creating a gully on the road and adjacent hillslope. Diverted flow from this plugged culvert has created a large gully on the road fill slope and a gully is beginning to migrate up the roadbed. Note the person for scale at plugged culvert inlet.

FIGURE 4A.

Sidecast road construction on steep or unstable stream-side slopes and canyons has a high potential for causing landslides which deliver sediment to downslope stream channels.



Roads built on steep or unstable slopes may trigger landsliding which deposits sediment in stream channels (Figures 4a and 4b). Filling and sidecasting increases slope weight, road cuts remove slope support, and construction can alter groundwater pressures, all of which may trigger landsliding. Unstable road or landing sidecast materials can fail, often many years after the materials were put on steep hillslopes. Lack of inspection and maintenance of drainage structures and unstable road fills along old, abandoned roads can also result in soil movement and sediment delivery to stream channels.

F. HYDROLOGIC CONNECTIVITY OF ROADS

Roads are corridors not only for vehicles and wildlife, but for water and sediment too. Roads and their drainage systems are frequently interconnected or linked with the natural stream network and surface waters of a watershed; surface runoff in some ditches and road surfaces flows directly into nearby streams (Figure 5).

FIGURE 4B. *At a smaller and more common scale, fill slope failures on roads built on steep slopes near stream channels have a high likelihood of delivering sediment directly to the stream channel.*





FIGURE 5. Hydrologic connectivity occurs where road and ditch runoff is delivered to the natural stream channel system. It most commonly occurs where road ditches discharge road runoff and eroded sediment directly to stream crossing culvert inlets. In this photo, both road ditches are hydrologically connected to the natural stream where it enters the culvert.

The degree of interconnectedness, or connectivity, is typically characterized as the length or percent of the road that drains to streams and other water bodies (lakes, wetlands, etc.) during a “design” runoff event. These roads and road segments are termed “hydrologically connected roads” and the degree of connectedness expands and contracts depending on the magnitude of the rainfall and runoff event.

Gravel and native surfaced roads in rural and upland landscapes are important sources of runoff and sediment to streams. The downstream effects of these sources on stream channels, water quality and aquatic ecosystems is a function of the degree of connectivity (e.g., the percent of the road drainage system that is connected) and the nature and volume of products (water, nutrients, sediment and other pollutants) that are delivered to the stream network and aquatic system. **Perhaps the greatest impact comes from hydrologically connected forest, ranch and rural roads that experience high traffic levels, or significant commercial traffic, due to the rapid generation of fine sediment on the road surface that is then transported along the road surface or in ditches to nearby streams and**

waterbodies. Other sources of sediment pollution can come from roads with eroding cutbanks and ditches, especially in areas with highly erodible soils (e.g., decomposed granitics) where revegetation of cutbanks is slow or incomplete.

The higher the percentage of the road system (mostly cutbanks, ditches, road surfaces) that is connected, the greater will be the potential effect on the receiving waters. Hydrologic connectivity for older, unimproved forest and ranch road systems has typically averaged from 30% to 55% over large watershed and river basin areas. On a smaller scale, hydrologic connectivity has been found to range from 0% (e.g., some ridge roads) to over 80% (e.g., some streamside roads or insloped, ditched roads with frequent stream crossings). Roads are either hydrologically connected to the stream system, or they are not. **Roads and road segments that are connected and drain to streams and waterbodies have the potential to impact these systems, while roads that are not hydrologically connected will not. Simple road surface drainage treatments can greatly reduce the degree of connectivity and levels of chronic fine sediment pollution typically**

associated with rural road systems. Using simple road drainage techniques, connectivity can usually be reduced to 10–15%.¹

G. IMPORTANCE OF PROPER PLANNING AND CONSTRUCTION

Road construction does *not* have to result in excessive erosion and downstream sedimentation. Proper planning, design and construction techniques used in road location and building, and drainage structure installation and maintenance, can prevent water quality problems and can significantly extend the useful life of the road. Roads can be planned and located to avoid unstable, erodible areas, and stream crossings can be planned, located and built using techniques which minimize the potential for post-construction erosion or slope failure. **Good planning, proper location and the use of progressive construction and reconstruction practices can largely avoid the impacts normally associated with road building. Do it right and you'll end up with a low-maintenance, low-impact road. Do it wrong and you're destined for high maintenance costs and high environmental impacts. The choice is clear.**

H. ELEMENTS OF A STABLE ROAD

The features described in this section form the building blocks of stable roads. They include elements of the road's physical environment, critical control points (locations of special concern or sensitivity along the alignment), restrictions on road location (legal and physical), how to keep a stable road once it's built, and where to find additional help and information.

¹ See Appendix C for California Forest Practice Rule requirements for hydrologic disconnection and Technical Rule Addendum No. 5 for additional information on this topic.

1. PHYSICAL ENVIRONMENT

The physical environment of the road includes such factors as the slope of the land, the types of bedrock and soils through which the road passes, as well as surface and subsurface drainage across the alignment. Together, these physical factors determine the best choice for road location in a watershed, as well as the most suitable techniques for constructing a stable, low-maintenance road.

a. Slope of the land

The slope of the land is one of the most important elements that control where and how roads are built. Road building becomes more difficult and expensive as land slopes become steeper. Roads built on steep slopes are also more likely to have erosion and stability problems.

Slope gradient can be expressed in several different ways. The slope of the land is usually expressed in percent, such as "50%." The slope gradient of cut slopes and fill slopes is often expressed as a ratio, such as 2-to-1. A 2-to-1 slope means that for every two feet in the horizontal direction, the land surface rises or falls 1 foot in elevation (two feet out for every one foot up or down). A 2-to-1 slope is also said to have a gradient of 50 percent (50%) (Figure 6). A 100% gradient would correspond to a 1-to-1 slope pitch, and a 25% slope has a 4-to-1 slope ratio. Less often, in road work, slopes are expressed in degrees (e.g., 30°). Road grade (the slope of the road along which you drive) is usually expressed as a percent, such as a road with a gentle 2% grade or a steep road with a 14% or steeper grade, that is usually unrelated to the slope of the land over which it passes.

Table 1 shows typical land and bank slopes, expressed as horizontal-to-vertical ratio (e.g., 2-to-1, or 2:1), percent (e.g., 50%) and degrees (e.g., 27°), and Figure 6 graphically depicts some of the more commonly expressed slopes.

Fill slopes and cutbanks are also described using these slope measurement units.

Land slopes can be estimated from the contours on topographic maps, based on the scale of the map, the spacing between the contour lines and the stated "contour interval" for the map. **Table 2** provides the needed data for determining land slope from a standard 1:24,000 scale topographic or contour map.

Keep in mind, however, that the map shows an average slope between contour lines. In the field, land slope often varies considerably over short distances and is best measured using a simple, inexpensive, handheld instrument called a clinometer (**Figure 7**). A pocket-clinometer measures slope steepness, expressed in both degrees and percent, by looking either up or down the slope through the instrument.

FIGURE 6. Slope diagram graphically shows common cut and fill slope angles, and expresses steepness in both percent and slope ratio (H:V = horizontal distance to vertical distance) (Fay et al., 2012).

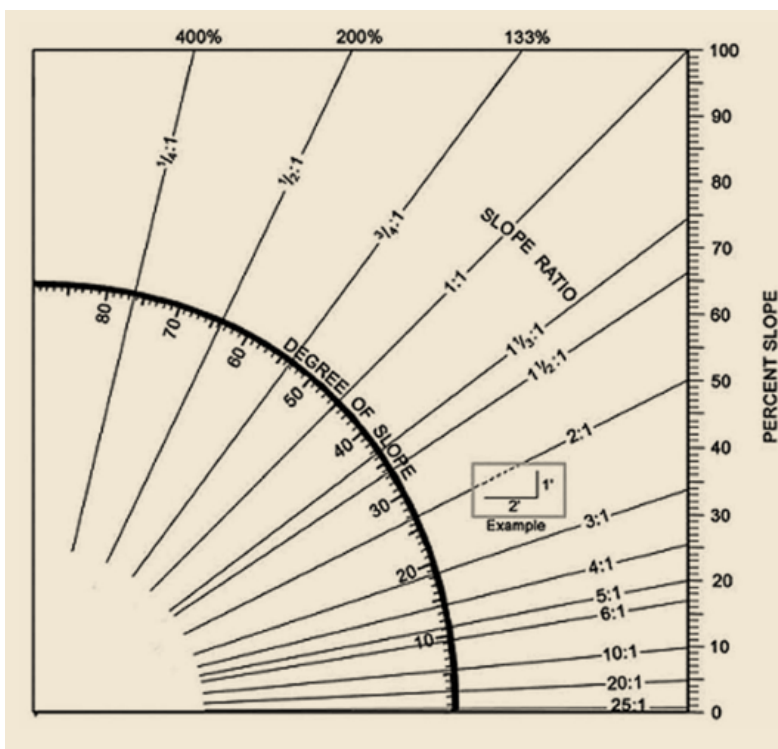


TABLE 1. Relationship between slope ratio, percent slope, and slope degrees as a measure of slope steepness

Slope Ratio (H:V)	Percent Slope (%)	Slope Angle (degrees)
	5.0	2.5
10:1	10.0	5.7
	17.6	10.0
4:1	25.0	14.0
3:1	33.5	18.0
	35.0	19.0
	45.0	24.2
2:1	50.0	26.6
	65.0	33.0
1½:1	66.7	33.7
	70.0	35.0
	80.0	38.6
	90.0	42.0
1:1	100.0	45.0
½:1	200.0	63.4
¼:1	400.0	76.0

TABLE 2. Land slope (%) as derived from a 1:24,000 scale topographic map

Contour interval of map (ft)	Measured distance (mm) between contours on topographic map (best if averaged along fall line over several contour lines)															
	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	2.0	2.5	3.0	4.0	
20	51	42	36	32	28	25	23	21	20	18	17	13	10	8	6	
40	102	85	73	64	56	51	46	42	39	36	34	25	20	17	13	
80	203	169	145	127	113	102	92	85	78	73	68	51	41	34	25	
120	304	254	218	191	169	152	139	127	117	109	102	76	51	61	38	

FIGURE 7.*Estimating slope with a clinometer.*

Logistically for ease of use, roads should not be built directly up a slope, especially on steep grades that exceed about 15%, unless it is for a short pitch of less than 500 feet with a road grade not exceeding about 20%. Roads that extend directly up a natural hillslope, no matter how gentle, are very difficult to drain to one side or the other. Road runoff will flow straight down the fall line of the slope and road, eventually eroding into the roadbed and causing the road to become increasingly entrenched over time. This not only generates sediment but requires repeated and significant maintenance to keep the road useable.

Most roads traverse across the slope, and it is not difficult to keep road grades to less than 3%–5%, even where the slope of the land exceeds 50%. This side slope construction also helps prevent serious drainage and surface erosion problems because they are much easier to drain and to disperse the runoff onto the slope below. Ridges, natural benches and gentle sideslopes far away from stream channels are usually the best places to build roads. Steeper pitches are sometimes required to avoid unstable

areas or other obstacles, or they are needed to avoid crossing property boundaries.

b. Bedrock and soils

The stability and erodibility of a road alignment is controlled by the underlying bedrock and soil material, as well as by the occurrence of water. Bedrock composition and the properties of soils vary dramatically along most road routes. Each soil and bedrock type reacts differently to road construction and road drainage.

Some important bedrock properties that influence slope stability and the ease of excavation for road building include rock hardness, direction and inclination of rock layering, amount of natural fracturing, amount of weathering or natural decomposition, and mineral composition. Highly fractured or weathered rocks, or rock layers that slope parallel to the hillside, are likely to result in erosion and stability problems during or after construction. These conditions often lead to high maintenance costs.

A number of soil properties will also influence how easy it is to build a road, how stable the road will be following construction, and

how much erosion is likely to occur when the soils are exposed. Such properties include soil depth, erodibility, coarse fragment content, texture, and compactibility. Soil texture is one factor used in determining the erodibility or “erosion hazard rating” of a soil², and can be evaluated using simple field tests (Figure 8). The properties of soils in an area can generally be determined from soil survey maps and reports available from the local office of the Natural Resource Conservation Service or on their website (<http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>). The responses of soils to road construction and use can often be anticipated from the information in these reports. In practice, where a road is to cross steep slopes, or portions of the route will traverse unstable areas, soil maps and geologic maps should be reviewed and a professional geologist should be consulted to evaluate the suitability of the site for the planned road building activities. You can also learn a lot by researching past land use studies and permits, geologic reports, timber harvesting proposals, engineering reports and historic aerial photos that may be available for the area.

c. Drainage

“Drainage,” refers both to subsurface drainage (groundwater and soil water through-flow) and surface drainage (runoff). Well drained slopes and properly drained roads are critical to low impact, low maintenance road locations, and can have significant effects on road construction and subsequent road stability.

i. Subsurface drainage Water held in the soil, or moving through the soil, is called soil

² If soil maps do not exist or are not available, simple tests can be performed in the field to estimate the soil’s most important properties. For example, California Board of Forestry Technical Rule Addendum #1 (see Appendix C) outlines a procedure for estimating the surface erosion hazard rating (EHR) of a soil. However, this procedure only estimates the soil’s susceptibility to surface erosion caused by rainfall and runoff. The likelihood of mass soil movement (landsliding) should be determined in other ways.

water or groundwater. Water that cannot move freely through the soil often emerges on the ground surface as springs and seeps. Even where subsurface drainage (the flow of water through the soil) is good, it can be affected by road construction and, in turn, roads can be damaged by obstructed or disturbed subsurface drainage. For example, poor subsurface drainage can result in persistent saturation and damage to the road materials as well as subsequent erosion problems. If too much water is in the surface soils (because of seasonal wetness or poor drainage), or groundwater is emerging beneath the road, the weight of vehicles can deform the soil and turn it into mud with little form or texture and little or no strength. On a sloping road, the mud can become a safety hazard, the roadbed may be damaged, and sediment can flow into ditches and nearby streams, causing water quality problems.

Some soils are naturally wet and poorly drained, and should be avoided during road building operations. These are often indicated by pools and wet areas on the ground surface during the wet season. Such sites can often be recognized during dry summer periods by noting changes in vegetation types and/or color (lushness). Wet areas can sometimes be drained, but unless the source of the emerging groundwater is eliminated, wetness may be a continual problem at the site. Once water has emerged onto the ground surface (on the cutbank, in the ditch or on the road surface) it should be directed away from the site and discharged onto a stable area.

Similarly, poor subsurface drainage can create slope stability problems for roads built across steep, wet hillslopes. Subsurface drainage techniques can be employed to relieve or prevent a buildup in pore water pressures within the soil mantle or within road fill materials. Following intense storms and rain events it is not uncommon to see road fill failures that

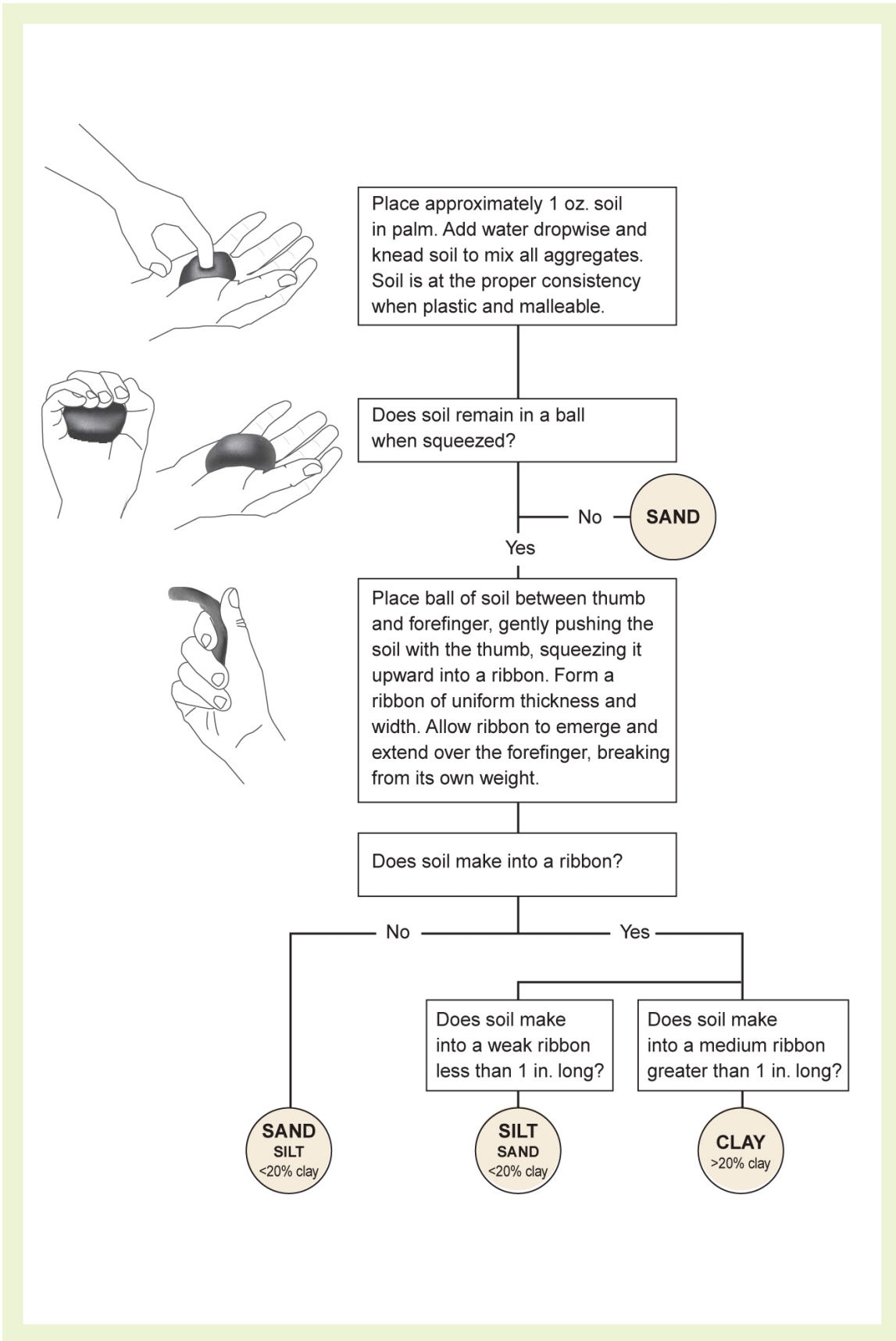


FIGURE 8. The texture of fine sediments and soils, an important component used to evaluate soil erodibility and erosion hazard, can be estimated using a simple hand-texturing field test (Kramer, 2001).

were triggered by elevated hydrostatic pressures. Significant road and hillslope failures (e.g., debris slides and debris flows) can sometimes be attributed to a road's adverse effect on subsurface drainage. For example, when a road is built across a steeply inclined swale in mountainous terrain, the thick road fill can compact the subsurface soil pores through which groundwater flows, thereby causing increased pore pressures and failures of the road fill and underlying soils during storm events.

If the road must pass over a known wet area, including springs or seeps, subsurface drainage techniques can be used to drain the ground beneath the roadbed and to prevent the buildup of pore water pressures within the underlying soils. Subsurface drainage techniques include the use of gravel-lined "French-drains," with or without perforated pipes buried in ditches, and other combinations of gravel blankets and overlying filter fabrics. If you are unsure about recognizing or treating a wet area, obtain professional assistance; a mistake made here can lead to increased construction and maintenance costs later, and to significant environmental impacts. Avoidance is the least expensive and most successful method for preventing subsurface drainage problems, and it is almost always best to re-route the road to avoid natural wet areas.

ii. Surface drainage The key to successful surface drainage is to get the water off the cut slopes, fill slopes and road surface as quickly as is possible, before it has the opportunity to concentrate into a large volume of flow or saturate the ground. **The three most important rules for accommodating surface runoff are 1) drain and disperse water off the road rapidly so it cannot erode or seep into the roadbed, 2) direct runoff off the road often to avoid large, erosive flows from developing in long, undrained ditches or road surfaces, and 3) direct runoff to safe locations away from watercourses and unstable areas.**

A simple method, called the 5-D Test, can be used to measure the effectiveness of road drainage systems. This test relies mostly on visual information and analysis of road surface drainage. The 5-D's are:

1. Are *all* natural **DRAINAGES** conveyed (e.g., carried in dips, fords, culverts or bridges) across the road and released back into their natural channels (this includes both small and large streams and watercourses)?
2. Does the road drainage system actually **DIVERT** water off the road surface?
3. Is drainage frequently and quickly **DISCHARGED** from the road?
4. Is the energy of flowing water **DIS-SIPATED** onto non-erodible material at the point of discharge?
5. Is the **DISTANCE** between drainage structures adequate to prevent erosion of the roadbed and fill slope while preventing sediment delivery to nearby stream channels?

These five tests apply to all drainage methods, including road outslipping, waterbars, rolling dips, ditch relief culverts, stream culverts and bridges. The first four tests can be conducted by observation; the fifth test can be evaluated by assessing local site conditions including road grade, surface material, elevation, expected rainfall, soil type, road shape, and location of existing drainage structures (Washington DNR, 2011). A variety of road handbooks and manuals provide standards for spacing of ditch relief culvert and surface drainage spacing, although it is important to emphasize that effectiveness of road drainage design is dependent on site-specific conditions. Using published standards without evaluating site conditions can lead to (1) increased erosion if drainage spacing is too infrequent or (2) unnecessary high construction costs if surface drainage is

TABLE 3. Examples of road surface drainage spacing standards¹

Source	Maximum surface drainage spacing based on road gradient (ft)			
	2–4%	5–8%	9–12%	>12%
Colorado Forest Service, 2011	500–900	300–700	200–500	–
Idaho Department of Lands, 2014	400–600	300–500	–	–
Bureau of Land Management, 2007	240–400	180–325	140–250	–
Keller and Sherar, 2003	245–400	130–295	115–195	100–165

¹Refer to Appendix C for the California Forest Practice Rules (2013) suggested maximum distance between waterbreaks.

over designed. **Table 3** illustrates selected road surface drainage spacing standards based on road gradient steepness. The variability between suggested standards shows that road drainage design and frequency of drainage structures is not a one size-fits-all approach and requires the evaluation of site-specific conditions.

The use and correct placement of drainage structures such as culverts, rolling dips, diversion ditches, insloping, outsloping, inboard ditches, ditch relief culverts, waterbars and stream culverts are worth the initial cost of installation. Correction and repair may be 2–10 times more costly than the original installation, and damage to the land and nearby streams may be uncorrectable and irreversible.

2. CONTROL POINTS FOR ROAD LOCATION

The stability of a road and its impact on the environment are often determined by how the road is designed and located around physical points of control in the landscape. Efforts should be made to avoid as many obstacles and stream crossings as is possible when planning and locating a road alignment.

a. Obstacles

Obstacles to a stable road include scars identifying unstable slopes (slumps, debris slides, debris flows, earthflows, rock falls, etc.); hard

rock outcrops; cliffs and very steep slopes; wet and unstable or highly erodible soils; ponds and lakes; wetlands and swamps; and property boundaries. These features should be precisely located during road reconnaissance since they constitute control points that will influence the final location of the road.

Agreements with adjacent landowners should be arranged when needed to prevent property boundaries from forcing roads to be built in unstable or unsuitable locations that could cause excessive erosion and damage in downslope and downstream areas. In addition, recognition of slope instabilities may sometimes be easy, but the skill and expertise of a qualified and experienced geologist or engineering geologist is often needed to determine the full extent of unstable areas and to choose a suitably stable alternate route which bypasses the obstacle. **In the long run, employing a qualified professional to solve a technical problem is much less expensive than repairing a major road failure.**

b. Stream crossings

Stream crossings are particularly vulnerable to erosion and failure; they are often considered the weak point in a road alignment as they are usually the most vulnerable and failure-prone feature. For this reason, **the number and size of stream crossings that have to be**

constructed along a new road should be strictly minimized. The more deeply incised a stream canyon is, the more excavation, soil disturbance and erosion are likely to occur during and after construction of the crossing. Therefore, stream crossings should be located where the channels are least incised, across natural benches, and where sideslopes are as gentle and stable as possible. In addition, stream crossings should be built at right angles to the stream channel, and, where possible, streams requiring a 60", or larger, diameter culvert, large volumes of fill, or fish passage should be considered for a bridge.

The use of designed, constructed crossings is required wherever roads must cross a stream or watercourse. They may be permanent, including a culverted fill crossing, a bridge, an armored fill or a ford, or they may be temporary, such as a temporary culverted fill, a log crossing or a temporary bridge that needs to be removed before the beginning of the following wet season or winter period (generally considered as beginning in mid-October in the western USA). All forest, ranch and rural road stream crossings that are to remain in place for one (1) or more winter or wet season periods should be designed to pass at least the 100-year storm flood flow, including floating organic debris and sediment loads. This is good practice and is often required by regulation. Crossings on older forest roads that need reconstruction should also be designed to current 100-year peak flow standards (methods for estimating the 100-year flood flow for small ungagged streams are included in Chapter 4 and in Appendix A). These standards are appropriate for all wildland roads, including forest, ranch and rural road systems. Stream crossing installations typically require both environmental permitting and design details (or BMPs) and these requirements are likely to vary depending on your location.

Some stream crossings require extra careful design to accommodate both juvenile

and adult fish passage. These will require consultation with agency experts, and perhaps qualified consultants, to determine the best crossing type and fish passage design. Preparing and installing the proper crossing in the first place is likely to be more successful in meeting passage goals, and perhaps less expensive, than having to retrofit or replace a poorly designed structure that has already been built.

c. Road grade

The slope of the road is called "road grade." This is not the same as the slope of the land. Road grade is typically expressed in percent (%). A road that rises or falls 10 feet for every 100 feet of its length has a grade of 10%.

Road alignments should be designed with gentle to moderate grades to minimize damage to the roadbed, to allow for frequent and effective road surface drainage and for safety. Flat road grades (<1%), such as those on valley bottoms, are often difficult to drain and may develop potholes and other signs of impaired drainage. Steep roads are more likely to suffer from erosion and vehicle damage, especially if they are used when wet. This can also lead to increased safety hazards compared to lower gradient roads. Steep roads are more difficult to drain because surface runoff often flows down the road in wheel ruts rather than off the outside edge where it can be discharged and dissipated. In snow zones, steep roads may represent a safety hazard if they are used during cold weather periods. New road alignments should use grades of 3% to 8%, or less, wherever possible. Forest roads used for log hauling should generally be kept below 12% (try for an 8% average maximum) except for short pitches of 500 feet or less where road grades may go up to 20%. These steeper road grades should be paved or rock surfaced and drained frequently, especially if they

TABLE 4. Timing of road planning and construction activities for a Mediterranean climate¹

Season	Planning and design	Field layout	Construction and re-construction	Inspection and maintenance	Closure
Winter	+ ¹	+	No	+	No
Spring	+	+	✓ (late)	+	–
Summer	+	–	+	+	+
Fall	+	–	✓ (early)	+	+

¹Key to symbols: + = good or excellent season for this activity. ✓ = OK or good time to perform this work. – = not a very good season for this type of work. No = this is not a good time for construction or closure work using heavy equipment, unless there is an extended dry period. Each season has periods when work can be undertaken. Wet weather equipment work, if undertaken, should be planned and conducted carefully, with erosion control work kept up to date.

are to be used during the wet season or winter months. Grades for rural roads that are used by passenger vehicles should be at the lower end of these road gradients.

3. OTHER LIMITATIONS ON ROAD LOCATION AND CONSTRUCTION

A number of physical limitations on road location have already been discussed, including obstacles and stream crossings. But other factors may also limit when and where a road can be built.

a. Seasonal construction limitations

Climate can dictate when the best and most favorable road building conditions occur. For example, California’s coastal Mediterranean climate is generally one of wet winters and dry summers, and these extremes limit the time of year when construction activities can be most effective. Although road construction should not occur during wet weather conditions, there are a number of planning and reconnaissance activities that can, and should, take place during wet periods. Indeed, winter is the best period for field reconnaissance and to identify springs, seeps and small streams that might not be visible during the dry season.

Generally, construction and reconstruction (upgrading) activities should be timed to minimize soil erosion, to give vegetation time to take hold before heavy rainfall begins, and so heavy equipment will not have to work on wet soils. Late spring through middle summer is the best period for heavy equipment work in many locations. Some moisture is required and desirable for adequate compaction of fill materials, but road construction should not begin before the soil has had time to drain and dry. Construction activities can take place during dry weather and dry soil conditions as long as water is available to add soil moisture when it is needed for compaction and dust control.

Table 4 outlines activities that can be safely and effectively conducted during various times of the year. In some years there are extended dry periods during the winter months when some heavy equipment work can be performed. However, local regulations may limit the types of work that can be performed during the wet season, and how that work must be conducted. For example, the 2013 California Forest Practice Regulations require that erosion control work be kept current with soil disturbing operations (daily), that a winter period operating plan be prepared and filed (if necessary) to guide winter operations, and that work be immediately shut down before conditions begin to affect water quality.

TABLE 5. Recommended minimum widths for buffer/filter strips between wildland roads and streams to improve or protect water quality¹

Recommended width ²	Authors
≥50 ft	Woodard and Rock (1995)
≥80 ft	Young et al. (1980)
≥100 ft	Lynch et al. (1985)
≥30 ft	Dillaha et al. (1989)
≥60 ft	Nichols et al. (1998)
≥30 ft	Corley et al. (1999)
≥60 ft	Shisler et al. (1987)

¹adapted from Fischer et al. (2000)

b. Operations near streams, lakes and wetlands

A sufficient buffer or filter strip of undisturbed soil and vegetation should be left between road building, road reconstruction, and road maintenance activities, and nearby streams, lakes and wetlands. Road surface drainage should be dispersed and discharged into a filtering area with enough ground cover and slope distance to infiltrate water and catch any sediment coming from road runoff. Filter strips should be retained for all watercourses, including ephemeral and intermittent streams that may not be flowing at the time of road construction or maintenance.³ **Streambeds and wetlands do not make good road locations and should never be used for that purpose.**

Buffer strip design and width are dependent on the purpose of the buffer (e.g., water temperature moderation, sediment removal, nutrient removal, and species diversity), vegetation type, soil permeability, and slope gradient. **Table 5** lists several recommended minimum filter or buffer strip widths for protecting water quality, but these distances may have to be modified depending on local site conditions, as well as regulatory requirements. Buffer widths are directly tied to the steepness of the land adjacent to the stream and

soil permeability; with steeper slopes or less permeable soils requiring longer buffer distances. Although recommended buffer widths in **Table 5** vary between 30 feet and 100 feet, buffer width should be no less than 30 feet to protect water quality. Regulations may dictate acceptable buffer widths and operations that can be conducted within the buffer area.

Where there is inadequate roadside vegetation, physical barriers (logs, brush, ditches, etc.) or small sediment retention structures/basins may be added to trap some of the sediment coming off the road surface or fill slopes. For example, the filtering effectiveness of buffer strips can be dramatically improved if slash is intermittently placed at the base of fill slopes along the road alignment, leaving some outlet for wildlife to pass. These structures are called filter windrows. **Inboard ditches and ditch relief culverts should be discharged onto vegetated slopes and never into natural stream channels or watercourses.**

4. KEEPING A STABLE ROAD

Building or upgrading a road should be viewed as a long-term commitment of both resources (money and equipment) and personnel. If you are unable to make that commitment, then the road either should not be constructed, or it should be built as a temporary road with drainage

³ See Appendix C for the California Forest Practice Rules relating to watercourse protection.

structures that are removed after use.

Many dead-end spur roads built during timber harvesting or other resource extraction activities can and should be designated as temporary. If and when they need to be rebuilt in the future, stream crossings can be reconstructed and the road regraded and reopened.

A road built with drainage structures and stream crossings needs to be maintained during the winter or wet weather period (as storms occur), during the summer or dry season period (as it is being used), and preceding each wet weather season (to prepare the road for rainfall and runoff). Periodic and storm maintenance inspections and activities need to be performed frequently and regularly during the first several rainy seasons as the road “settles in” and stabilizes. Each year that follows, the road and its drainage structures should be regularly checked and, when necessary, repaired.

Roads need to be accessible in order to be effectively inspected and maintained. Gates can be installed along seasonal, unsurfaced roads to limit wet weather access by the public or by trespassers to prevent damage to the roadbed and to drainage structures. The use of permanent barriers, like logs or large ditches and soil berms, to prevent unwanted access also prevents inspections and maintenance that is critical to keeping a stable road. **Permanent barriers should only be used on closed or decommissioned roads, and not on roads that may require maintenance.**

When the need for a road diminishes, it is not sufficient to close the road by simply abandoning it or by putting up barricades or a gate. If a road is not going to be inspected or maintained for multiple seasons, it needs to be proactively decommissioned or “storm-proofed” (stabilized against damaging erosion). This is done by excavating stream crossings and removing

culverts, and by excavating potentially unstable fill material that might fail and deliver sediment to local stream channels during winter storms (see Chapter 8). In most cases the road can be reopened when it is again needed for land management or for other purposes.

5. WHERE TO FIND HELP

Many experienced people and practical handbooks are available to help you make wise decisions on planning, designing, locating, constructing, reconstructing, and proactively abandoning forest, ranch and rural roads. There’s nothing like experience in being able to develop a good project, so find respected professionals and practitioners who regularly perform these tasks and learn from them. **Table 6** lists some of the typical sources you can contact for guidance on plans for where, how and when to build a road in California and in much of the USA. You are likely to find similar information sources in your area.

I. PERMITTING

Prior to the commencement of any road construction project, specific federal, state, and local government permits, agreements, and other authorizations may be required. These permits and agreements are required to ensure that projects are considered and assessed for (1) their adverse effects on the environment (e.g., negative effects on water quality, sensitive or endangered species, or critical habitats), (2) proper design and construction plans, and (3) potential mitigation plans in the case of unintended environmental impacts.

Some examples of required permitting for road construction activities for California are listed below. Regulatory requirements will be different for each area of the country, but it is important to research and determine those that apply in your area.

TABLE 6. Sources of information for planning, constructing, maintaining, and abandoning small private roads

Suggested source	Aerial photos	Spatial data	Weather reports	Vegetation	Permits	Technical assistance	Maps and Literature			
							Soils	Geology	Topography	Roads
Federal										
NRCS	✓	✓	✓	✓		✓	✓	✓	✓	✓
USDA	✓	✓		✓		✓	✓	✓	✓	✓
USFS	✓	✓	✓	✓		✓	✓	✓	✓	✓
BLM	✓	✓		✓		✓	✓	✓	✓	✓
USDA Extension Service						✓	✓	✓	✓	✓
USGS	✓	✓					✓	✓	✓	
NOAA			✓							
Army Corps of Engineers					✓					
State										
Department of Forestry and Fire Protection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Geological Survey	✓	✓				✓	✓	✓	✓	
Department of Transportation					✓					✓
Department of Fish and Wildlife		✓			✓	✓				✓
Regional Water Quality Control Board					✓	✓				
Cooperative Extension System				✓		✓	✓		✓	✓
Universities (Departments of Forestry, Geology, and Engineering)		✓	✓	✓		✓	✓	✓	✓	✓
University libraries				✓			✓	✓	✓	✓

TABLE 6. Sources of information for planning, constructing, maintaining, and abandoning small private roads

Suggested source	Aerial photos	Spatial data	Weather reports	Vegetation	Permits	Technical assistance	Maps and Literature			
							Soils	Geology	Topography	Roads
County										
Public Works, Road or Building Departments	✓				✓	✓	✓	✓	✓	✓
Natural Resource Departments	✓			✓		✓				✓
Planning Department	✓				✓	✓				
County library				✓?			✓	✓	✓	✓
City and local										
City library				✓?			✓	✓	✓	✓
Government					✓					
Other sources										
Private consultants (forestry, geology, engineering, wildlife, etc.)	✓	✓		✓		✓	✓	✓	✓	✓
Outdoor stores									✓	✓

¹NRCS- Natural Resources Conservation Service; USDA – U.S. Department of Agriculture; USFS – U.S. Forest Service; BLM – Bureau of Land Management; USGS – U.S. Geological Survey; NOAA – National Oceanic and Atmospheric Administration.

1. COUNTY

Department of Public Works and/or Building Departments often have grading ordinances that describe how private roads may be constructed and how these roads may connect with existing public roads. Permits may be required, and County Planning Departments may also want to review proposed roads that are being constructed for large and small lot splits and land subdivisions, even in rural areas. Certain standards related to proposed road use and emergency vehicle access standards may be required. In areas of proposed road construction or maintenance that are underlain by soil or bedrock containing naturally occurring asbestos, special mitigation measures may also be necessary to comply with the requirements of the California Air Resources Board. The Asbestos Airborne Toxic Measure for Construction, Grading, Quarrying and Mining in California is administered by each County Air Quality Management District.

2. STATE

Each state in the U.S. has its own regulations and standards for forest and rural road work, some more stringent than others. In California, state regulatory agencies with jurisdiction on road construction and related activities include the Department of Transportation, the Department of Fish and Wildlife, the Department of Forestry and Fire Protection, and the Regional Water Quality Control Boards. Several other agencies have special jurisdiction. The California Department of Transportation (Caltrans) controls private road connections with state maintained roads and highways. An application fee and bond or deposit may be required for this type of work. You should also check with the California Coastal Commission when planning a road within the Coastal Zone. For new roads, archaeological clearance may be needed in areas where records show prehistoric activity or habitation. For developing rock pits and borrow sites over one acre in size, or

exceeding 1000 cubic yards of overburden or rock material, the Department of Conservation should be consulted regarding development and reclamation requirements of California's Surface Mining and Reclamation Act (SMARA). (California Office of Mine Reclamation, 2012).

The Department of Fish and Wildlife will need to be notified of any road construction, road reconstruction, road removal or related projects that would result in the diversion or obstruction of natural streamflow or in physical modification of the bed or banks of any stream or lake. A formal notification called a Lake and Streambed Alteration Agreement (LSAA) (sometimes referred to as a 1600 or 1603 "permit") needs to be submitted to the Department on Form 1603, describing the proposed work and including an application fee⁴ (see Appendix B). Permanent or temporary stream crossing structures, fords, riprap or other bank stabilization measures, culvert installations, bridges, or skidding across temporary crossings are some of the projects which are subject to the LSAA notification process (Appendix B).

To build or rebuild a road for commercial harvesting of trees, firewood or other forest products, a Registered Professional Forester in California needs to file a timber harvesting plan (THP) with the Department of Forestry and Fire Protection (CAL FIRE). This includes any commercial timber or other saleable wood products from road building or reconstruction work. Specific regulations must be followed for planning, designing, constructing and maintaining these logging roads (Appendix C). Fire-safe road standards have also been developed for rural subdivision roads that require CAL FIRE review prior to construction.

The State Water Resources Control Board and the Regional Water Quality Control Board with jurisdiction in your area administer and enforce provisions of California's

⁴ The application fee is not needed for commercial timber harvesting plans.

Porter-Cologne Water Quality Act, as well as the Federal Clean Water Act. Whenever water quality and the beneficial uses of water could be affected, these agencies need to be consulted. Sediment entering streams and watercourses is a serious pollutant and road construction, reconstruction and maintenance activities, if not performed properly and with care, can cause downstream pollution. Clean-up and correction actions ordered by the Board can be costly and cause significant delay, so it is always best to follow practices which are protective of water quality.

3. FEDERAL

Federal regulations may also apply to your road building activities. In many cases, federal regulatory authorities may have been delegated to state agencies. In California, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, and others, have jurisdiction over certain aspects of construction projects and the environment in which they occur. If funding for any of your road work is derived from federal monies then it is more likely that various federal regulations will apply. You are responsible for determining what agencies have jurisdiction for your project, and for working with them prior to conducting any on-the-ground construction activities. You will need to check with local and state agencies to see if any of these federal regulatory entities affect your project.

Table 7 provides a list of federal and California state permits, certifications, and authorizations that are typically required for road construction projects, along with contact information.

4. OTHER STATES AND COUNTRIES

For road projects proposed in other states, you should contact their specific state government

agencies to determine which permits, agreements, or other authorizations are required for the project. In addition to federal and state permitting, local government permitting is frequently required. Contact your local county planning departments, Resource Conservation Districts, or other local agencies to determine which county or city permits are required for your project. Make sure to plan ahead when applying for and acquiring permits. In some cases, it can take two to three months, or longer, to obtain the necessary permits. **Not only is it important to understand what environmental regulations pertain to your project and know which permits are required, you should also review and understand the implications and consequences for not complying with the regulatory and permitting process.**

5. PERMITTING COSTS

Permitting requirements for road construction projects can be costly. In some cases, permitting costs can account for approximately 5 to 10% of the overall project budget depending on project size, types of treatments implemented, natural resources impacted, and the number of permits required. Road construction or restoration projects may be funded by grant monies distributed and controlled by federal or state agencies. Some grant programs, such as the Fisheries Restoration Grant Program administered by the California Department of Fish and Wildlife, involve a programmatic permitting process where all necessary permits and authorizations are secured by the grant funding agency through a one-stop permitting process. This reduces the time and expense of acquiring multiple permits from federal, state, and local agencies. Similarly, county-coordinated permitting processes may be available through your local RCD office or through other landowner assistance programs. Contact your local state or county agencies to determine whether your

TABLE 7. List of potential federal and California state permits, agreements, or authorizations required for road construction projects¹

Name of permit, agreement, or authorization	Agency	Project activities	Contact information
Federal			
Discharge of Dredge or Fill Material Into Waters of the U.S. (Section 404 permit)	U.S. Army Corps of Engineers (USCOE)	Any construction activities conducted in waters of the U.S. (e.g., tidal waters, wetlands, and other water bodies).	http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits.aspx
Work in Navigable Waters (Section 10 permit)	U.S. Army Corps of Engineers (USCOE)	Any construction activities conducted in navigable waters of the U.S. (e.g., tidal waters, wetlands, and other water bodies).	http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits.aspx
Construction General Permit (NPDES)	U.S. Environmental Protection Agency	Any construction activities requiring ground disturbance of greater than 1 acre in size.	http://cfpub.epa.gov/hpd/es/stormwater/cgp.cfm
National Environmental Policy Act (NEPA)	Variable, depends on federal agency and project type	According to the NEPA process, federal construction projects are required to develop Environmental Assessments or Environmental Impact Statements to ensure that projects are designed, located, and operated in ways that reduce adverse environmental impacts and increase the beneficial effects.	http://ceq.hss.doe.gov/hepa/citizens_guide_Dec07.pdf
Incidental Take Permit/Section 7 of the federal Endangered Species Act (Section 10(a)(1)(B) permit)	U.S. Department of Fish and Wildlife (USFWS) National Marine Fisheries Service (NMFS)	Any non-federal construction activities that may adversely impact federally and state listed species or critical habitat. Note that a §7 Incidental Take Permit involves consultation between federal agencies only (e.g., USACE, NRCS). If no federal agency is involved, the take authorization occurs through §10 of the Endangered Species Act.	http://www.fws.gov/endangered/permits/ http://www.nmfs.noaa.gov/pr/permits/incidental.htm
State (California)			
Lake or Streambed Alteration Agreement (1600 "permit")	California Department of Fish and Wildlife	This Notification (not technically a permit) is required for construction activities that substantially divert or obstruct the natural flow of any river, stream, or lake; substantially change or use any material from the bed, channel, or bank of, any river, stream, or lake; or deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it may pass into any river, stream, or lake.	http://www.dfg.ca.gov/habcom/1600/

TABLE 7. List of potential federal and California state permits, agreements, or authorizations required for road construction projects¹

Name of permit, agreement, or authorization	Agency	Project activities	Contact information
Coastal Development Permit	California Coastal Commission	For any construction projects within the Coastal Zone. Note: Issuance of a CDP is often delegated to the county in which the activity will occur through a Local Coastal Plan.	http://www.coastal.ca.gov/cdp/cdp-forms.html
Water Quality Certification (Waste Discharge Requirements (WDR)/Section 401 permit)	California State Water Resources Control Board and Regional Water Quality Control Boards	Any construction projects that may result in a discharge of pollutants into waters of the United States, must obtain a state water quality certification that the activity complies with all applicable water quality standards, limitations, and restrictions. If the project requires a U.S. Army Corps of Engineers CWA Section 404 permit, falls under other federal jurisdiction, and has the potential to impact Waters of the State, then a Section 401 permit is required. If a project does not require a federal permit, but does involve dredge or fill activities that may result in a discharge to "Waters of the State", then a Waste Discharge Requirements permit is required.	http://www.waterboards.ca.gov/water_issues/programs/cwa401/
California Environmental Quality Act (CEQA)	Variable, depends on state or local agency and project type	Small projects less than 5 acres or along less than 500 feet of stream may be eligible for a categorical exemption under Title 14 (CCR), Div. 6, Ch.3, Art. 19, Sec 15333 or "Small Habitat Restoration Projects." This permit has special and temporal limitations, but is suitable for smaller road project and has lower fees. According to the CEQA process, non-federal construction projects are required to develop categorical exemptions, initial study checklists, mitigated negative declarations, or environmental impact reports (EIRs) to disclose potential adverse effects to the public and decision makers, as well as ensure that projects are designed, located, and operated in ways which reduce adverse environmental impacts, and which increase the beneficial impacts.	http://ceres.ca.gov/ceqa/more/faq.html#enforce
California Endangered Species Act (CESA)	California Department of Fish and Wildlife	Incidental take permit for California state listed threatened and endangered species (e.g., coho salmon, California red-legged frog) as described in Title 14 CCR, Sections 783.4(a) and (b).	http://www.dfg.ca.gov/habcon/cesa/incidental/incid_perm_proced.html
THP, NTMP, and other commercial timber harvesting regulations	California Department of Forestry and Fire Protection	Road construction or reconstruction associated with commercial timber harvesting in California.	http://calfire.ca.gov/resource_mgmt/forestpractice.php
California Surface Mining and Reclamation Act (SMARA)	California Department of Conservation	For developing rock pits and borrow sites over one acre in size, or exceeding 1000 cubic yards of overburden or rock material, the Department of Conservation should be consulted regarding development and reclamation requirements of SMARA.	http://www.conservacion.ca.gov/omr/lawsandregulations/Pages/SMARA.aspx

¹This table only includes state permits required in the state of California. Check with your state and federal government to determine what permits are required for your project. Other permits may also be required from county/city agencies. Refer to your local government to determine what permits are required.

project can receive financial and permitting assistance from federal or state programs.

J. PROFESSIONALS AND PROFESSIONAL LICENSING

Depending on state laws and regulations, road construction and restoration work that involves earthwork may require inspection, oversight, design, or certification by licensed professionals. In addition, complex geologic, geomorphic, hydrologic or engineering issues occurring on your property may require consultation and inspection by a licensed professional. The type of licensed professionals required on your project will depend on the type of problems or sensitive conditions that exist, or the type of road construction or restoration work that is proposed. In some cases, licensed professionals can provide important input for on-the-ground decisions when unforeseen conditions arise during the construction phase of road construction and road upgrading projects. **Table 8** lists the standard licensed professionals that provide assistance and expertise to road construction and restoration projects in many jurisdictions.

For example, if the landowner has identified a landslide problem that exists within

the proposed project area, then a licensed geotechnical specialist, such as a Certified Engineering Geologist, should be utilized for further analysis of the problem, assessment of risk, and recommendations for control and correction. Consultation with licensed and experienced professionals may also be required in situations that need a more detailed evaluation of field conditions, prescription options and treatment methods to address complex geologic or geomorphic processes, or in situations that require highly technical analyses or employ complex treatment methods.

If trees will be cut during restoration activities and the logs and wood sold as byproducts of the restoration work, the project may be subject to the respective state's forest practice rules (e.g., California Forest Practices Act and Rules). A Registered Professional Forester can assist with preparation of required permits needed for commercial forest operations. If, on the other hand, the wood will not be sold but used in the project (e.g., to place in the stream channel or to use as bank protection), a timber harvesting plan may not be necessary. In either case, consultation with a local state forestry department (e.g., CALFIRE) is recommended.

TABLE 8. List of licensed professionals that typically work on road construction projects

Type of licensed professional	CA professional license title	Typical areas of expertise and project work
Civil, Hydraulic or Structural Engineer	CE – Civil Engineer	Bridge designs, fish passage, in-stream structures, embankments, and general road construction design and construction.
Geotechnical Engineer	GE – Geotechnical Engineer	Design earthworks, bridge and structure foundations; evaluate soil and rock mechanics in relation to development, such as designs for levees, dams, channels and reservoirs; geologic risk analysis; work significantly overlaps with Engineering Geologist, below.
Engineering Geologist	CEG – Certified or Registered Engineering Geologist	Geologic investigations; assessment, design and remediation of mass wasting or slope instabilities; existing and potential in-stream structures and grade control; stream crossings, and general road construction and reconstruction. General road construction design and project oversight.
Geologist	PG/RG – Professional or Registered Geologist	Assessment and subsurface drainage of landslide or fill instabilities; existing and potential in-stream structures and stream crossing designs; and general road construction and maintenance. General road construction project oversight.
Forester	RPF – Registered Professional Forester	Timber harvest plans and other forest management issues; general road planning, design and construction oversight.
Landscape Architect	LLA – Licensed Landscape Architect	General road construction and maintenance design and oversight (excluding landslide or fill instability assessment).
Landscaping Contractor	(CA-C27) - Landscape Contractor License – SL	Constructs, maintains, repairs, installs, or subcontracts the development of landscape systems and facilities for public and private gardens and other areas which are designed to aesthetically, architecturally, horticulturally, or functionally improve the grounds within or surrounding a structure or a tract or plot of land.
General Engineering Contractor	(CA-A) General Engineering Contractor License - CG	Performs land leveling and earthmoving projects, excavating, grading, trenching, paving and surfacing work and cement and concrete works in connection with highways, streets and roads, as well as other types of fixed works requiring specialized engineering knowledge and skill.
Earthwork and Paving Contractor	(CA-C12) Earthwork and Paving Contractor License	Digs, moves, and places material in such a manner that a cut, fill, excavation, grade, trench, backfill, or tunnel can be executed.
Biologist, Archaeologist, Hydrologist	Specific certification depending on area of expertise	Investigations pertaining to the presence of endangered animal and plants species; or sensitive habitats (e.g., wetlands); cultural resources; or surface water hydrology, respectively.



2 PLANNING

A. INTRODUCTION TO ROAD PLANNING

Good planning can minimize the impact of a road on the environment and provide low-maintenance, low-cost access for landowners. It will pay many times over to sit down and seriously plan for the road and road network before making irreversible decisions that cost extra money, waste time later and damage the environment. Poor planning and road location is often associated with the most common causes of road failure and high maintenance costs. Road “planning” should not be the purview of heavy equipment operators blazing a path from one point to another. Rather, it is a systematic process that requires consideration of a number of variables and is a part of a larger management strategy that includes transportation and land use planning, logistics, economics and environmental protection.

Two basic tenets of road planning should be followed. **First, minimize the number of roads constructed in a watershed through basin-wide transportation planning.** If you don’t own the entire watershed, consider meeting with other landowners to see how road network planning can benefit everyone by saving money and causing the least impact. Most landowners want to cause as little disturbance as is possible and to minimize construction and subsequent maintenance costs. There is great economic and environmental benefit to developing a coordinated road plan and reducing road construction in a watershed. Roads should be minimized because

they remove land from production and often cause erosion and water quality degradation.

Second, existing roads should be used wherever possible, unless using such roads would cause more severe erosion and water quality or environmental problems than building a new alignment elsewhere. Alternatives to roads in sensitive environmental areas, such as streamside and riparian zones, should be identified wherever possible if their reopening or use would have unavoidable, adverse impacts. Existing roads might require some rebuilding or upgrading, but using them is usually much less expensive

than new construction. Sometimes, because of property lines that divide ownerships, roads have been built close together on adjacent properties. Cooperative use of existing roads can prevent this kind of duplicate and unnecessary construction in the future.

Treat your neighbors well. Efforts should be made to develop easements or agreements that allow mutual use of roads on or near property boundaries, saving time and expense. Written and recorded rights-of-way mutually benefit all parties concerned. Such agreements should define the road location, ingress and egress routes, road width, levels of use, maintenance responsibilities, monetary considerations, and any other pertinent points. A survey, properly recorded, may be needed to clearly identify the boundary line. It is suggested that an experienced local attorney be consulted to ensure that all legal and liability requirements have been addressed.

B. NEED FOR A ROAD

Two of the most important steps in planning for a road are 1) determining whether or not the road is actually needed and 2) deciding what standard of road is called for. Ask yourself these questions:

- **What will the road be used for?** Will it be used for residential access, access for grazing or farming, timber hauling, fire control, and/or for recreation? What kind and size of vehicles, log yarding equipment or commercial vehicles will be used?
- **How often and when will the road be used?** Is it a one-time use (e.g., for timber removal or mining) or daily use (e.g. for residential access)? How fast do you expect vehicles to travel? Is it only to be used during the dry summer months or will you need to use it during wet weather conditions (i.e., does it need to be an all-weather road)?

- **Is there an existing road, either on your property or on an adjacent property that could be used or rebuilt?** If the road is being built for timber removal or other resource extraction, can an alternate harvesting, yarding or extraction method be selected that would either shorten the length of a new road or eliminate the need for a new road altogether?

A sound, thoughtful review of the present and future needs for this road will assure that it is needed and that it will accommodate the expected type and level of traffic. It is frustrating, and potentially costly, to build a road that cannot accommodate all the needed uses. At the same time forest, ranch and rural roads should be built to the minimum standard necessary to accommodate all reasonably anticipated uses and equipment.

C. ROAD SIZE AND STANDARDS

After deciding why a road is needed, you can determine the minimum size or standard that is appropriate to meet your requirements (Figure 9). Table 9 provides suggested minimum standards for single lane, packed gravel surface and native surfaced roads with traffic of less than 100 vehicles per day.

Horizontal curves occur where the road goes around a ridge, watercourse or other obstacle, and vertical curves are those where the road goes over the crest of a hill. Both kinds of curves require a minimum length of visibility at a given driving speed to assure safe stopping distances for trucks and other vehicles.

It is also important to provide passing lanes and turnouts on narrow, single lane roads, and turnarounds are needed at the end of all dead-end roads. Turnouts should generally be located so you can see from one to

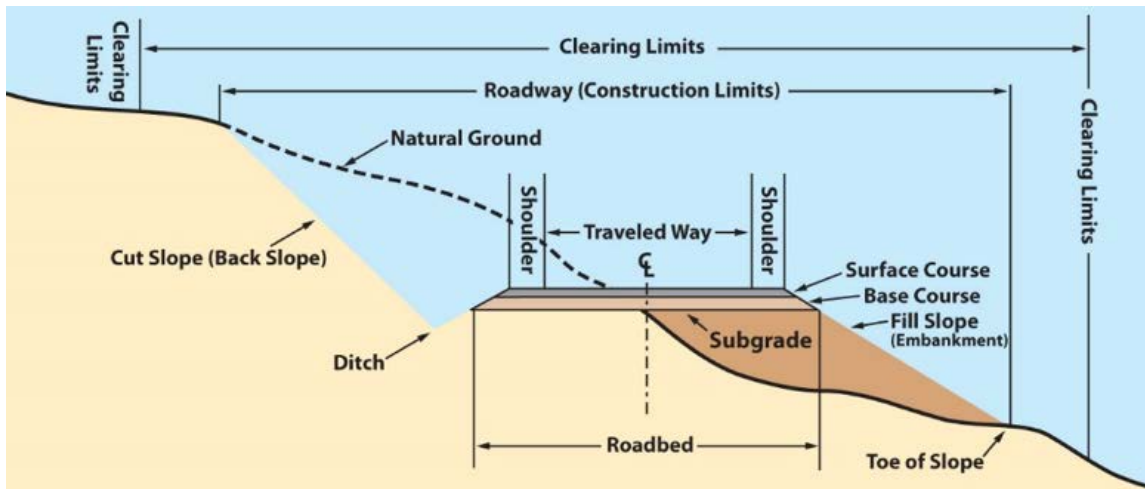


FIGURE 9. Road element terminology (Steinfeld et al., 2007).

the next, and so oncoming traffic can safely pass without vehicles ever having to back up.

In some situations, long, straight roads may encourage excessive speeds. To discourage unsafe driving speeds, straight sections of road can be limited to 400 feet, or less. The road should be contoured to the landscape to minimize cuts and fills. Rolling grades or rolling dips, used for surface road drainage, also help keep travel speeds at a safe level.

Other considerations may also dictate road size. For example, in erodible, unstable or steep terrain, small narrow roads are often preferred

because of their smaller footprint, reduced excavation requirements, and lessened environmental impact. Spur roads and other low volume roads are often narrower and of lower standard than trunk roads that service large areas or serve as major connecting links in the road network.

All other conditions being favorable, financial considerations and planned uses may play large roles in determining road standard and size. Costs are directly proportional to the standard of the road, and high standard roads are usually built where economic returns from land management (such as logging, mining or residential development) can pay for the

TABLE 9. Typical minimum standards for low-volume roads¹

Design standard	Collector or mainline road	Rural access or secondary road
Design speed (mph)	40–55	20–30
Road subgrade (ft)	16–20 ft wide (optional 2–3 ft ditch)	12–16 ft wide (optional 2 ft ditch)
Running surface width (ft)	12–16 ft	12 ft
Road grade (%)	12% max.	15% max.
Curve radius (ft)	80 ft min.	50 ft min.
Road shape	Outsloped, insloped, crowned (5%)	Outsloped, insloped, crowned (5%)
Road drainage types	Ditch, ditch relief culverts, rolling dips	Ditch, ditch relief culverts, rolling dips, water bars
Road surface material	Gravel, chip-seal, pavement	Native or gravel

¹based on Keller and Sherar (2003) and Oregon Department of Forestry (2000)

FIGURE 10.

This well-built permanent road is designed for year-round use. It is contoured to the natural topography, is slightly outsloped, has no outside berm, is occasionally rolled to provide continuous surface drainage and is rock surfaced for wet-weather traffic. This self-maintaining design will provide years of uninterrupted use.



added improvements, or where planned uses require high standard roads (e.g., for wet weather access to residential properties).

Road classification also indirectly affects road standard.¹ Forest, ranch and rural roads are often divided into classes called permanent, seasonal and temporary, in generally decreasing order of road standard and size. **Permanent roads** form the core of the all-season road network, and are surfaced to allow winter uses, such as log hauling and year-round residential access (Figure 10). Permanent roads have watercourse crossings designed to accommodate at least a 100-year flood flow, including debris and sediment loads, at all streams. **Seasonal roads** are a part of the permanent road network with drainage structures (or fords) designed to pass the 100-year flow, but they may not be of sufficient standard for heavy, wet-weather use or hauling (Figure 11). Both permanent and seasonal roads require regular, seasonal and storm period inspection and maintenance.

Temporary roads are lower standard roads with a surface adequate for use during the

¹See Appendix C for the California Forest Practice Rule specifying these requirements.

dry periods and drainage structures adequate for flows during the anticipated period of use, but are removed before the beginning of the wet weather period (Figure 12).²

Upon abandonment or closure, all drainage structures and stream crossing fills are removed, and the road surface is permanently drained using a combination of outsloping, rolling dips, waterbars and ditches.

For combined public use and commercial routes (e.g., forestry or mining), road standards and size may also be dictated by mining, harvesting and yarding equipment needs, as well as the season of use. For example, U.S. federal forest roads are classified for the combined use of forestry and recreation. Roads are classified by use type and traffic levels into 5 maintenance classes. Other types of land use have their own special or unique requirements for standards. Features such as paving or rock surfacing, dual lanes, and oversized drainage

²See Appendix C for the California Forest Practice Rule specifying these requirements. Temporary roads on timber harvest plans may remain in-place for the life of the approved plan (several years) before they are removed *only if their drainage structures are designed to accommodate the 100-year design flood event and road surfacing and surface drainage is designed for the expected use during that period. That is, it must meet standards for at least a seasonal road.*



FIGURE 11. Seasonal roads are built to the same specifications as permanent roads, but are not surfaced for all-weather traffic. They typically provide summer or dry period access to watershed areas. The potentially erodible road surface may be waterbarred before each winter (not shown), or outsloped with rolling dips to provide for rapid drainage of surface runoff.



FIGURE 12. Temporary roads are often spur routes constructed off permanent or seasonal roads that provide short-term access to watershed areas. They are usually outsloped, unsurfaced and used only during dry soil conditions. All stream crossings need to be physically excavated and removed upon the completion of operations or prior to the onset of the wet weather (winter) season (October 15 for non-federal CA forestry roads). In forested areas, if the roadbed is ripped or tilled, it can be planted with trees to return the site to productivity.

structures can all add substantially to construction costs. If these features are not needed, given the planned use of the road and requirements for environmental protection, they should not be built into the project.

D. ROAD SYSTEM LAYOUT

In forest and ranch road planning, the concepts “less is best” and “avoid the worst” generally describe the most economical and environmentally sound approach to planning for road building and road system layout. Some of these important concepts are listed below:

1. Minimize total road miles in your watershed;
2. Minimize new road construction by using existing roads that are stable and in good repair;
3. Minimize construction of permanent and seasonal roads by using these standards only when absolutely necessary; use temporary roads to minimize long-term maintenance and reconstruction costs and reduce environmental damage;
4. Strictly minimize the number of watercourse crossings by building roads near ridges;
5. Minimize cuts, fills and vegetation clearing by contouring roads across the landscape; particularly by avoiding steep terrain;
6. Minimize road construction work near streams and riparian zones, and on unstable areas, inner gorges and steep slopes;
7. Minimize road width;
8. Minimize road gradient;
9. Minimize the concentration of runoff on and from the new road; and
10. Avoid problem areas and serious obstacles, when possible.

Road system layout is influenced by many factors, including topography, property lines, obstacles (rock outcrops, unstable areas, wetlands, etc.), and proposed land use activities. Controls on the location of a road include both natural features and man-made elements (e.g., [Table 10](#)).

1. HARVESTING AND YARDING TECHNIQUES

For timberland owners, road systems are often planned around the preferred method of timber harvesting and yarding for the terrain, and hauling routes for logs. Downhill tractor skidding, a common yarding technique in the past, required roads to be built in lower hill-slope positions where slopes may be steeper, soils less stable and streams are larger and more incised into the landscape, or near floodplains and riparian zones where aquatic values are higher. These conditions can lead to greater erosion and soil loss from road construction, higher long-term maintenance costs, and higher environmental impacts. In forestry, cable yarding allows most roads to be built near ridges and in upper hillslope areas where environmental impacts are usually significantly reduced. Integrated planning for modern yarding techniques and road location and design will achieve the most economically and environmentally sound road system for that land use.

2. ROAD CONSTRUCTION VERSUS ROAD RECONSTRUCTION (UPGRADING)

In the last 70 years, tens of thousands of miles of low standard road have been constructed on private forest and ranch lands in California and throughout the western USA. Most of these roads were built to accommodate

TABLE 10. Some man-made controls which affect road location¹

Control	Comment
Legal	Boundary lines limit the location of the road. Talk to adjacent landowners and work out written right-of-way agreements to share roads and reduce road construction.
Specific location	The beginning and ending points of a road are often fixed. They may be certain geographic features (e.g., a ridge top) or desired road intersection. These represent major controls.
Safety	Each class of road and level of use have specific safety requirements. Common sense should be applied in setting speed, grades, curve radius, sight distance, and turnouts. Regulations may specifically dictate certain safety-related road parameters.
Pollution control	Roads should avoid problem areas. Allow ample room to trap sediment in a buffer before it reaches a stream. Do not allow any direct discharge points where road runoff flows directly into a stream. Avoid floodplains, landslides, unstable or erodible soils, wetlands, and waterbodies, as well as slopes over 40% wherever possible.
Design elements	Physical limits for curve radius, road grade, pitch grade, stopping distance, fill slope length and separation from streams are set by you! Design to reduce maintenance costs and pollution potential. Road width may be dictated by emergency vehicle or equipment access requirements.
Migrating fish	Observe and maintain substantial buffers. Know what species use your streams, their habitat requirements, the susceptible periods of their life cycle, and their environmental tolerance limits. Permits may be needed from regulatory agencies (e.g., Department of Fish and Wildlife, NOAA Fisheries, etc.).
Approach road permits	Issued by the state's Department of Transportation or the jurisdictional county for roads connecting to public highways. Locations of intersections may be restricted.

¹ modified from USDA-SCS/USFS (1981)

timber harvesting, ranching and rural development. Some of these roads are now abandoned and grown over with vegetation. Some were built in locations which would not be acceptable for new road construction today. As these areas are re-entered for additional logging and/or rural land development, decisions must be made as to whether or not it is better to use the existing poorly maintained or abandoned road system, or to build a new road network in a better location using state-of-the-art techniques and standards (Figure 13).

The answer lies in considering both economics and environmental impacts. In many instances, reconstruction can be viewed as an opportunity to cost-effectively improve watershed conditions and reduce the threat of long-term erosion, while providing the opportunity to economically access a previously harvested or managed area.

Roads can be reconstructed for use, for stabilization, or for permanent closure. For example, in a

final forest re-entry in an area it is often possible to temporarily open an old road for forestry activities, and then to systematically and permanently close it upon completion of operations, thereby removing all erosion threats. Proactively planning for this option, where it can be used, is often both economically and environmentally advantageous. Similarly, an old, abandoned road system may be located in an environmentally suitable location, but it is now overgrown with vegetation. In this case, reconstruction may cost significantly less than new construction in a different location and result in little erosion. Except in the worst cases, where reopening a road would cause excessive erosion risk, old roads that are not needed and pose environmental threats may be temporarily reopened without regard to road standard (i.e., pioneered open) so they can be permanently decommissioned.

When roads are planned for reconstruction, and to be a part of the permanent and seasonal road network, it is best to

FIGURE 13.

Because of our increased awareness of the potential impacts to streams in a watershed, some roads which were built in the past would not be built in the same locations today. In this example, a side-cast constructed road was built alongside a large, fish-bearing stream and ditch relief culverts still discharge muddy road runoff into the channel during storms (below person in photo).



anticipate upgrading all drainage structures to current design standards (100-year peak flow, including debris and sediment loads) and redesigning road surface drainage to more modern standards (e.g., outsloping with rolling dips). Regulations may dictate some of the reconstruction standards that occur. For example, in California the Forest Practice Act and Rules require replacement and upgrading of all stream crossings to accommodate the 100-year peak flow, including debris and sediment loads, on watercourse crossings that need reconstruction.³

3. SELECTING FAVORABLE GROUND FOR NEW ROADS

In laying out a new road system in a watershed, the most favorable ground should be identified and utilized wherever possible. Favorable ground consists of ridges, saddles, natural benches and flatter natural slopes. Less excavation is needed if the road is built in comparatively low gradient areas and utilizes natural benches. Generally, a slight slope can

improve road drainage, but steep slopes pose a number of problems. Well-drained soils are preferred for roads in order to maintain a dry travel surface. Terrain to avoid includes hard rock areas, inner gorge slopes, steep slopes, watercourse and lake protection zones, highly erodible soils, floodplains, flood prone areas, riparian areas, wet areas and swamps, areas of unstable soils or naturally occurring asbestos, and sensitive wildlife habitat (Figure 14).

If any stream crossings are required, you should identify the best locations for the crossings first and then plan to bring the road to those locations. Stream crossings are ideally placed where the channel is straight and narrow, the banks are low and the soil is firm and rocky. The approaches to the crossing should be as low or flat as possible and outside the 100-year floodplain, and the banks should allow for crossing directly perpendicular to the channel.

4. ROAD ROUTING THROUGH DIFFICULT TERRAIN

Avoidance is almost always the best solution to road-building in difficult terrain. Indeed,

³See Appendix C for the California Forest Practice Rule specifying this requirement.

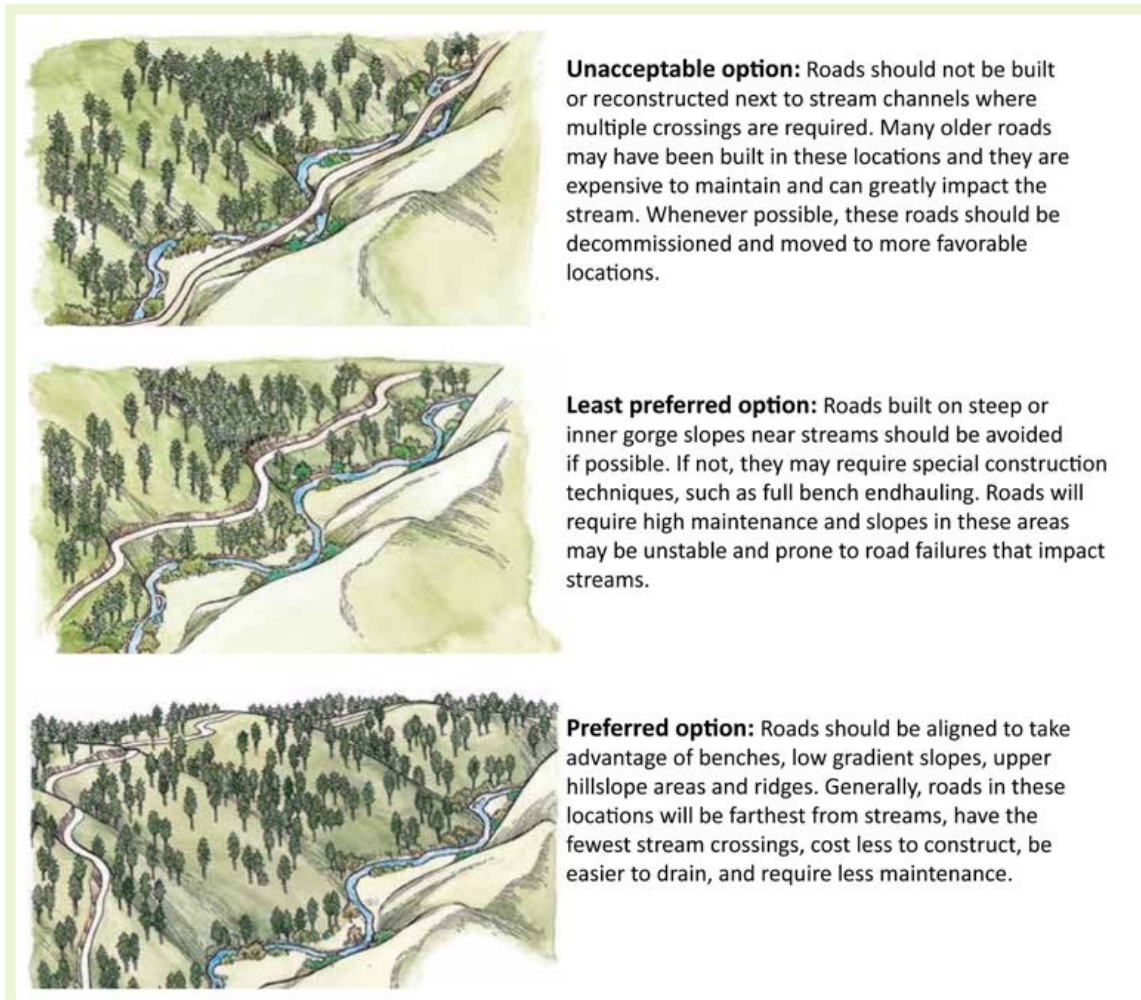


FIGURE 14.
Road location
(Modified from:
Adams and Storm,
2011).

the recognition and avoidance of unstable slopes is without doubt the most effective and cost-efficient method of managing landslide-prone terrain. Similar avoidance measures should be taken for highly erodible soils, steep slopes, water bodies, wetlands and other obstacles which are likely to threaten the integrity of the road or degrade environmental conditions. When possible, all serious obstacles to road construction should be avoided through complete realignment or by locally changing grade and circumventing problem spots as they are encountered. **It is far better to plan for a route containing fluctuating grades than to build a straight road which ignores the landscape through which it traverses.** Construction and maintenance costs will be minimized by sticking to the most favorable terrain.

In order of priority, the road planner and designer should consider:

1. **Avoiding** unstable slopes or soils.
2. **Preventing** destabilization using special road building techniques, when potentially unstable slopes cannot be avoided (consult a qualified geologist).
3. **Stabilizing** slopes which show signs of instability using special techniques developed by a licensed engineer or engineering geologist.
4. **Protecting** downslope resources when an unstable area cannot be physically or economically avoided, prevented, or stabilized.

Federal and state requirements for road planning, location, construction and maintenance of forest roads in the U.S. often include protection of resources through the application of best management practices (BMPs). The most common requirements include the following:

- Avoid filling wetlands and lowlands if practicable alternatives exist—especially in breeding and nesting areas for migratory birds and spawning areas for fish.
- Limit the number, length, and width of forest roads and skid trails to minimum necessary to accomplish the forest and ranch management goals, consistent with topographic and climatic conditions.
- Locate roads outside of riparian management zones (RMZs), except at stream crossings.
- Place bridges or culverts in road fill to prevent constriction of expected flood flows – other design methods may also be appropriate.
- Stabilize fill to prevent erosion and sedimentation—before, during, and after road construction.
- Minimize the use of equipment in wetlands outside of fill areas.
- Minimize disturbance of wetland and aquatic vegetation during the design, construction, and maintenance of roads.
- Design, construct, and maintain wetland crossings to avoid disrupting movement of fish and other aquatic species.
- Use good quality fill from upland sources whenever feasible.
- Place fill so as to not affect any threatened or endangered species and to prevent any adverse modification or destruction of critical habitat for these species.
- Do not place fill near public or private water intakes or where it could be eroded and delivered to a stream.
- Do not place fill in areas of concentrated shellfish production.
- Do not place fill in National Wild and Scenic River Systems, riparian zones, or stream channels.
- Use fill that is clean, stable and not highly erodible.
- Remove all temporary fill and restore disturbed areas to their original elevation and slope.

If it is impossible to move the alignment to avoid serious obstacles, construction costs and maintenance requirements are likely to climb sharply as special construction techniques (such as endhauling of fill material) are employed to build a stable road bench and to minimize post-construction erosion.

E. PRELIMINARY ROAD LOCATION

The road should be plotted and located by a person with some knowledge of the area to be served by the road and of the terrain where the road is to be built. A tentative road location should first be roughly plotted on aerial photographs and topographic maps. At this stage, several alternate routes should be developed and plotted for investigation during later field reconnaissance. These alternative locations should be visually fitted to the topography (roughly paralleling the contour lines) as much as possible to minimize cutting and filling. Aerial photos and satellite imagery (e.g., Google Earth) are useful for identifying natural features on the landscape that don't show up on the topographic map.

One procedure for plotting an alignment on topographic maps is shown in **Figure 15**. Using the known contour interval printed on the map, together with a set of measuring dividers, you can easily plot a tentative course for the road while keeping within the allowable grade limits. By combining this method with observations from aerial photographs, some of the recognizable obstacles and control points can be located, and a route with a suitable average grade can be identified and plotted on the topographic map.

Table 11 shows the computations for the example in **Figure 15**, including three possible alignments for a road to be built from point "1" to point "4." A simple, 6-step methodology can be followed to arrive at these "paper alignments."

1. Mark the beginning (1) and ending points (4) of the road.

2. Mark other known control points along the route (control points are natural features that dictate or limit your choice of road location, such as a stream crossing, lake, landslide, rock outcrop or saddle in a ridge).
3. Compute the elevation difference between each control point.
4. Compute the estimated average grade of each road segment between control points (dividing the difference in elevation between two points by the length of road between them gives the sustained or overall grade of the road segment).
5. On a divider, set the scale distance equal to the contour interval (C.I.) divided by the decimal percent grade (distance = C.I./grade). Then, simply mark the primary and alternate road alignments using the dividers as set, and move from one contour line to the next.

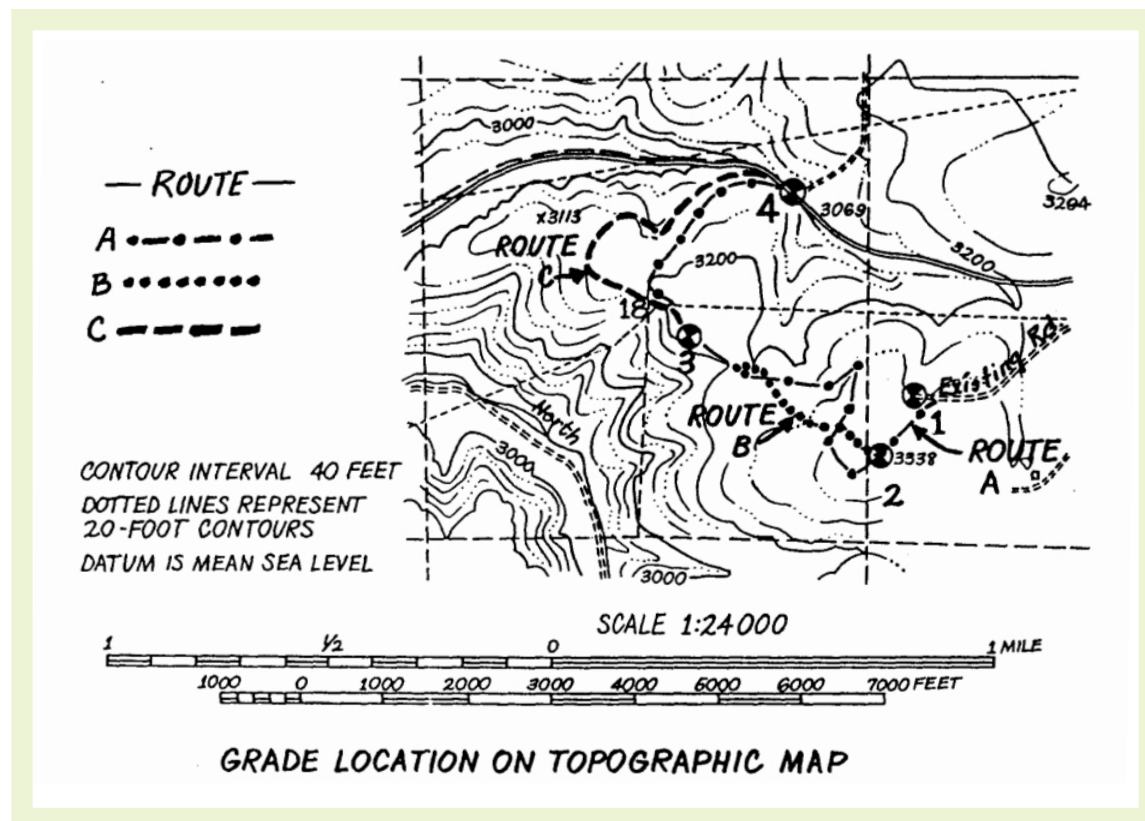


FIGURE 15. On this topographic map, three preliminary road routes across a hillside have been identified. Identifying possible alternate routes on maps and photos can save time and money when the next step of field reconnaissance is performed. Several alternate routes should always be identified in the planning process since field conditions may require minor or major adjustment of the route (USDA-SCS/USFS 1981).

TABLE 11. Control section and grade computations for three possible road routes (see Figure 15)¹

Route	Road reach	Elevation difference between control points (ft)	Estimated road distance between control points (ft)	Estimated average road grade (%)	Caliper distance setting	Measured road distance (ft)	New estimated road grade (%)	Comment
A	1 to 2	+58	800	+7	290	800	7	Route is too long; try again
	2 to 3	-128	3,200	-4	500	3,200	4	
	3 to 4	-150	2,400	-6	330	2,200	7	
B	1 to 2	+58	800	+7	290	800	7	Route is OK; field check
	2 to 3	-128	2,000	-6	330	2,100	6	
	3 to 4	-150	2,400	-6	330	2,200	7	
C	1 to 2	+58	800	+7	290	800	7	Route is OK; field check
	2 to 3	-128	2,000	-6	330	2,100	6	
	3 to 4	-150	3,000	-6	400	2,600	6	

¹USDA-SCS/USFS (1981)

For example:

- Contour interval = 40 feet
- Max. desired grade = 8% (or 0.08)
- Computation: $40/0.08 = 500$ feet

In this example, you must go 500 feet before climbing 40 feet to keep the grade to 8%. The dividers should be set at a spacing equal to 500 feet on the map. Then the dividers can be used to mark where the proposed road will cross each contour line on the map (at 500 foot intervals).

6. If any road segment fails to reach the identified control points or endpoints, or if the required grade between these points would be too steep, then either individual segments or the whole road needs to be re-routed until each alternative segment and grade is satisfactory.

With several alternative alignments available, at least on paper, other tests can be made before going out in the field to scout the routes. You

can overlay the routes with soil maps to identify potentially unstable or erodible sites. Aerial photos and satellite imagery can be viewed to identify possible landslides or rock outcrops that lie in the path of one or more of the routes. Ownership boundaries can be identified and, if necessary, permission can be secured to scout possible alignments that lie on adjacent property.

For most roads, half a day spent in the office can save much wasted time in the field trying to identify possible alignments for the road. Remember, topographic maps are not always accurate in the small details of the landscape, so no alignment is satisfactory until field reconnaissance is performed. Most small benches, streams and unstable areas will not show up on the standard 1:24,000 scale topographic sheet. While general routing of the alignment, from starting point to ending point, can be performed ahead of time and then be used to guide subsequent field work, field reconnaissance and assessment is the critical next step to confirm the map route and identify all the marked and unmarked features along the possible alignment.



3 FIELD RECONNAISSANCE AND LOCATION

A. SCOUTING THE ALIGNMENT

Now it's time to walk proposed routes on the ground, to scout, measure and record the actual field conditions, and to determine the feasibility, advantages and disadvantages of each alignment. If another route looks good in the field, don't hesitate to walk it, flag it, record observations and grades, and plot its position on the map. **Remember, road building is one of the main destabilizing activities carried out in forestry, range management and wildland land use, and avoidance is usually the most cost-effective means of dealing with unstable terrain and other significant obstacles.** Steer clear of sensitive obstacles such as unstable slopes, erodible soils and steep stream canyons.

First, walk the entire length of the proposed road to become familiar with the topography and ground conditions and to identify important features that were not visible on the aerial photos or topographic map. Items and conditions to identify and locate on the map in this first reconnaissance include:

1. favorable topography (especially benches and low gradient areas for landings, turnouts, spoil disposal and building sites),
2. control points (the beginning and ending points, saddles and other sites),
3. obstacles (especially unstable or erodible soils, large rock outcrops and wet areas),
4. stream channels (including their degree of incision) and favorable crossing points,
5. inner gorge locations,
6. areas of steep and/or unstable slopes, especially steep concave slopes at the heads of natural swales, and
7. any other obvious hazards or controls.

It is important that all control points be noted at this time, with only a minimum of marking

(flagging) necessary to indicate the route traveled, along with any other important features to either utilize or avoid. **The ideal road location is terrain with a gentle cross-slope of 10 to 30%, because road construction requires minimal cuts and fills, but still allows for good road surface drainage.**

B. RECOGNIZING HAZARDS AND OBSTACLES

Identifying many “obstacles” or hazards in the field can be fairly simple. Streams, surface wet areas (springs and seeps), rock outcrops and steep slopes are usually readily apparent. Other potential obstacles to a stable road may take training and experience to identify. These include sensitive wildlife habitat, endangered plant species locations, archaeological sites, and a variety of “hazardous” hydrologic and geologic conditions (Table 12). Final identification of these potential problem areas should be left to trained specialists.

For example, a geologist may be needed to locate unstable subsurface geology, soft or weak bedrock materials, contact zones and faults, rock layering that is susceptible to failure when undercut by road construction, existing and potential landslide areas, potentially unstable stream banks and stream crossing sites, and the suitability of local spoil material for use in road fills and stream crossings. Many of these conditions may not be apparent to the untrained observer. It is important to identify all the unstable and potentially unstable areas along the proposed alignment and treat them as control points. Avoid unstable areas and unsuitable stream crossing sites by linking up all the stable slopes and suitable stream crossing locations.

When a final alignment has been identified, a trained wildlife biologist and botanist may be required to investigate the alignment and the surrounding terrain for endangered species or species of special concern. An archaeologist may occasionally be needed to identify cultural sites

that have to be avoided or mitigated before construction can begin. If you are unsure whether or not you need specialized advice, ask the appropriate regulatory agencies with responsibility for those resources (see Chapter I, sections I and J). They won’t do the technical consulting work for you, but they can give you pointers, describe your legal requirements, provide advice about the need for additional help and describe where to find it.

Specialists and qualified professionals identify problems, suggest alternate alignments to avoid many of these problem areas, and design mitigations for problems areas that cannot be avoided. The expense of these professional consultations is, in most cases, well justified and quickly repaid by lower construction and maintenance costs over the first few years of the road’s existence. Benefits are also gained from minimizing impacts to watercourses along the alignment. **So called “low-cost” roads can be very expensive if they are poorly planned, located or constructed, while roads which initially cost slightly more to build often end up costing far less in the long run when lower maintenance and rebuilding costs are accounted for.**

C. MARKING THE PROPOSED ALIGNMENT

First, a preliminary traverse of the approximate route(s) is conducted. For this, and later detailed field layout, the following tools and materials should be carried:

1. a hand-held clinometer or Abney level (to measure road grades and hillslope gradients),
2. a measuring tape, range finder or hip-chain (to measure distances),
3. an altimeter (to measure elevations),
4. stakes and/or colored flagging for marking the alignment, hazards and obstacles),

TABLE 12. Some natural controls which affect road location

Control	Comment	
Saddles	Major control for road location.	
Ridges	Major control and often a satisfactory road site.	
Stream crossings	Major control. Seek locations with gentle sideslopes and locations wide enough to accommodate the road. Good sites for bridges or culverts are needed. Evaluate and design for migratory fish where needed. Will require state Fish and Wildlife agreement.	
Benches	Often a good location for road junctions, switchbacks, landings, turnouts, etc.	
Cliffs or rock outcrops	Cross above or below at a safe location. Rock which can be ripped is less costly to remove than hard rock needing blasting.	
Hillslope instabilities (e.g., landslides)	Major control. Avoid or cross at the safest point. Ask for professional geological or geotechnical assistance.	
Wetlands (e.g., bogs, swamps, wet meadows)	Major control. Avoid where possible or cross at the safest point. May require State Fish and Wildlife clearance or agreement.	
Valley floor	Wide	Low gradient, desirable road location if above the flood line. If crossing a stream, cross and get out of floodplain quickly. Little excavation should be required. Stream crossings will require a State Fish and Wildlife agreement.
	Narrow	Poor location because of flooding, erosion, and pollution potential; and high costs to cross stream if it meanders. Keep road above floodplain. Stream crossings will require a State Fish and Wildlife agreement.
Slopes	>40%, but <60%	Avoid sidestepping and sliver fills (thin blankets of fill placed on steep slopes) in which large bare areas are exposed to erosion. This loose sediment may be difficult to control because of long buffers needed.
	≥60%	Construction in unstable areas should be avoided. Full bench road construction and endhauling material will be needed where slopes remain steep alongside stream channels. Proceed only with extreme caution. Avoid road construction on these steep slopes, if possible.
	Ridge crest	Good alignment and likely little excavation required. Roads should travel along shoulder of ridge for good drainage control. Fewer culverts are required. Adverse grade will be encountered on uneven ridges. Spur roads will have an adverse grade.
Aspect	Maintenance requirements in moist climates can be minimized by placing roads on south-facing slopes to promote drying and snow melt. In dry climates, the north-facing slopes have more vegetation and experience better revegetation and less erosion. Extremely wet or dry climates negates this effect.	
Rock slope (dip)	Place roads on the hillside where rocks dip (slant) into the hillside, not parallel to or out of the hillslope. Consult a professional geologist for technical assistance or advice.	
Soils	Where possible, avoid road building on naturally erodible or unstable soils, or those with naturally occurring asbestos. Check soils maps for potential problems and ask USDA extension agents, the NRCS or qualified geologists for advice. Frozen soils require special care; ask for assistance.	

¹modified from USDA-SCS/USFS (1981)

5. a hand-held compass (to check bearings),
 6. a map and/or aerial photos (showing the alternative alignments plotted earlier), and
 7. a quality handheld GPS unit to provide good spatial control on the location of control
- points, road centerline, and other geographic features and elements along the proposed alignment; these data points can be used to provide a more accurate map of the alignment and depicted electronically on a geo-referenced topographic map.

Next, a preliminary road location survey is conducted, using one or two people. Based on the first traverse, and the identification of obstacles and hazards, a tentative route is identified on the ground. Beginning at one end, the center line of the route is roughly marked with stakes and/or flagging along a pre-selected grade line (the average grade of this route was determined in the 6-step map procedure described earlier). The grade between each flag is measured

using a clinometer or an Abney level. Flagging, by color convention, may be hung on the approximate centerline, or they may be hung to mark the top edge of the cutbank (so they aren't destroyed during construction). Cuts and fills, and drainage features, can also be flagged. Broad ridge crests and benches should be identified and flagged for possible locations for landings, road turnouts and spoil disposal locations (Figures 16 and 17). If the predetermined fixed grade does

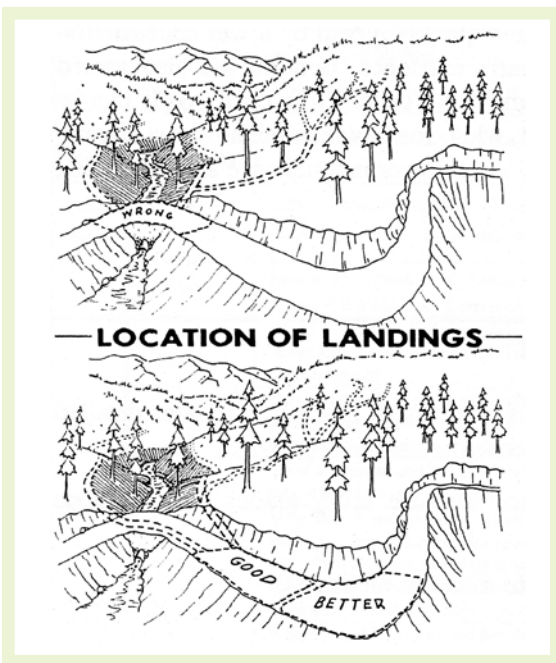


FIGURE 16.

Log landings on forest road systems should be kept to the absolute minimum size necessary to accommodate yarding, loading and hauling equipment and the minimum number needed to remove timber resources. Landings constructed on gentle ground and broad ridge crests far removed from stream channels are least likely to cause water quality problems, whereas landings built on steep slopes and near watercourses can result in severe impacts (USDA Forest Service, 1963).

FIGURE 17.

Small log landing used for cable yarding has been built on this single lane forest road. It is correctly located on the nose of a ridge and also serves as a vehicle turnout. Minimal cutting and sidecasting has been used. If excessive sidecast or debris has accumulated along the outside edge, it should be excavated or stabilized.



not exactly meet the desired ending point, you can work back from that endpoint and connect the two surveys at a convenient location.

The marking of curves and switchbacks requires a little more thought and care during road layout. Each turn should be of sufficient radius for trucks and the anticipated equipment to negotiate easily and safely (Figure 18). The radius should be no less than 35 feet for standard pickups and field vehicles, and 50 to 55 feet for tractor trailers (such as log trucks or cattle trailers). A minimum horizontal curve radius of 200 feet is suggested for roads supporting 20 mph traffic.

Where curves are short and gentle, they can be located by eye to follow the topography and the flagged grade location. Sharper curves (such as those where roads cross deeply incised stream channels, and where switchbacks will be used to climb a steep hill) require some surveying. **The center stake method is one of the simplest methods for marking these curves during the road survey.** First, decide on the radius of the curve. Then, using a string or a tape that is the length of the desired radius (or using a range finder), simply identify and stake the center of the curve and stake the centerline in an arc extending out from the center stake (Figure 19).

The Center Stake Method assumes the ground is flat as you're marking the arc. This isn't usually true, so some adjustment of the lengths marked in the field is needed to compensate for the slope of the hillside (see Table 13). To use the center stake method, true horizontal distances need to be marked on the ground. To get the slope distance, multiply the horizontal distance (desired curve radius) by the correct multiplier shown in Table 13. For example, to switch back across the slope above with a 110 foot horizontal radius on a hillside with a 65% slope, the curve should be marked 131 feet upslope ($110' \times 1.19 = 131'$) and 131 feet downslope

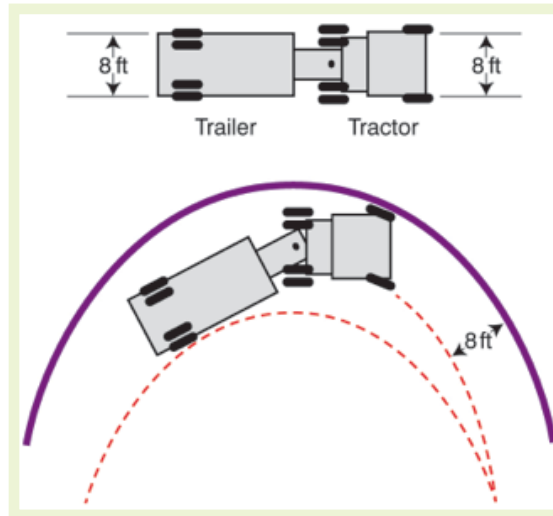


FIGURE 18. A vehicle off-tracking on a horizontal curve. Depending on the radius of the curve, road width will need to be widened through the curve to accommodate the expected type of vehicle traffic: the tighter the curve, the wider the road (Kramer, 2011).

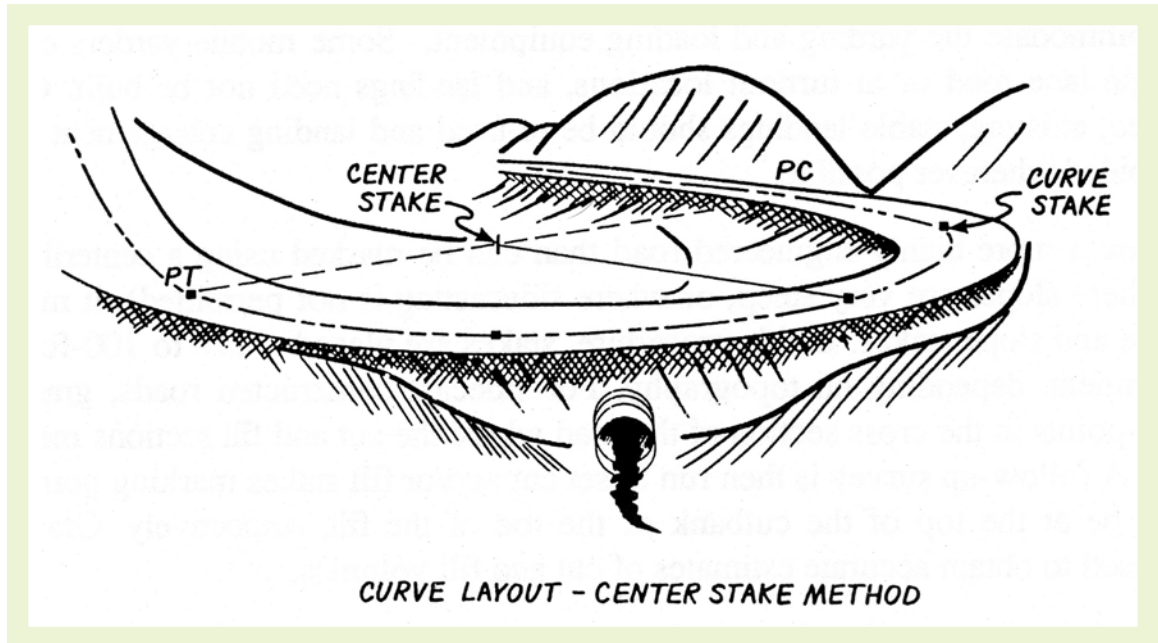
TABLE 13. How to convert horizontal distances to true “slope distances” measured on hillslopes needed for marking road curves and switchbacks

Slope gradient (%) (use a clinometer)	Slope correction factor to determine true slope distance ¹
10	1
15	1.01
20	1.02
25	1.03
30	1.04
35	1.06
40	1.08
45	1.10
50	1.12
55	1.14
60	1.17
65	1.19
70	1.22

¹True slope distance = Measured horizontal distance x Slope correction factor.

FIGURE 19.

Staking and identifying simple curve layout using the center stake method (See Appendix D) (USDA - SCS, 1983).



from the center stake. Straight ahead, on contour, the stake is marked at 110 feet.

Ideally, the road within a switchback should have little or no grade so that trucks and equipment can pass safely and so they won't tear up the road surface while turning the corner and continue climbing. This may require increasing the average grade of the road coming into and leaving the switchback. Depending on the curve radius, the grade of the road should at least be reduced through the curve to provide for safe handling of vehicles and equipment (Table 14). Where longer curves are needed, the Stick Method of curve layout may be more convenient (see Appendix D).

Landings and turnouts should be identified and staked at the same time curves are staked. Typically, turnouts should be intervisible and located where a minimum of excavation will be required to increase the road width (Figure 20). Landings should be the minimum length and width necessary to accommodate low boy (equipment) trailers, yarding and loading equipment, and any other commercial vehicles and trucks that could use the road. Some mobile yarders used in forestry operations can work directly off a single lane road or at turnout locations, and landings need not be built. On roads to be reconstructed, existing, stable landings should be re-used and landing enlargement or expansion should be avoided wherever possible.

TABLE 14. Suggested reductions in road grade through curves of different radius¹

Curve radius (ft)	Reduction in road grade (%)
150 to 460	1
90 to 150	2
65 to 90	3
50 to 65	4

¹USDA-SCS (1981). It is suggested that road grades through switchback curves be flat (0%), or very low.

For situations that require a more highly engineered road than can be marked using a center-line location survey (e.g., where slopes are very steep, or where sidecasting is not appropriate or permitted), it may be necessary to set grade and slope stakes. In this procedure, stakes are placed at 50- to 100-foot intervals, depending on topography, along the alignment. For sidecast constructed roads on gentle slopes, grade stakes

are first placed at points in the cross section of the road where the cut and fill sections meet and are reduced to zero. A follow-up survey is then run to set cut and/or fill stakes marking points on the ground that will be at the top of the cutbank or the toe of the fill, respectively. Grade surveying may then be used to obtain accurate estimates of cut and fill volumes.

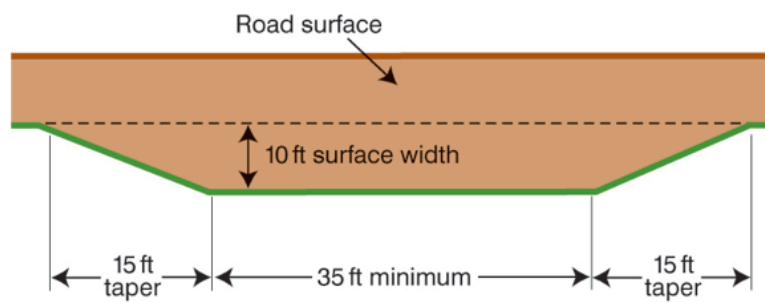


FIGURE 20. Standard turnouts allow for vehicles to pass each other on low standard roads by safely pulling off and back onto a single lane road. Turnouts and landings should be located to take advantage of benches and broad ridges where the additional road width can be developed with a minimum of added excavation and sidecasting. Turnouts should be intervisible (Kramer, 2011).



4 ROAD AND STREAM CROSSING DESIGN

A. INTRODUCTION

1. BASIC DESIGN CONSIDERATIONS

Road design is often a combined result of economic and environmental factors that influence construction, operating and maintenance costs. Unfortunately, because construction costs are felt immediately, economics was once the most important consideration employed in choosing a road's final design. However, excessive hauling expenses and difficulty of travel on a road, high road maintenance costs, as well as high environmental costs may have a far greater effect on the long-term economics of forest or ranch operations, or rural development, than the savings in initial construction of a low standard, poorly located or inadequately designed road.

Roads are designed for the expected type and frequency of use. Most forest, ranch and rural roads are designed as "low volume roads" that carry an average of less than 400 vehicles per day (Keller and Sherar, 2003), and have an appropriate design geometry for that level of use. Over-design can be a costly mistake. For example, construction costs for a 14-foot wide road on a steep sideslope may be as much as 30% higher than for a 12-foot wide road in the same location, simply because of the extra 2 feet of excavation width. Long-term maintenance costs are also likely to be higher for the wider road. For this reason, it is important to determine the main types of vehicles and the

expected volume and speed of traffic so that the required, minimum road standards can be established well before actual construction begins.

Both road length and road width should be designed to minimum standards for the anticipated uses of the road. Narrow roads without inside ditches dramatically reduce excavation and sidecast volumes, thereby reducing cutbank height and decreasing the likelihood of slope failures (**Table 15**). For example, building a 12-foot wide insloped road with a 3-foot wide inside ditch requires moving almost 60 percent more material during construction than if the road were outsloped with no ditch (**Table 15**).

TABLE 15. Excavated soil volume for full bench roads with various road widths and hillslope gradients

Hillslope gradient (%)	Excavated volume to construct a full bench road assuming ½:1 cutbanks (yd ³ excavated per ft of road)			
	Road width 12 ft	Road width 14 ft	Road width 16 ft	Road width 18 ft
30	0.94	1.28	1.62	2.17
35	1.13	1.54	2.01	2.55
40	1.33	1.82	2.37	3.00
45	1.55	2.10	2.75	3.48
50	1.78	2.42	3.16	4.00
55	2.02	2.81	3.60	4.55
60	2.28	3.11	4.06	5.14
65	2.57	3.50	4.57	5.78
70	2.87	3.91	5.11	6.46
75	3.20	4.36	5.69	7.20

Road design begins with planning for the road's location. Selection of the final route will constrain many future design decisions. Two important design questions that need to be answered early in the planning process are 1) road prism design and 2) road surface design. Routing the alignment through or around various obstacles and hazards may dictate the use of certain road prism designs. In addition to these, there are special situations that often arise and require special road design considerations.

When considering road prism design, it is impossible to over-emphasize the importance of drainage in maintaining stable roads and protecting water quality. Roads should be designed and constructed to cause minimal disruption of natural drainage patterns. Provisions for two components of road drainage should be included in every road project: 1) road surface drainage (including drainage which originates from the cutbank, road surface and fill slope) and 2) hillslope drainage (including drainage from large springs, gullies and streams which cross the road alignment).

Finally, because hillslope morphology and hydrology varies greatly across the landscape, rarely can a single type of road prism and road surface drainage design be uniformly applied to a new or reconstructed road. One size does not fit all circumstances, and both road prism and road surface design is best varied to meet local conditions!

2. DESIGNING ROADS TO MINIMIZE HYDROLOGIC CONNECTIVITY AND PROTECT WATER QUALITY

Roads can adversely impact streams, water quality and aquatic habitat in several ways, including erosion and sediment delivery, altering hillslope and stream hydrology, and discharging chemical spills to streams and water bodies. Sediment is delivered to streams as a result of both episodic (usually storm related) and chronic (every runoff event) erosion processes. The most common storm-triggered erosion includes stream crossing washouts (gullyng), stream diversions (and resultant hillslope gullyng and slope failures), culvert outlet

erosion, hillslope gullying, bank erosion, and road and landing (turnout) fill slope failures.

In chronic erosion, sediment is delivered to streams every time there is a rainfall and runoff event sufficient to cause erosion of bare soil areas, concentrated runoff on compacted road surfaces and ditches, and sediment transport to nearby streams. The most common road-related bare soil areas include unpaved road surfaces, as well as unvegetated fill slopes, cutbanks, ditches and landslide surfaces. **If the runoff path from one of these bare soil areas delivers surface runoff and eroded sediment (even turbid water) to a stream it is termed “hydrologically connected” to the stream system. Hydrologic connectivity refers to the length or proportion of a road or road network that drains runoff directly to streams or other water bodies.**

A hydrologically connected road or road segment has been defined as: “Any road segment that has a continuous surface flow path to a natural stream channel during a ‘design’ runoff event” (Fumiss et al., 2000). A suitable “design” runoff event for many purposes has been suggested to be the 1-year, 6-hour storm, with antecedent moisture conditions corresponding to the wettest month of the year. This is the type of frequent rainfall and runoff event that is likely to generate surface

runoff from most or all compacted and bare soil surfaces. **During runoff events, a hydrologically-connected road becomes an extended part of the natural stream network. Inboard ditches that drain to stream crossings and roadside ditches draining to gullies below ditch relief culverts are the most common road segments that are hydrologically connected to streams** (Figure 21). Other road drainage structures (e.g., rolling dips and waterbars) may also discharge runoff and sediment to nearby waterbodies. Wherever a hydrologic connection exists, concentrated runoff, eroded sediments and road-associated chemicals have a direct route to the natural channel network and surface waters.

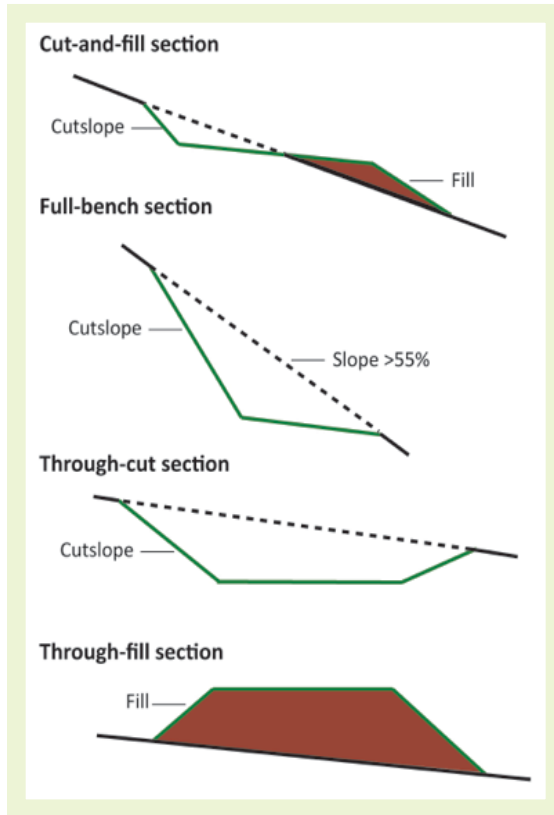
Compared to unroaded hillslopes, roads always increase hydrologic connectivity. Hydrologic connectivity is affected by natural processes and human intervention. It will increase with increasing intensity and duration of precipitation or snowmelt. **In contrast, connectivity will be reduced where there are sediment obstructions and natural depositional areas, soils are deep and permeable, hillslopes are gentle and ungullied, streams are far away, and cross-drains are spaced closely together on the road.** All these road and hillslope factors are important in predicting sediment travel distances below cross-drains,



FIGURE 21. Road approaches to bridges are often hydrologically connected. This through cut approach to a temporary bridge drains directly into the stream.

FIGURE 22.

Idealized diagrams depicting (a) a partial bench or cut-and-fill road (with both cut and sidecast); (b) full bench road (all material endhauled—no sidecasting); (c) a through cut section (all cut, with spoil material endhauled); and (d) a full (through) fill road (no cut—all fill placed and compacted in shallow layers). Road surface shapes can be outsloped, outsloped with a ditch, crowned with a ditch, or insloped with a ditch, depending on local conditions (Modified from: Kramer, 2001).



and in planning and designing for reduced connectivity and sediment pollution.

Simple road location, design, construction and maintenance measures can be employed to reduce hydrologic connectivity. Connectivity can be reduced by good road location, such as upper hillslope locations far from streams. Hydrologic connectivity is also increased with increasing stream crossing frequency; so roads should be located where there will be fewer crossings. Hydrologic connectivity on existing roads can be greatly reduced by designs that remove ditches and convert road shapes from insloped to outsloped, as well as by constructing frequent road surface and ditch drainage structures to disperse road runoff so it cannot reach a stream. **Reducing the length of road that is hydrologically connected to streams will directly and immediately improve water quality and protect downstream aquatic habitat.**

B. ROAD PRISM AND ROAD SURFACE DESIGN

1. ROAD PRISM DESIGN

Road prisms may be designed to be **full bench**, **partial bench** (part cut and part fill, also called balanced cut and fill) or **full fill** (Figure 22). Roads which are constructed without endhauling are **partial bench** roads where spoil generated during initial grading is used to widen the roadbed and fill depressions and stream channels crossed by the road. This has been the most commonly used construction practice for rural forest and ranch roads. The fill is placed and compacted, or (more commonly) sidecast loosely into the desired location. However, there are many circumstances where sidecasting is no longer acceptable and alternative designs and methods are needed and required to reduce environmental impacts and to provide a stable roadbed. The fourth design type is a **through cut** road where the alignment is cut through a ridge and for a short section the road has a cutbank on both sides. Through cut road sections, if needed, should be short because they are not easily drained.

Roads may need to be **full bench** on steep slopes (those over about 55%), especially where the road is close to or approaches a watercourse, or where water quality could be impacted by road work (Figure 23)¹. Full bench construction requires that all the spoil generated by cutting into the hillside must be either used in filling local stream crossings and low spots in the new road, or endhauled to a stable storage site where spoil materials have no risk of entering a watercourse.

Outside of stream crossings, which are always full fill, road segments constructed with **full fill** techniques are less common, but may be employed on lowlands, wet valley bottoms,

¹ See Appendix C for California Forest Practice Rules requirement for full bench slopes.



FIGURE 23. Full bench road. The height of the cut-bank, the slope of the natural hillside and the small amount of sidecast indicates that this road is full bench and cut entirely into native hillslope materials. Note that the road has no inboard ditch.

extended wet areas, or wherever the road needs to be elevated to provide proper subsurface drainage, or where it is inadvisable to cut into the hillside. Roads using this technique are usually confined to short reaches where slopes are potentially unstable and cuts into the slope could trigger soil movement. Full fill sections of road are often supported by structurally engineered fills with steep fill faces.

Cut-and-fill design: For most forest, ranch and rural landowners, use of cut-and-fill road construction has been preferred because it minimizes the amount and cost of earth moving. In other words, less soil moved generally means less expense (Figure 24). Most older roads on the landscape have probably been built with this construction technique, using only a bulldozer for road building.

However, the indiscriminate use of sidecast road construction (the simplest method of cut-and-fill construction) has probably caused more problems for landowners than any other type of road building. Sidecasting construction techniques should

not be used on slopes over 55 to 60 percent because this results in fill slopes of about 67 percent, the average angle of repose (stability) for most loose soil materials (Figure 25). For this reason, **sidecast construction should be limited to gently sloping areas where streams are far from the road prism.**

Cut-and-fill construction techniques can be used on slightly steeper slopes when excavated keyways and subgrade benching are employed to develop stable, well compacted road fills. In general, cuts should equal the needed fill volume, plus about 20 percent to allow for expansion and settling of loose fill. That is, the loosened, excavated soil will take up about 20% more space than when it was “in-place” (before it was excavated). During the process of cutting and filling, it is critical to avoid letting sidecast or waste material enter streams or watercourses, or placing it on unstable or steep slopes where it might erode and be delivered to a nearby water body.

The angle or steepness of both cut and fill slopes is very important in building stable

FIGURE 24. In contrast to the road in Figure 23, this partial bench road was built by extensive side-casting. At least half the roadbed is built on fill materials.



FIGURE 25. For most earth materials, sidecasting on natural slopes over about 55% in steepness will result in steep, loose, unstable sidecast slopes that are easily eroded or prone to sliding. The face of an uncompacted sidecast slope should not exceed about 67% with most materials (less with granular or non-cohesive soils). This is the maximum angle of stability for most uncompacted, sidecast soil material.

roads. There is a tradeoff in determining the optimum cut slope angle to construct (Table 16). **Cutbank slopes** should be designed to achieve maximum stability as well as a minimum exposure of bare soils.

Cut and fill slopes are usually expressed as horizontal-to-vertical ratios, such as ½:1, 1:1, or 1½:1 (Table 1). Road banks can be cut as steep as the stability of the material will permit, ranging from ¼:1 for very stable rock

materials to 3:1 for erodible or unstable soils (Table 17). The stability of cut slopes is also highly dependent on soil types, groundwater conditions and local climate. Observations of cut slopes in settings similar to your proposed road project will provide useful information on in-the-field performance of cuts of various heights and angles. Use this field information to help you design the best cuts possible. A general guide for the maximum steepness of road cuts in various rock and soil materials is

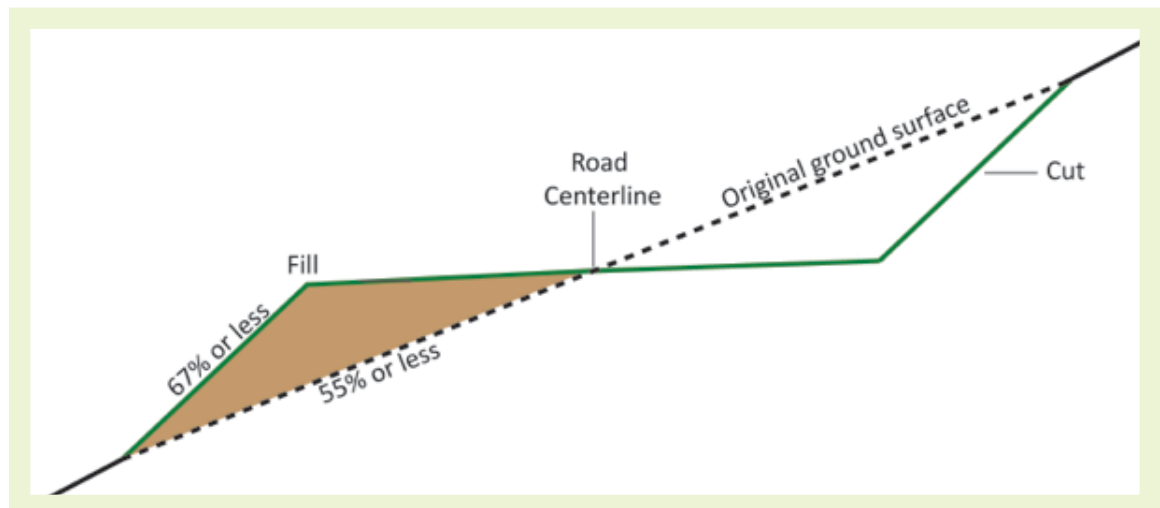


TABLE 16. Advantages and disadvantages of steep cut slopes¹

Advantages of steep cut slopes	Disadvantages of steep cut slopes
1. Less right-of-way	1. Difficult to revegetate
2. Less excavated material	2. Prone to raveling
3. Less sidecast material	3. Prone to tension cracks and failure
4. Shorter slope exposed to surface erosion	4. Slightly greater risk of a rotational failure

¹BCMF (1991)

shown below (Table 17). Note that wet slopes, unstable or erodible soils, and highly fractured or bedded rocks may require gentler slope cuts.

Cut height and cut angle also affect the stability of the final cut slope. Cuts which are stable at ½:1 at a 6-foot height may not be stable when the cut height is twice as high at 12 feet. Higher cuts lead to increased gravitational force and reduced stability at the face of the slope. Tall (deep) cuts are also more likely to intercept emerging soil water that can weaken the cut slope and cause failures that block the road or result in persistent ditch and roadbed maintenance problems.

Fill slopes can be built to a variety of angles depending on the properties of the material used, the amount of properly applied compaction, soil moisture and the type and density of

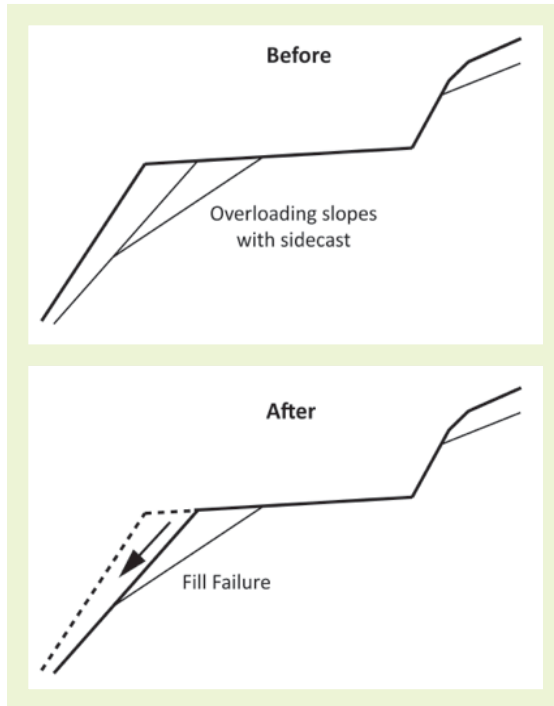
vegetation that is established on the surface. In contrast to cut slopes, a typical fill slope angle of 1½:1 or 2:1 will be stable under normal soil and site conditions. The greater the rock fragment content in the soil, the steeper the fill slope can be and still remain stable. A slope angle of 2:1 is most easily vegetated and provides the best long term stability to most fills. In general, thick accumulations of loose, dry, side-casted soil that is not compacted will not usually hold a slope over about 60 percent, whereas many fill materials that are placed and properly compacted in thin, less than 1-foot horizontal layers (lifts) may be stable at slopes up to or slightly greater than 1½ to 1 (67%), or steeper. While a thin veneer of angular sidecast materials may hold on a slope steeper than 65%, a thick wedge of loose sidecast may not be stable even at a 50% slope (Figure 26).

TABLE 17. Common soil/rock types and stable slope ratios¹

Soil/Rock type	Slope Ratio (horizontal:vertical)
Most rock	¼:1 to ½:1
Most in-place rocks	¾:1 to 2:1
Very fractured rock	1:1 to 1 ½:1
Loose coarse granular soils	1 ½:1 to 3:1
Heavy clay soils	2:1 to 3:1
Soft clay-rich zones or wet seepage areas	2:1 to 3:1
Fill of most soils	1 ½:1 to 3:1
Fill of hard angular rock	1 ⅓:1 or flatter
Low cuts and fills (<6–10 feet high)	2:1 or flatter (for revegetation)

¹From Keller and Sherar, 2003. Note that slope stability is also very particular to the soil type and slope angle, and somewhat to rainfall, soil moisture, and other factors.

FIGURE 26. Overloading steep slopes with uncompacted sidecast material can result in landsliding that damages streams hundreds of feet downslope (Modified from: BCMF, 1991).



Stable road fills can be built on moderate and steep slopes by using benching, keyways and layered compaction methods.

Here, a bench is excavated at the base of the proposed fill, and layers of moist, compacted soil are built up on this stable bench. The stability of the fill can be further increased by starting with an insloped bench that helps anchor the base of the fill into the native hillslope. A keyway is sometimes used to “lock” the fill into the denser or more stable underlying native soils or bedrock materials. Fill can then be compacted in lifts on top of this bench and steeper fill slope angles are possible. A keyed and benched fill depends on the fill being as strong as, or stronger than, the soil removed in the excavation. This bench and keyway locks the fill in place on the slope and prevents the fill from developing a failure plane where it is placed on the natural ground surface (Figure 26).

In critical areas, engineered fills that utilize reinforcing geotextiles or other internal supports can be constructed with nearly vertical faces. These are especially useful in short road

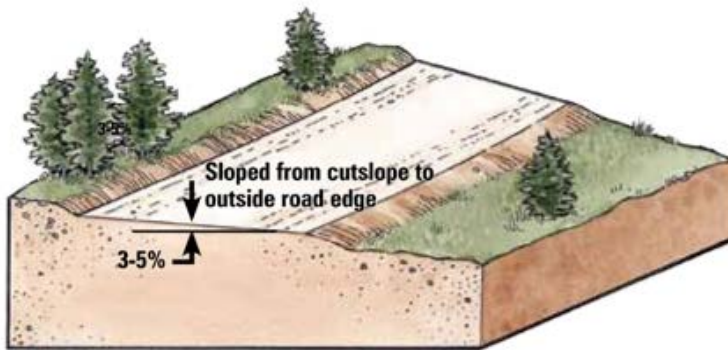
sections where other fills would be unstable or erode and sediment could then enter a watercourse. In such cases, it may be necessary or prudent to employ a qualified, experienced geotechnical engineer or geologist to design a stable cut and fill road. Depending on the stability of the cut slope rock and soil materials, it may be simpler and cheaper to construct a full bench road where all the excavated material is simply endhauled off-site and deposited in a stable storage site.

2. ROAD SURFACE (SHAPE) DESIGN

Road surface design is really road surface drainage design, and should be chosen based on both maintaining safety for the intended uses, protecting the integrity of the road, and minimizing erosion and sediment pollution in streams. All three design standards should be met. Road surfaces can be designed as outsloped, crowned, or insloped (Figure 27). Often, more than one of these road surface designs is used along the road length. A road should never be graded with a flat road shape since this has no drainage. A flat road shape that does not drain to one side or the other is prone to puddling and pot holes in areas of no road grade, or to ruts and surface erosion if it is sloping up or down a hill. Flat, poorly drained roads often require a high level and frequency of maintenance.

Outsloped roads are considered the best and most preferred road shape for most circumstances. Insloped and crowned roads require inside ditches, and ditches generally require regular maintenance. In addition to construction costs (ditched roads require considerably more excavation and construction costs—see Table 15), it is important to consider long term maintenance requirements and costs when deciding whether to construct an outsloped road or an insloped/crowned road.

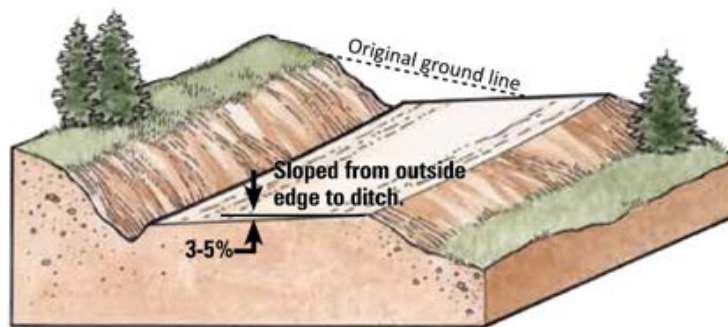
Outsloped



Outsloped roads are used:

- where road grades are gentle or moderate ($\leq 8-12\%$)
- to minimize construction costs
- where cutslopes are dry
- with an inside ditch, where cutbanks are wet
- where road surface drainage is to be dispersed
- always in concert with rolling dips

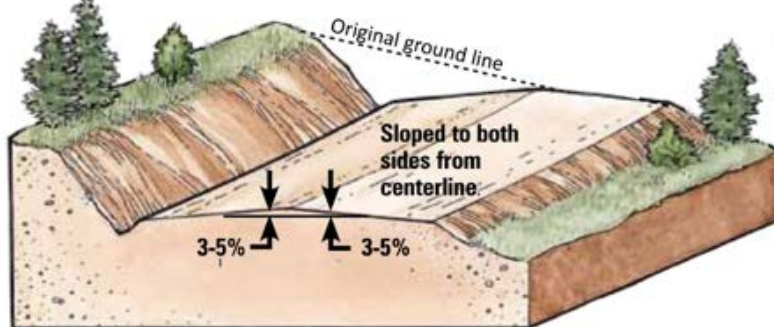
Insloped



Insloped roads are used:

- where road grades are moderate to steep ($\geq 8-12\%$)
- where road grades are moderate or steep and slippery (muddy, snowy or icy)
- where cutbanks are wet and ditches are used
- where ditches can be maintained
- where fillslopes are unstable or highly erodible

Crowned



Crowned roads are used:

- where road grades are gentle or moderate ($\leq 8-12\%$)
- where ditches are maintained and can be drained frequently
- where roads are wide and two way traffic is common
- where commercial or high traffic use is common
- where slippery or icy conditions are common

FIGURE 27. Road surface shapes include outsloped, insloped and crowned. The diagram depicts an outsloped road with no ditch (top), an insloped road with the inside ditch (center), and a crowned road with an inside ditch (bottom). Outsloped road shapes are generally preferred because of lower construction and maintenance costs. Where cutbanks are wet with spring flow an outsloped road shape can be combined with an inside ditch. Note that insloped and crowned roads generally require more hillslope cutting and have higher cutbanks than outsloped roads because of the extra width needed for a ditch (Modified from: Adams and Storm, 2011).

Road shaping for proper drainage is not an all-or-nothing proposition. For example, roads which contour the landscape may alternate from outsloped to insloped as the road traverses the hillside. Roads that are outsloped for much of their length may also be locally insloped to deal with local conditions (e.g., a sharp outside curve). While some wet cutbanks may require the construction of an inside ditch (or French drain) for drainage, the roadbed itself may still be a worthy candidate for outsloping. **Ultimately, it is critical to properly design road surfaces to minimize erosion of the roadbed, ditch, cutbank and fill slope surfaces, while minimizing sediment delivery to streams.**

a. Outsloped roads, with or without an inside ditch

It is generally recommended that most forest, ranch and rural roads be constructed as single lane (minimum width), outsloped roads with minimal cut-and-fill, wherever conditions are suitable.

Intervisible turnouts can be provided to allow

passing. An outsloped road cross section is likely to cause the least disturbance and soil movement, create less environmental impact and have lower maintenance costs than other designs. Outsloped roads disperse and drain runoff along the entire outside edge of the road (Figure 28). They are less expensive to construct and less difficult and expensive to maintain than insloped roads, provided they are constructed in appropriate hillslope locations.

If hillslopes are dry, and cutbanks along existing roads display little or no evidence of emergent water (springs or seeps) during the wet season, there is no reason to construct or maintain an inboard ditch along a road. Analyzing cutbank and hillslope hydrologic characteristics will allow you to determine whether an inside ditch is necessary along your road.

Roads built wherever the surface can be kept dry and free draining should generally be outsloped to disperse runoff. Conditions that might limit road outsloping include: 1) steep road grades ($\geq 20\%$) which may make adequate outsloping difficult; 2) winter use of

FIGURE 28. Well built, outsloped road displaying minimum cut, smooth free draining surface, and no outside berm. The road contours the topography and its rolling grade and rolling dips disperse surface runoff.



an unsurfaced road (snow or muddy conditions on a steep, outsloped road may be hazardous); or 3) upslope runoff or excessive spring-flow from the cutbank or roadbed (which might make an inside drainage ditch necessary).

However, many ditched roads are also candidates for surface outsloping, thereby draining surface runoff to the outside and not into the ditch. The inside ditch will carry relatively clear water flows from seeps and springs, while the outsloped road surface ensures that turbid road runoff and fine sediment eroded from the roadbed will be drained to the outside edge of the road where it can be safely discharged into vegetation and onto undisturbed soils. Outsloping thereby minimizes flows in the inside ditch and reduces the potential for erosion and sediment delivery from the road surface.

Clearly, if conditions permit, roads should be constructed with an outsloped surface, no ditch and no berms along the outside edge of the road. If berms are needed for safety, they should be frequently breached along their length to allow for dispersed road surface drainage. **Table 18** shows design criteria for the degree of outsloping needed to drain road surfaces on differing grades. The design of outsloped road surfaces, especially on steeper road grades, should also consider safety where the road

surface may be slippery (e.g., in rain or snow conditions) during parts of the year.

Where fill slopes are stable, roads should be designed and constructed with minimum width and with a mild, 3 to 5% outslope (**Figure 29**). However, on most roads, especially those with grades in excess of eight percent (8%), outsloping is not always enough to get surface runoff out of wheel ruts and off the road quickly. Here, in addition to outsloping, **waterbars (for seasonal or temporary roads) or rolling dips (for permanent and seasonal roads) are necessary to divert surface runoff off outsloped roads.**

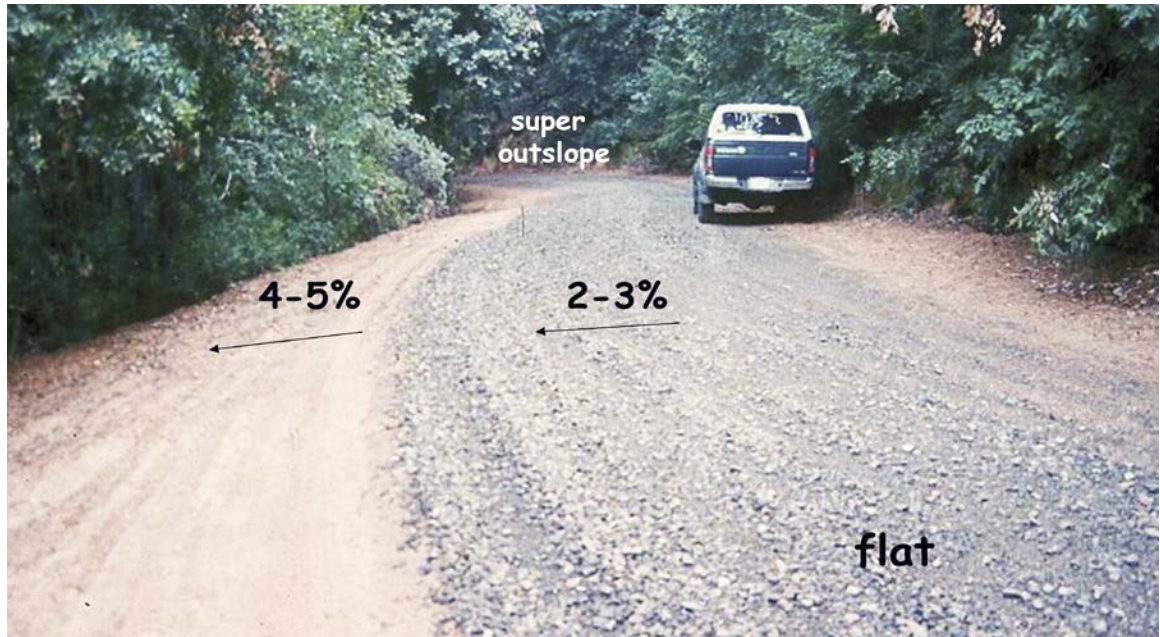
Where an outsloped road turns on an outside curve the outslope is frequently tapered to a flat or insloped road shape, depending on the direction of the turn, and then back to an outslope in the following straight stretch. These safety measures are commonly called super-inslope (turning around a ridge) or super-outslope (turning around a depression or swale). The shape of the road keeps vehicles slightly “banking” around turns in the road and allows them to maintain constant speeds without increasing the risk of skidding off the turning road. The short sections of alternating road shape also allow for dispersed road surface drainage.

TABLE 18. Outsloping “pitch” for roads up to 8% grade¹

Road grade	Outslope “pitch” for unsurfaced roads	Outslope “pitch” for surfaced roads
≤ 4%	3/8” per foot	1/2” per foot
5%	1/2” per foot	5/8” per foot
6%	5/8” per foot	3/4” per foot
7%	3/4” per foot	7/8” per foot
≥ 8%	1” per foot	1 ¼” per foot

¹California Department of Forestry and Fire Protection (2008)

FIGURE 29. Road shape changes as the road travels through the landscape. For example, an out-sloped road will have a steep or “banked” outslope through inside curves, a consistent outslope through straight reaches and a flat or slightly insloped shape as it goes through an outside curve. The road may have an outslope of 2-3% across the travel surface while the shoulder is more steeply outsloped to ensure runoff and sediment will leave the roadbed.



b. Crowned roads

A crowned road surface is one which traditionally slopes gently away from the centerline of the road and drains to both sides of the crown (Figure 30). Crowning is most commonly used where roads are wide enough for two lane traffic. Crowning may also be employed for safety purposes to keep traffic separated and where road grades are steep or snow is common; the crowned shape helps keep vehicles from sliding off the road.

The inside portion of a crowned road drains inward to the cutbank and ditch, while the outside portion drains out across the fill slope, thereby reducing the volume of road surface runoff (and fine sediment) that flows into the inside ditch. Crowning can be peaked at the center of the road, essentially dividing road surface drainage in half, or offset from the center so that more of the road surface drains to one side or the other. For example, crowning at the inside $\frac{1}{3}$ of the road surface results in most

FIGURE 30. Crowned roads are peaked near the center of the roadbed and each side of the road surface drains to a ditch. This stable, crowned road reach is through cut into the hill and the ditches are drained frequently to prevent ditch erosion.



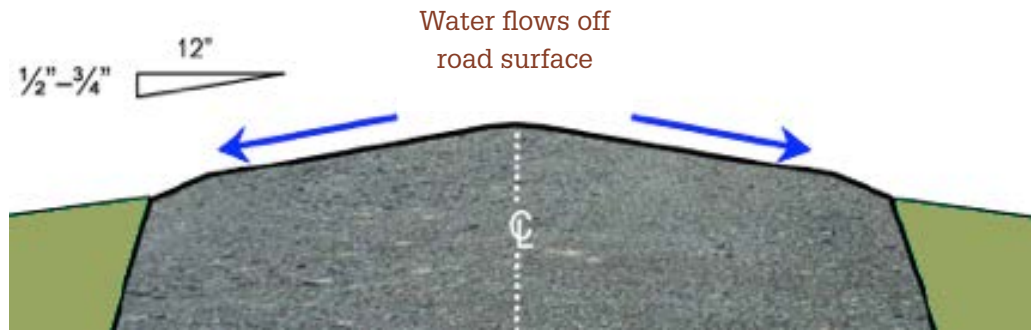


FIGURE 31A. Centerline crown with proper cross-slope for an unpaved road. Road drainage flows without obstruction off the road surface into surrounding vegetation. Note the slight grade increase at the road shoulder to encourage off-road drainage (Center for Dirt and Gravel Road Studies, 2005).

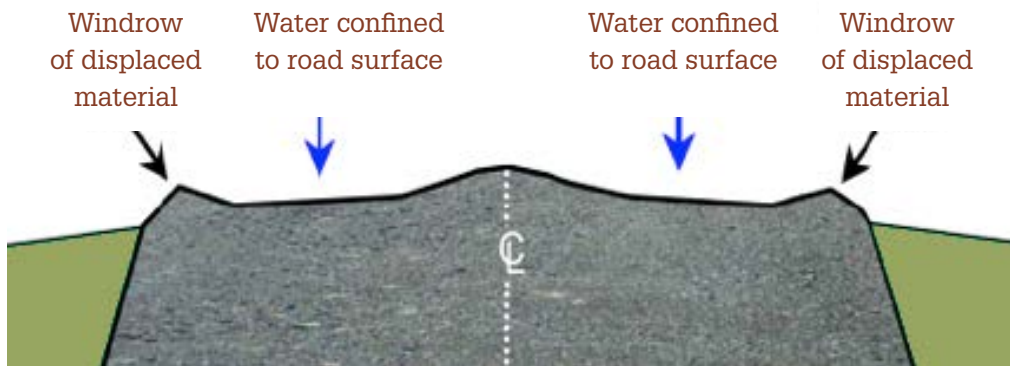


FIGURE 31B. Centerline crown has become misshapen over time. Road surface drainage is trapped on the road by gravel movement, grader berms or by road rutting under heavy traffic. Road drainage travels down the rutted road surface causing erosion, loss of road material, and increased maintenance. The road can be reshaped to restore cross drainage, but rolling dips are needed for effective, permanent surface drainage (Center for Dirt and Gravel Road Studies, 2005).

surface runoff and sediment being discharged to the outside of the road bench, much like an outsloped road. Regardless of the location of the crown, an inside ditch is still required.

On rock and native surfaced roads crowning requires frequent maintenance grading and/or the use of rolling dips to drain water off the road before it can produce ruts (Figures 31a, 31b). The recommended cross-slope is between 4% and 6%, or $\frac{1}{2}$ " to $\frac{3}{4}$ " of fall per horizontal foot of width. The steeper cross-slope means less potential for water to penetrate and

weaken the road and, therefore, longer intervals between maintenance grading operations.

c. Insloped roads

Insloped roads should be constructed only where road surface drainage needs to be kept off the fill slope (because it is unstable or the road is located right next to a stream), or where outsloping would create unsafe driving conditions. Insloped roads drain surface runoff to the inside of the roadbed, usually into a ditch, where it is combined with flow from the cut

slope and upslope hillside areas and discharged to nearby stream crossing culverts or ditch relief culverts (Figure 32). The ditch causes the water table beneath the road to be lowered as it flows out of the soil and into the ditch.

Depending on the type of traffic and the road surfacing materials, roads steeper than about 8 to 10 percent may be too steep for safely outsloping. In this setting, insloping with a ditch may be necessary, although the potential for gullying in the ditch increases with road grade. Inside ditches should be drained at intervals sufficient to prevent ditch erosion and outlet gullying, and at locations where water and sediment can be filtered

before reaching a watercourse. “Filtering” can be accomplished by thick vegetation, gentle slopes, constructed settling basins, or filter windrows of woody debris and mulch placed and secured on the slope.

As with outsloped roads, steep insloped road surfaces may be difficult to quickly drain. Rolling dips (for permanent roads and seasonal roads) or waterbars (for seasonal or temporary, unsurfaced roads) should be constructed at frequent intervals sufficient to disperse road surface runoff from steep road segments (Tables 3 and 19). Ditches and culverts need occasional maintenance to operate correctly and to carry the flows they were designed to handle. When

FIGURE 32. *This insloped ranch road drains to an inside ditch that shows evidence of past downcutting. Inside ditches need to be drained with ditch relief culverts frequently enough to prevent ditch erosion, as well as erosion of the slope where the culvert is discharged.*



TABLE 19. Recommended maximum rolling dip and ditch relief culvert spacing, in feet, based on road gradient and soil erodibility ^{1, 2}

Soil erodibility	Road gradient (%) and drainage structure spacing (feet)				
	0–3	4–6	7–9	10–12	>12
High to moderate	250	160	130	115	100
Low	400	300	250	200	160

¹Based on Keller and Sherar, 2003. Also suggested by California Board of Forestry and Fire Protection in Technical Rule Addendum No. 5 (see Appendix C).

²Table distances are designed to prevent ditch erosion, not to eliminate hydrologic connectivity. If road surface drainage is hydrologically connected to a stream crossing, install first a rolling dip and/or ditch relief culvert close to the crossing, but such that it drains onto the fill slope or hillslope and will not deliver runoff to the watercourse. The next (second) drainage structure should be placed so that it too will not discharge to the stream. Add additional drainage relief treatments along the road according to the approximate spacing recommended in this table.

ditches become blocked by cutbank slumps, they need to be cleaned. However, excessive maintenance of ditches (mostly grading) can cause continuing and persistent erosion, sediment transport and sediment pollution to local streams during storm runoff.

3. ROAD DRAINAGE STRUCTURES

Road drainage structures include those features of a road, other than road shape, designed to drain road surface and cutbank runoff off or away from the road prism. Road drainage structures include rolling dips, waterbars, drainage berms, ditches and ditch relief culverts (Table 20). The purpose of all drainage structures is to get water off of, and away from, the roadbed as quickly as possible so

roadbed materials do not become saturated, and roadbed/ditch erosion is minimized.

a. Rolling dips

Rolling dips and a smooth, sloped road surface are critical to maintaining a well-drained, out-sloped road. On climbing (or falling) roads, especially on out-sloped road shapes, the road surface can be drained using rolling dips or waterbars. Unlike abrupt waterbars, rolling dips should be able to be driven at prevailing speeds on the road where they are installed. Rolling dips are smooth, angled depressions constructed in the roadbed (Figures 33a, 33b). Typical design dimensions for rolling dips are shown in Table 21. **It is important to use rolling dips, rather than waterbars, on roads with even infrequent use because traffic will quickly break down and/or breach**

TABLE 20. Comparison of drainage structures used on dirt and gravel roads

Structure type	Ditch relief culverts	Rolling dips	Water bars	Cross road drains
Purpose	Drains the road's inside ditch	Drains the road surface; Only drains the ditch if dip is deep and intersects the ditch	Drains the road surface	Drains road surface, ditch and springs on decommissioned or closed roads
Construction costs	High	Medium	Low	Low to Medium
Maintenance	Medium Needs frequent inspection and inlet cleaning	Low Needs occasional repair or reshaping	High Needs frequent cleaning, reshaping and replacement	None Should not need any maintenance
When to use	On all road grades On high or low traffic roads with frequent maintenance	On low and moderate grades On high or low traffic roads	On all road grades On low traffic roads or seasonal roads	On all closed or decommissioned roads, especially at springs and seeps
When not to use	On infrequently maintained roads; or wherever they would discharge to streams or onto unstable areas Below unstable or raveling cut slopes	On steep grades (>12% to 18%), depending on traffic type On curves	On high traffic roads	Where the cross road drain would feed water onto an unstable area or deliver eroded sediment to a stream

waterbars. Waterbars should be reserved for unsurfaced seasonal roads that are to have little traffic and/or no wet season use.

Rolling dips are usually used on outsloped roads to drain road surface runoff to the outside of the road, but may be built on either insloped, crowned or outsloped roads to drain runoff in either direction. However, keep in mind the goal of effective road drainage is to disperse

rather than collect and concentrate road runoff. Drainage structures that drain to the inside of the road will likely require a greater number of ditch relief culverts to prevent ditch erosion and/or the formation of hillslope gullies.

Rolling dip design—In general, broad rolling-dips are usually built perpendicular to the road alignment, with a cross slope of 3 to 5 percent greater than the grade of the road.

FIGURE 33A.

Rolling dip constructed on a rock surfaced rural road. The rolling dip represents a change-in-grade along the road alignment and acts to discharge water that has collected on, or is flowing down, the road surface. This road was recently converted from a high maintenance, insloped, ditched road to a low maintenance, outsloped road with rolling dips.



FIGURE 33B.

This side view of an outsloped road shows that the rolling dip does not have to be deep or abrupt to reverse road grade and effectively drain the road surface. This outsloped forest road has rolling dips that allow all traffic types to travel the route without changing speed.



TABLE 21. Table of rolling dip dimensions¹

Road grade (%)	Upslope approach ² (distance from up-road start of rolling dip to trough) (ft)	Reverse grade ² (distance from trough to crest) (ft)	Depth below average road grade at discharge end of trough ² (ft)	Depth below average road grade at upslope end of trough ² (ft)
<6	55	15–20	0.9	0.3
8	65	15–20	1.0	0.2
10	75	15–20	1.1	0.1
12	85	20–25	1.2	0.1
>12	100	20–25	1.3	0.1

¹USDA-SCS (1981)²See also Figure 36

The cross grade slope ensures proper drainage to the outside of the dip. If the upslope in the axis of the rolling dip is insufficient, water will not drain, sediment will be deposited, and puddles and potholes will form. The morphology of the dip results in an up-and-down or slight rolling movement when driven. Some rolling dips are built at a 30 to 45 degree angle to the road alignment, but if the road is to receive commercial truck and trailer traffic (e.g., log trucks or cattle trailers) this angle can cause a significant rocking and twisting action to heavy truck loads and trailers that may not be acceptable.

Rolling dips are built with a long, shallow approach on their up-road side and a more abrupt rise or reverse grade on their down-road side (Figure 34, Table 21). Dips should be constructed deep enough into the road subgrade so that traffic and subsequent road grading will not obliterate them. Their length and depth should provide the needed drainage, but not be a driving hazard (Figure 35).

Rolling dips can be broken down into three types, depending on the existing road gradient and conditions of the outboard edge of the road. Figure 36 provides the general design characteristics of the three rolling dip types.

- A Type 1 rolling dip is the standard rolling dip design for roads that do not have a through cut or large berm that would prevent the dip

from draining onto the adjacent outboard fill slope. Type 1 rolling dips are built on roads with road gradients less than 12–14%, and with or without a small outboard berm that can be easily removed. If an outboard berm is present make sure to remove the berm through the entire length of the dip.

- Type 2 rolling dips are designed for roads with gradients less than 12–14% within a small through cut, or that have a large (i.e. tall and/or wide) berm on the outboard edge of the road. This type of dip requires “breaching” or excavating the outboard through cut or large berm through the axis of the dip. The width of the breach is dependent on the road conditions (e.g., width of berm, road steepness, and road subgrade materials).
- Type 3 rolling dips are suggested for roads with gradients that exceed 12–14% where road steepness prevents the construction of a rolling dip with a reverse grade. Instead of building a dip with a reverse grade, a Type 3 rolling dip is constructed by building an aggressive 6–8% upslope from the inboard to the outboard edge of road to ensure that runoff travels obliquely across the road and exits the road within the rolling outslope. This outslope is developed by ripping the roadbed and pushing road fill from the outboard half to the inner half of the road.

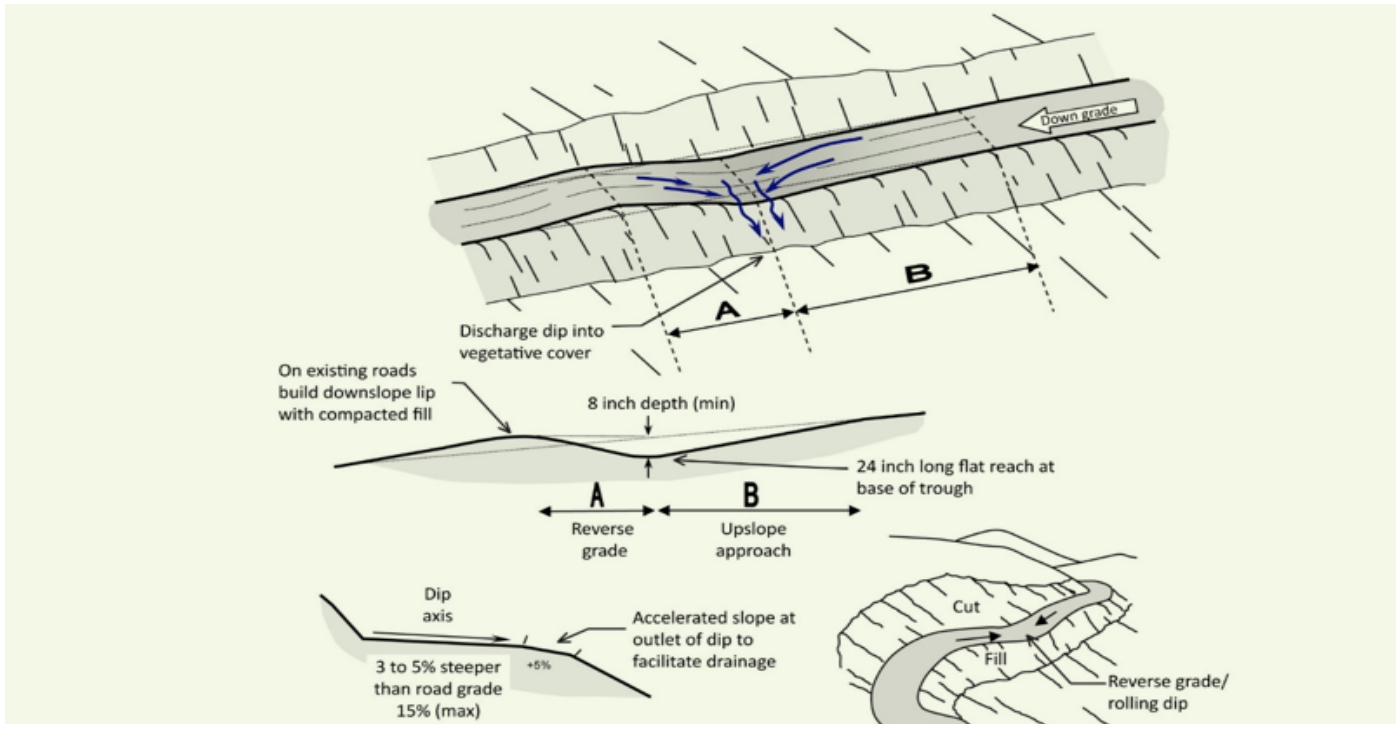
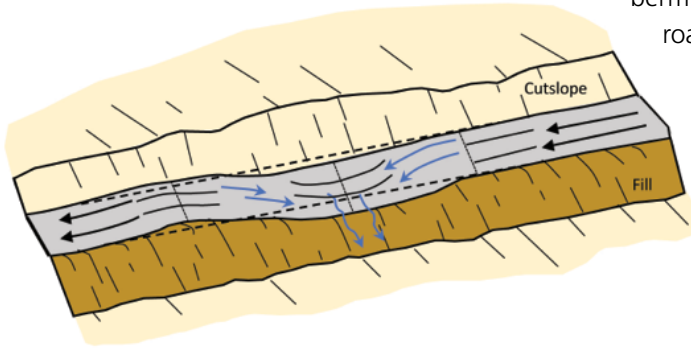


FIGURE 34. A classic Type I rolling dip, where the excavated up-road approach (B) to the rolling dip is several percent steeper than the approaching road and extends for 60 to 80 feet to the dip axis. The lower side of the structure reverses grade (A) over approximately 15 feet or more, and then falls down to rejoin the original road grade. The dip must be deep enough that it is not obliterated by normal grading, but not so deep that it is difficult to negotiate or a hazard to normal traffic. The outward cross-slope of the dip axis should be 3% to 5% greater than the up-road grade (B) so it will drain properly. The dip axis should be outsloped sufficiently to be self-cleaning, without triggering excessive downcutting or sediment deposition in the dip axis (Modified from: Best, 2013).

FIGURE 35. This outsloped forest road is used by commercial logging trucks and was constructed with frequent rolling dips to promote road surface drainage. The dips were built as a part of planned road construction for use by truck and trailer traffic. Note that the cut-banks are rocky, dry and stable, and there is no inside ditch.

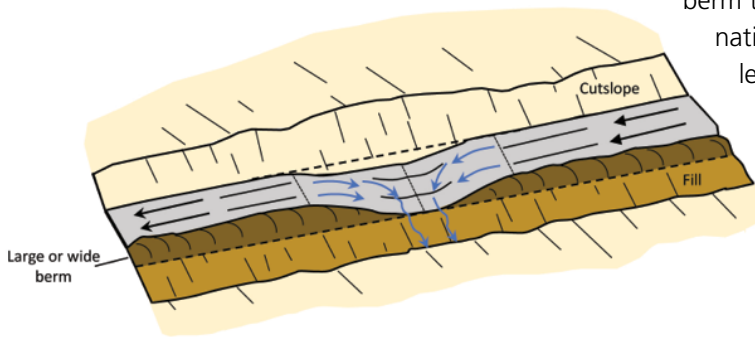


Type 1 Rolling Dip (Standard)



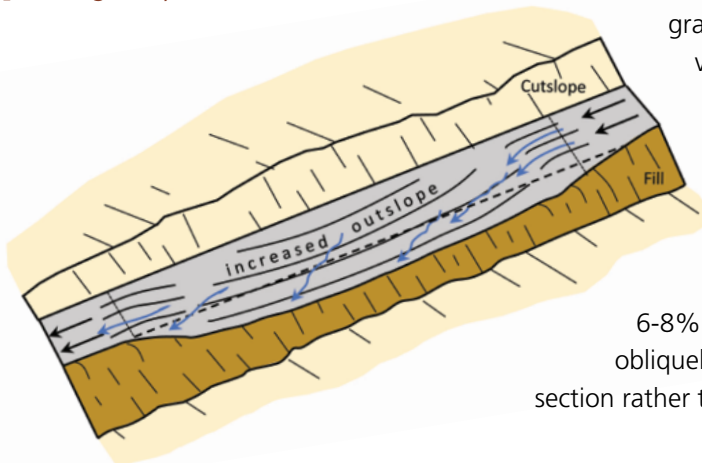
Type 1 rolling dips are used where road grades are less than about 12-14% and road runoff is not confined by a large through cut or berm. The axis of the dip should be perpendicular to the road alignment and sloped at 3-4% across the road tread. Steep roads will have longer and more abrupt dip dimensions to develop reverse grade through the dip axis. The road tread and/or the dip outlet can be rocked to protect against erosion, if needed.

Type 2 Rolling Dip (Through-cut or thick berm road reaches)



Type 2 rolling dips are constructed on roads up to 12-14% grade where there is a through cut up to 3 feet tall, or a wide or tall berm that otherwise blocks road drainage. The berm or native through cut material should be removed for the length of the dip, or at least through the axis of the dip, to the extent needed to provide for uninterrupted drainage onto the adjacent slope. The berm and slope material can be excavated and endhauled, or the material can be sidecast onto native slopes up to 45%, provided it will not enter a stream.

Type 3 Rolling Dip (Steep road grade)



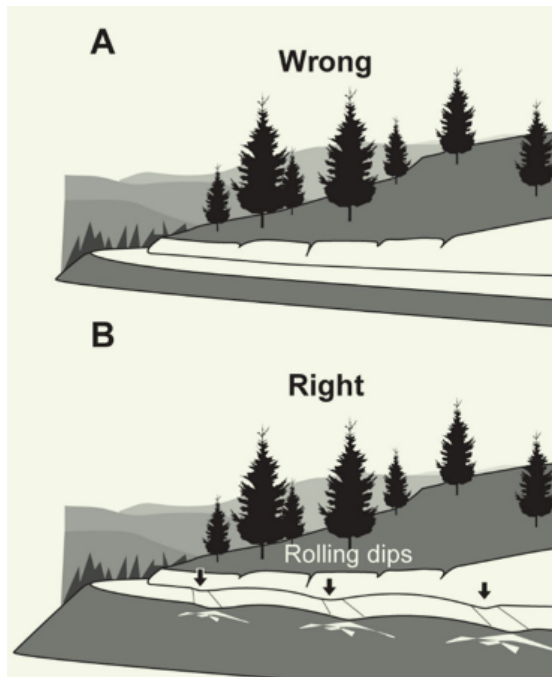
Type 3 rolling dips are utilized where road grades are steeper than about 12% and it is not feasible to develop a reverse grade that will also allow passage of the design vehicle (steep road grades require more abrupt grade reversals that some vehicles may not be able to traverse without bottoming out).

Instead of relying on the dip's grade reversal to turn runoff off the roadbed, the road is built with an exaggerated outslope of 6-8% across the dip axis. Road runoff is deflected obliquely across the dip axis and is shed off the outsloped section rather than continuing down the steep road grade.

FIGURE 36. Rolling dip types

FIGURE 37.

Installing rolling dips, or “rolling the grade” of an out-sloped road helps guarantee that surface runoff will not concentrate on the road surface and erode the roadbed, and that road runoff will be dispersed across the hillside. Spacing of rolling dips depends on road grade, soil erodibility and proximity to the nearest water body (Kramer, 2001).



Rolling dip spacing—The frequency or “spacing” of rolling dips and grade breaks (Figure 37), and the amount of “out-sloping” needed to drain the road surface, depends on the grade of the road, as well as the road surfacing (Table 19). To design drainage structure spacing, it is useful to look at local roads to determine the maximum spacing that is likely to work for the soils and climate in your specific area. Example design criteria for drainage structure spacing to minimize road surface and ditch erosion (waterbars and rolling dips) are listed in Table 3 and, alternately, Table 19 (rolling dips and ditch relief culverts).

Drainage tables provide guidance and are common in the literature, but local observations are key to determining the most appropriate spacing in your particular area. In general, the spacing of road drainage structures is appropriate when you can observe minor rilling (incision) on the road fill slope where the road runoff is occurring, but hill-slope rills and gullies are absent or do not extend continuously on native slopes below the drainage structure outlet (Figure 38).

The basic spacing guidance of Table 19 must be tempered by the proximity of the discharge points to streams and other waterbodies, and considering factors that might increase the probability of runoff and sediment being transported to the stream, lake or wetland. Those things that are likely to increase the probability of sediment delivery include such factors as: a short distance to the nearest stream or water body, steep slopes, unstable terrain, the presence of gullies or channels that could collect and efficiently transport road runoff and sediment, bare soils or low vegetation density, and shallow or clay rich soils with low infiltration rates. **To account for hydrologic connectivity in the suggested drainage spacing tables you must significantly and progressively reduce the spacing of drainage structures as you get closer to streams and other waters, accounting for the proximity of stream or lake, slope steepness and the other contributing factors.**

b. Waterbars, rubber waterbars and open top box culverts

Waterbars can also be used to drain a road surface. These are shallow, abrupt, excavated dips or troughs with an adjacent, downslope hump or mounded berm that are built at an oblique angle across the road (Figure 39). To maintain the greatest effectiveness, the axis of the waterbar (including where it drains onto the adjacent hillslope) should be constructed at a gradient slightly steeper than the road gradient it is intended to drain. This prevents deposition within or at the outlet of the structure and maintains flow and sediment transport along its length.

Waterbars are useful only on low standard seasonal or temporary, unsurfaced roads where winter or wet season use will not occur, because traffic easily cuts through the soft berm and fills the adjacent dip. Waterbars should be constructed at proper



FIGURE 38. Rolling dips should be spaced on outsloped roads so that the road surface is well drained and free from erosion, and the slopes below each dip show minimal erosion. Three broad rolling dips (see arrows) are visible in this upgraded road reach used by both commercial and residential traffic.

spacing according to the grade of the road (Figure 40; Tables 3 and 19). Waterbars are usually regraded (smoothed out) at the beginning of each operating season in which the road is to be used and opened to traffic, and then reconstructed prior to the beginning of each winter or wet season period.

Waterbars are high maintenance drainage structures that are prone to failure if not properly built and maintained. Unauthorized winter traffic is likely to break down waterbars and result in serious road surface erosion and water pollution. Roads that are drained with waterbars

should be restricted from most traffic, especially during the wet season when soils are softest.

On seasonal rocked roads and roads where waterbars cannot be built and maintained each year, thick rubber flaps or “rubber waterbars” are occasionally constructed into the roadbed. The rubber waterbar is most useful where frequent road grading is not necessary but the road surface needs better drainage.

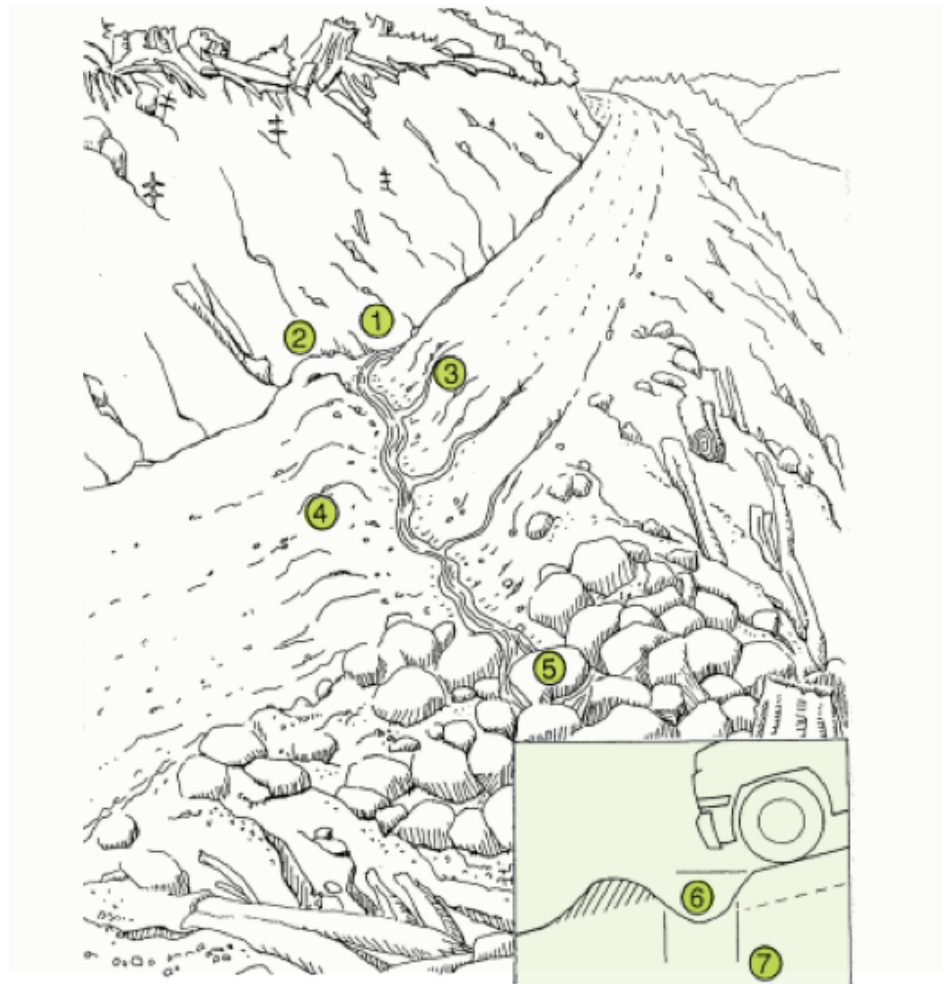
These drainage diversion devices are sometimes made of thick rubber strips or salvaged conveyor belt fabrics, and are dug at least 12



FIGURE 39.

Waterbars are often used to drain surface runoff from seasonal, unsurfaced roads. Because they are easily broken down by vehicles, waterbars are only used on unsurfaced roads where there is little or no wet weather traffic. In this photo, a waterbar and ditch relief culvert are used to drain all road surface and ditch runoff from the insloped road prism.

FIGURE 40. Waterbars are constructed on unsurfaced forest and ranch roads that will have little or no traffic during the wet season. The waterbar should be extended to the cutbank to intercept all ditch flow (1) and extend beyond the shoulder of the road. A berm (2) must block and prevent ditch flow from continuing down the road during flood flows. The excavated waterbar (3) should be constructed to be self-cleaning, typically with a 30° skew to the road alignment with the excavated material bermed on the downhill grade of the road (4). Water should always be discharged onto the downhill side on a stable slope protected by vegetation. Rock (shown in the figure) should not be necessary if waterbars are spaced close enough to prevent serious erosion. (5) The cross ditch depth (6) and width (7) must allow vehicle cross-over without destroying the function of the drain. Several alternate types of waterbars are possible, including one that drains only the road surface (not the ditch), and one that drains the road surface into the inside ditch (BCMF, 1991).



inches into, and anchored in, the roadbed at an angle oblique to the road alignment, much like a waterbar. They stick up about 4 inches above the running surface and divert surface runoff to the side of the road. The flap bends down as vehicles pass over the waterbar and then immediately springs back to deflect runoff. Unlike waterbars, vehicles can drive over the flap without having to slow down; it folds over and pops back up when the vehicle passes.

The main shortcomings include the labor intensive installation required to build each diversion device, and the difficulty of grading the road surface that contains frequent rubber waterbars.

Open top box culverts (usually made of wood or metal) can also be used to drain the road surface, but they often fill with soil and rock,

are difficult to grade over, and usually require higher levels of maintenance to keep open and functional. They should have a relatively steep grade so they self-clean during runoff events, and are often fitted with a surface grate on top to prevent large rocks from entering the top of the culvert and obstructing flow.

Like waterbars, and for maximum effectiveness and minimal maintenance, these less common road drainage structures should be constructed obliquely across the road such that their slope is slightly greater than the grade of the road they are draining.

c. Drainage berms

Road berms are generally defined as a continuous row of fill and/or aggregate,



FIGURE 41. This outside berm on a crowned road prevents road surface runoff from draining onto the adjacent hillslope. If the road was insloped, the berm would not interfere with road drainage.



FIGURE 42. Short road reach where a soil berm has been intentionally constructed along the outside edge of the road prism to prevent surface runoff from flowing over the highly erodible fill. To prevent the accumulation of too much runoff, the berm can be intermittently breached and a small flared inlet and culvert or sheet metal berm-drain installed to carry runoff downslope past the base of the erodible fill slope.

usually on the outside edge of a road, which prevents surface water from leaving the road (Figures 41 and 42). Berms may be created in several ways and have several purposes, or they may be the result of poor grading practices. **Regardless of their origin, road berms can have the negative consequence of unintentionally collecting and concentrating road surface runoff.** Berms located along the outside edge of a crowned or outsloped road prevents road runoff from leaving the roadbed and may result in roadbed erosion or gully erosion where the concentrated runoff is discharged off the road.

Not all berms are bad. For example, where berms have formed or been built along the outside of an insloped road, and road surface runoff is flowing away from the berm and into the inside ditch, the berm will not have any negative hydrologic effects. Similarly, berms are sometimes used as a real or perceived safety measure to keep vehicles from sliding off outsloped or crowned roads that are steep or built in a snow-zone, or where the road is narrow and the adjacent hillside is extremely steep. In other locations, berms may be intentionally constructed on the outer edge of the road to keep drainage water from flowing into

a stream or onto an unstable area (Figure 42). Berms are often used by grader operators as a temporary reservoir of road surfacing material that can be brought back onto the road surface during routine maintenance grading operations.

Many other road berms along forest, ranch and rural roads are unintentionally built as a consequence of routine road surface grading and maintenance, leaving a small (or large) berm of spoil material along the out edge of the road. Over time, these small berms become permanent as they are covered with vegetation. The largest berms are often the unintended end-product of years of routine grading. **Road berms on the outside of an outsloped or crowned road can have the same effect on road drainage as does a through cut; road runoff may be blocked by the berm and unable to drain off the road surface. It collects, diverts and then discharges runoff where it can cause fill slope and/or hillslope gulying.**

Berms may also form because of physical obstructions that prevent effective road surface grading. The growth of vegetation or young trees on the outside edge of a road, or the presence of a property boundary or livestock fence along the inside or outside road edge, may prevent effective surface grading, thereby causing formation of a residual berm. Road berms may also be created by road maintenance crews when they decide to store spoil materials, created elsewhere (e.g., by slide clearance work), along the outside edge of a wide section of road.

Berm treatments—It is generally a good practice to completely or intermittently remove berms that are blocking road runoff and preventing effective road drainage. If berms are not blocking or diverting road surface runoff they may be left in place with no adverse effects. **Simple treatments can often be used to minimize the hydrologic impact of berms on roads, road surface drainage and downstream water quality:**

- Keep the outside edge of outsloped or crowned roads free of berms unless they are intentionally placed to control water or for traffic safety.
- Where they are preventing road surface drainage, remove berms or breach berms at strategic non-erodible locations to allow drainage onto non-erodible, stable slopes.
- Where driving hazards do not exist, avoid creating a windrow or small berm of material along the edge of an outsloped or crowned road during maintenance grading which may form a barrier to dispersing road surface runoff.
- Consider installing a raised berm on the outside edge of the road over newly constructed stream crossings to keep road surface runoff from discharging onto and eroding newly built fill slopes until they are well vegetated.
- Berms are also good to use where a road closely parallels a stream, lake or wetland. Berms can be used to control and direct road surface runoff, and to intentionally discharge it where the sediment will not impact streams, lakes or wetlands.
- When outside berms are needed as a permanent safety measure, daylight (breach) them at frequent intervals (e.g., every 30 to 60 feet) to break up the length of the berm and the accumulated runoff that would otherwise occur.
- Road berms on insloped roads do not affect road drainage and can usually be left in place with little negative effect.
- If they are not needed, or if they are causing road drainage and erosion problems, road berms on crowned and outsloped roads can be either partially or completely removed.

- Depending on the slope steepness and proximity of the road to a stream, berms can be removed by excavation or sidecasting. Sidecasting should not be used if there is a possibility that spoil or eroded sediment could enter a watercourse and/or increase fill slope instability.

d. Ditches

Historically, many roads have been “automatically” constructed as insloped, with an inboard ditch. For decades, that was the default engineered design standard, whether or not hillslopes were wet and a ditch was really needed. Landowners should evaluate soil moisture, usually during the wet season, to determine what portion of the road actually requires a ditch for drainage and to maintain a firm and stable roadbed. Dry road sections should be constructed, or reconstructed, as outsloped, without a ditch. In wet areas, the road can still be outsloped even if an inside ditch is needed to drain emergent water (Figure 43).

Well-constructed and maintained ditches are important to the long-term stability of an insloped or crowned road. Backhoe and excavator constructed ditches are often superior to bladed ditches built by a bulldozer or grader because they can be cut out of the subgrade rather than gouged into the cutbank. However, they are more difficult and time consuming to construct and maintain. The ditch cross section should be designed to accommodate expected storm flows, with the base of the ditch at least 12 inches below the adjacent roadway in order to prevent water from entering and saturating the road surface material and reducing road strength. A relatively deep ditch also allows for faster drainage of the subgrade into the ditch and helps maintain high soil strength beneath the roadbed. If the cutbank and ditch are relatively dry for most of the year, the ditch can be shallower as roadbed saturation should not be an issue.

There are two types of roadside ditches; those that are hydrologically connected and delivering runoff and sediment to streams, and those that



FIGURE 43. *This rural subdivision road has been converted from an insloped, ditched road to an outsloped road shape with rolling dips and an inside ditch. Broad rolling dips have been built at regular intervals to accommodate all traffic types. The ditch has been retained to drain clear spring flow from the small cutbank. The road surface no longer drains to the ditch.*

are not. **Road ditches that drain directly to stream crossing culvert inlets are typically the most common and important source of hydrologic connectivity between roads and streams.** During runoff events they act much like an ephemeral stream, and serve as “conveyor belts,” transporting road runoff and fine sediment to the natural stream channel network. **Connected ditch lengths should be minimized, and the ditches themselves should be constructed and maintained to minimize the amount of sediment that is delivered to the stream crossing.** Broad, low gradient, vegetated ditches immediately adjacent to the stream crossing will encourage sediment deposition (Figure 44). Connected ditches should be graded as infrequently as possible, and then seeded and revegetated after grading. Ideally, the roads draining to connected ditches should be rock surfaced (or paved) to minimize surface erosion or they should be outsloped so their runoff does not drain to the ditch.

In contrast, ditches that are not hydrologically connected to streams, lakes or wetlands should be maintained to be as efficient as needed to rapidly drain runoff away from the road and

into adjacent downslope buffer areas. Ditch gradients on insloped roads should be steep enough to prevent excessive sediment deposition and allow rapid drainage, but not so steep as to result in ditch erosion. The road gradient usually dictates the ditch gradient. Outsloped roads do not drain to the ditch, so sediment accumulation is not an issue.

On steep roads over about 10% grade, even small volumes of ditch flow may have high enough flow velocities to cause erosion of the ditch. In this case, it may be necessary to armor the ditch to prevent erosion, although armoring the ditch will make it more difficult to maintain. Any armoring of channels or ditches also has to follow specific design criteria to be effective. Dumping loose rock in the ditch will likely cause erosion rather than prevent it. The rock armor needs to be formed into a channel shape, with a bottom and sidewalls to contain the expected volume of flow.

When inside ditches are used along a road, frequent ditch relief culverts should be installed to minimize the concentration of runoff in the ditch and to disperse runoff to downslope

FIGURE 44. *This insloped, gravel surfaced road drains to a vegetated ditch. The ditch is connected to a stream crossing culvert, but the heavy vegetation in the ditch prevents sediment from being delivered to the stream.*





FIGURE 45. *If ditches show excessive erosion, or long gullies form below the outlet of a ditch relief culvert, then the ditch is carrying too much flow and additional ditch relief culverts are needed up the road to break up the flow. Gullies below culvert outlets are a common source of hydrologic connectivity, delivering road runoff and eroded sediment to the downslope stream channel.*

areas. **If the ditch shows signs of erosion, it is likely that additional culverts are needed to break up and disperse the ditch flow. Likewise, if ditch relief culverts show extended scour at or below their outlets, that is a sign that there is too much flow being discharged onto the slope below the road and that one or more additional culverts are needed to drain the ditch and disperse ditch flow without causing erosion downslope from the road (Figure 45).**

e. Ditch relief culverts

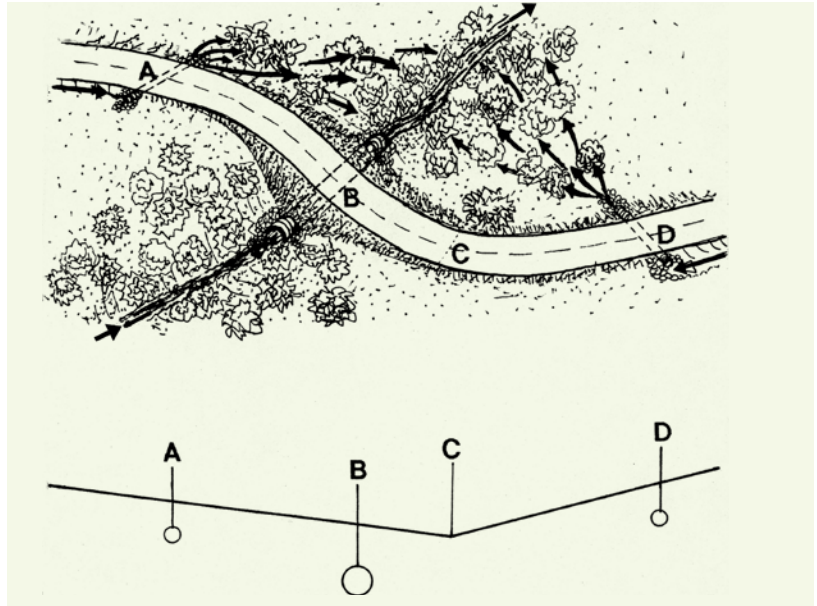
Hydrologically connected ditches which drain directly to watercourse crossing culverts should be treated and protected from disturbance and erosion, just as is an ephemeral stream or Class III watercourse. Ditch relief culverts should be installed sufficiently before watercourse crossings so that water and sediment can be filtered through a vegetated slope before reaching the stream. They should also be installed at intervals along the road that are close enough to prevent significant erosion of the ditch and below the culvert outfall on the native hillslope, and at locations where collected water and sediment

is not discharged directly onto unstable areas or into watercourses (Figure 46; Table 19).²

Spacing tables for ditch relief culverts that are often found in the literature, or even derived for your particular area, can provide guidance on how frequently to install road drainage structures to minimize erosion. **However, an inflexible spacing distance or frequency, derived from a spacing table, is not recommended because conditions along all roads change and some locations are more suitable for receiving runoff than others. The performance of the ditch, the ditch drain outlet and the receiving area (including the potential for hydrologic connectivity) are the**

² California's Forest Practice Rules do not prescribe the maximum or proper distance between inside ditch relief drains. Instead, they state that adequate drainage must be provided. Table 19 provides examples of suggested spacings, although it is important to remember that actual spacing is dictated by local conditions and proximity to a watercourse, with closer spacing near the channel (see Appendix C: California Department of Forestry and Fire Protection Technical Rule Addendum No.5). Indicators of inadequate relief drain spacing include: 1) gullying of the inside ditch, 2) gullying or sliding of the slope below the culvert outlet of a cross drain, 3) direct transport of sediment along an inside ditch to a watercourse, or 4) direct transport of road runoff and sediment from a drainage structure outlet to a stream.

FIGURE 46. Where a road approaches a stream crossing (B), ditch flow should be culverted across the road (A, D) and discharged into a vegetative buffer that can filter the runoff before it reaches the watercourse. If the stream culvert plugs with debris or is topped by flood flows, flow will spill over the road at the change-in-grade (critical diversion dip, or critical dip) at location “C” and back into the stream channel (Modified from: MDSL, 1991).



most important drivers for the placement of ditch relief culverts and other road drainage structures.

Ditch relief culverts do not need to be large, since they carry flow only from the cutbank, springs and sometimes from a limited length of road surface. **It is recommended that a minimum 18-inch diameter pipe be used for ditch relief culverts in forested locations (where woody debris is in transport).** Smaller culverts are too easily plugged, either by transported organic debris in the ditch or by cutbank slumps above the culvert inlet. If the cutbank above the inlet is unstable or rapidly eroding, a slotted drop inlet can be installed over the inlet to keep it from plugging. Where roads cross grassland areas, with no woodlands, the minimum culvert diameter can be reduced slightly but should never be less than 15 inches.

A general rule-of-thumb is to install the culvert at a grade at least 2% steeper than the ditch grade leading to it, and to skew the culvert at a 30° angle to the ditch line (Figure 47) to minimize inlet erosion and to efficiently transport sediment through the culvert (Figure 48). A minimum 10

percent grade through the culvert will usually be self-cleaning. Inlet protection, such as rock armoring or drop structures, can be used to minimize erosion, safely turn the flow, prevent inlet plugging and slow flow velocity as it enters the pipe. Culverts should be installed to discharge at the toe of the fill slope so their discharge does not erode the fill. If they are set shallower, they will need a full-round downspout, half-round/flume or properly sized, armored channel to carry the culvert flow to the base of the fill slope.

Culvert outfalls that show erosion can be protected with slash and/or rock armor to prevent erosion, but there is no reason to automatically armor the outlet of ditch relief culverts. **If erosion is isolated to the culvert outlet area, and does not extend downslope as a gully, then outlet armoring is probably not necessary. Where sedimentation at the inlet occurs because of over-steepened cutbanks, drop inlets can be installed to prevent culvert plugging.** Culverts should never be “shot-gunned” out of the fill, thereby creating highly erosive road drainage “waterfalls” and the resultant outlet gullies.



FIGURE 47. Ditch relief culvert installed across a low volume, permanent road. The culvert is set at the base of this shallow road fill and angled approximately 30° to the road alignment.

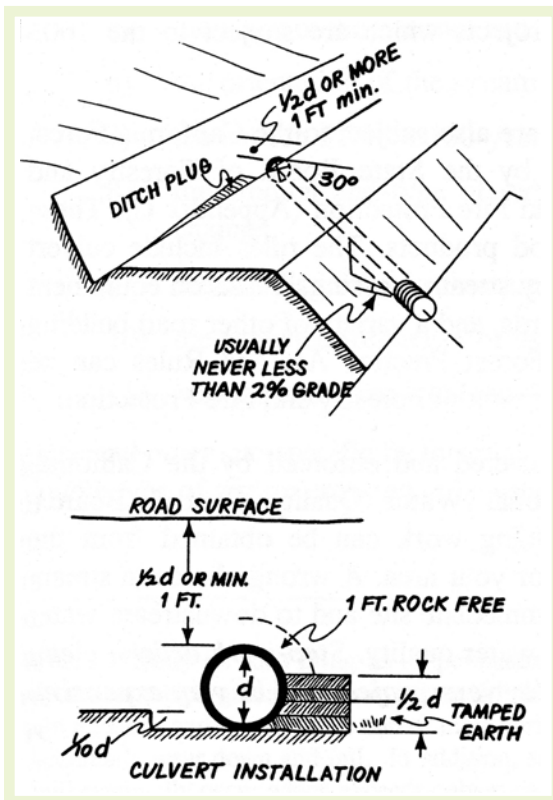


FIGURE 48. The elements of a properly installed ditch relief culvert. The culvert is angled at about 30 degrees to the road alignment to help capture flow and prevent culvert plugging or erosion of the inlet area. It is set at the base of the fill (ideally) or with a grade slightly steeper than the grade of the contributing ditch (but never with a grade less than 2 percent). At a minimum, the grade of the ditch relief culvert should be sufficient to prevent sediment accumulation at the inlet or deposition within the culvert itself (it should be self-cleaning) (USDA-SCS, 1983).

4. SPECIAL DESIGN CONSIDERATIONS

In forest, ranch and rural land settings, special design considerations may be required where roads cross unstable slopes, wet areas, watercourses and other potential hazards or obstacles. Some of these might involve using new, state-of-the-art subdrainage materials and methods.

Other special designs may simply involve the application of time tested methods of equipment exclusion, excavation, endhauling, bridge installation, road surfacing or additional requirements to provide increased protection to water quality. Guides for special road design are often available from engineering geologists or geotechnical specialists specializing in road construction, from literature and manuals,

and/or from suppliers of materials and supplies used in erosion control and road engineering.

a. Landing design and layout

Forest roads used for commercial timber harvest often have wide areas, or landings, built along their road systems where cut logs are loaded onto log trucks for transport to the mill. Log landings vary tremendously in size and frequency from one landowner to the next, but their design requirements differ little from other sections of a road system (Figure 17). Newer, mobile cable yarding machines can operate on narrow sections of road, with little more than a turnout required for their swing. Other yarders, including towers, may require an entirely separate “yarder pad” be constructed on a spur road above the main haul road where logs are landed and then loaded onto trucks.

Although such large yarding machines are becoming less commonplace, these legacy landings are found along many older forest road systems. Landowners who have purchased formerly logged lands to use for forestry or other purposes should identify and carefully evaluate landings for long term stability. For example, landings may be envisioned as good building sites for rural landowners, but most were built with little or no attention to proper compaction.

Tractor yarding requires moderate size landings that, over the years, may grow larger than needed as spoil and debris is carried down the converging skid trail network and then sidecast over the outside edge of the landing. In the Pacific Northwest, bulldozers were historically used to yard logs down small stream channels and steep slopes; creating large landings. Today, tractors are usually used only on gentle and moderate slopes and not in or near stream channels so their landings are less likely to impact streams.

Helicopter yarding requires the largest landings, but very few in number, and they are typically located high on slopes and ridge top areas. Their impact on hydrology and sediment delivery can be more easily mitigated.

The frequency of landings that need to be constructed is controlled, or influenced, by the type of yarding equipment, the slope of the land and the density of harvestable trees along the route. For example, on very steep slopes, stable landings might only be constructed on broad ridge crests (Figure 16). In general, landing construction should be limited to the fewest number and smallest size that are absolutely needed for yarding operations.³

Landing fills that are placed on steep slopes or near watercourses should be “keyed” or benched into the hillslope and compacted in shallow (1 foot) lifts from the bottom up. Sidecasting should be avoided. In addition, older landings that are being rebuilt or reused should not be enlarged by sidecasting of spoil or organic debris. Where roads are located far from the stream, maximum hillslope gradients for building small landings using sidecasting methods should be the same as for road construction: about 55 percent. It is recommended that benches or benches with keyways be constructed for catching sidecast and fill where landings are built on slopes steeper than about 40%.

The following terrain conditions should be avoided as sites for landings (Figure 16): 1) unstable slopes and soils, 2) open slopes steeper than about 55% with no natural benches, 3) steep headwater swales and inner gorge slopes, 4) narrow ridges between headwater swales, 5) any steep slopes (>50%) which lead without flattening to a watercourse and 6) areas underlain by steeply dipping sedimentary rock or highly fractured rock.

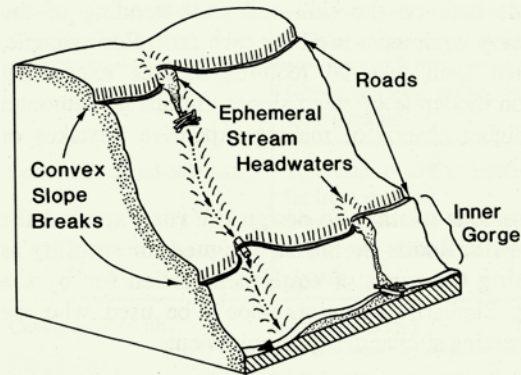
³ See Appendix C for California Forest Practice Rules regarding landing design.

Constructing full benches for landings on steep slopes produces tremendous volumes of spoil material. Although full benching might be necessary so that fills can withstand equipment vibrations and weight loads, spoil that is disposed of as sidecast can destabilize the hillside below. Sidecasting should be avoided during construction or enlargement work. Gully headwalls and swales are already naturally unstable sites and have little room for landing debris. Sidecasting into these steep headwater swales can trigger debris flows and torrents (Figure 49). Although steep, narrow ridges adjacent to these steep headwater channels provide good deflection for yarding, the sides of these ridges are often unstable and unsuitable for sidecasting.

b. Converging roads

Converging roads on steep slopes is one special case of road construction that commonly produces erosion and sediment problems. In this situation, a lower road may undercut and remove support for the upslope road. In addition, sidecast from the upper road can extend downslope to the lower road, with continuing sidecast from the lower road then

TYPICAL DEBRIS FLOW LOCATIONS



extending the blanket of bare soil downslope even farther. These steep, bare soil areas are notably difficult to stabilize and revegetate.

The best planning and design solution for converging roads is to locate road junctions on gentler slopes, or to plan for them to occur on broad ridges separating steep gradient slopes (Figure 50). If steep slopes cannot be avoided, it is recommended that the upper road be constructed as a full bench road with all spoil endhauled to a stable location, and the lower road be built with an

FIGURE 49.

Research in mountainous areas has shown that many destructive debris slides and debris flows caused by the construction of wildland roads occur at specific sites on a hillside. The most sensitive sites, and therefore those to avoid during road and landing construction, are steep inner gorge slopes, steep headwater swales or stream areas, and steep slopes immediately below a convex break-in-slope.

FIGURE 50.

Where roads diverge or converge on a steep hillside, there is an increased likelihood for slope undercutting, instability, excessive sidecasting, and subsequent erosion. Road intersections should be located on benches, or on gentler terrain, underlain by stable, dry or rocky soils to minimize required excavation volumes and subsequent instability and erosion.



engineered fill or as a full bench road to limit uncontrolled sidecasting. The road junction should be located sufficiently far upslope from watercourses such that water quality will not be affected. Full bench construction with endhauling, or other creative engineering solutions that minimize sidecast, may be designed for these “unavoidable” settings where the potential for sedimentation or slope failure is relatively high.

c. Developing stable cuts and fills

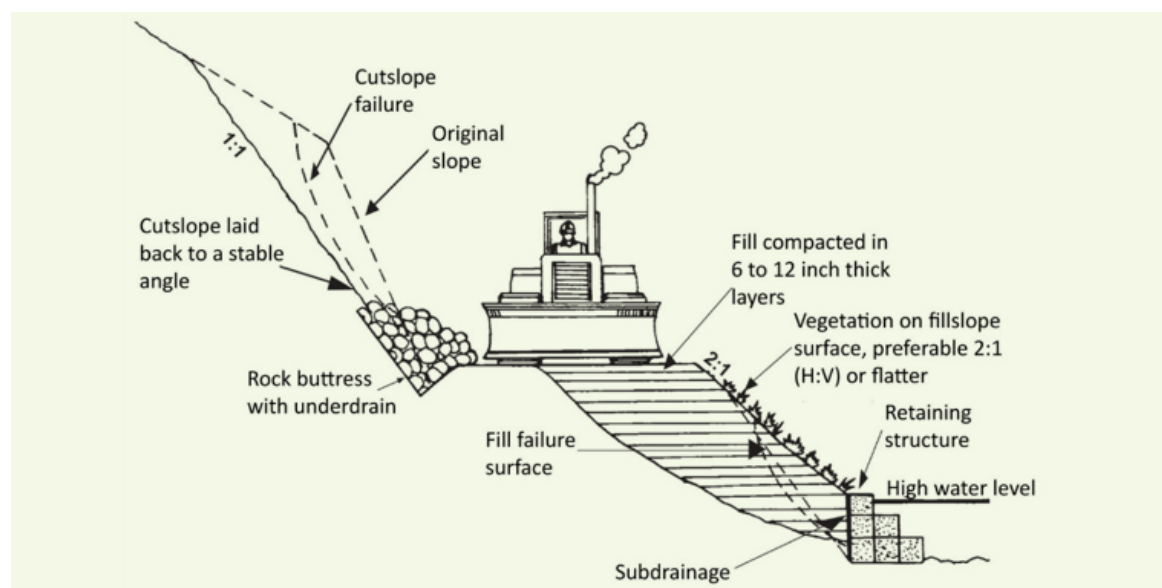
Roads are typically built across hillslopes using either cut-and-fill construction methods, or employing full bench (end-haul) methods. Balanced cut-and-fill road construction (no endhauling) is appropriate wherever slopes are moderate and stable, and slopes are less than about 40% to 50% gradient. As slopes steepen, balanced cut-and-fill methods become more difficult to employ and conditions may require benching and compaction to retain and control loose fill.

Roads built across steep slopes are generally more prone to failure than those on moderate or gentle slopes in the same soil types. Similarly, wet, unstable or fine grained soils are more prone to failure during storm

events than are those constructed through dry, coarse and angular materials. Road fills in wet areas may appear stable for long periods, but they can still represent potential weak points along the road alignment even years after initial road construction.

General diagrams and guidance have been developed for creating stable cutbanks and fill slopes in typical soil materials (Table 17). However, stable cut slope and fill slope angles will be highly specific to the type and character of the soils and hillslope hydrology through which the road passes. Cuts into erodible, unstable or wet soils can cause instability in otherwise stable hillslopes, as road construction undercuts natural slopes, removes lateral support, and exposes springs and through-flow of near surface soil water. Similarly, unstable, erodible soils may not be suitable for fill slope construction. These special situations may require rerouting of the alignment or the use of special designs, including full bench endhauling, fill slope benching, or the construction of slope revetment (rock buttresses, reinforced (engineered) soils or retaining structures) (Figure 51). If these sites are unavoidable along a proposed alignment, or if an existing road alignment is experiencing continuing stability

FIGURE 51. Slope stability solutions with a variety of stabilization measures. Other than simple excavation treatments, most slope stability solutions will require input and/or design by a qualified engineer or engineering geologist (Modified from: Keller et al., 2011).



problems, a qualified and experienced geotechnical engineer or engineering geologist can assist with one or more special designs.

On slopes steeper than about 50% to 65%, or within 100 feet of a stream, full bench endhaul construction is almost always preferred. Higher cutbanks from full bench construction can increase the risk of cut slope failures, but most of these are caught by the road bench and do not travel past the road or into a stream. **If full bench construction is not possible (say, because of a solid rock bank) road relocation or the use of various retaining structures, buttresses and engineered fills can be employed where a fill slope is needed on steep slopes.** These structures require engineering and significantly increase the cost of road construction or reconstruction, so **they are infrequently used on low volume roads in forest, ranch or rural settings.**

Rock buttresses keyed into the basal slope are the simplest and least expensive slope retaining

structure (Figure 52). Because of the large earth pressures involved, retaining structures typically require engineering design. Manufacturers of special application materials used for retaining wall structures will usually give engineering advice on the use of their products. Retaining structures should be reinforced and planted with live cuttings between the structural elements to provide for increased long term stability.

The simplest and most straightforward method of repairing unstable fill slopes is direct excavation of the unstable fill materials. If excavation would significantly reduce usable road width, widening the road into the cutbank may be a simple and low cost solution. **For unstable fills along the outside edge of a road where there are signs of instability (cracks and small scarps), but the road cannot be moved into the cut slope, a deep patch repair can be used.** This consists of excavating the unstable subsided materials, creating a stable bench in the native soils, and then backfilling the excavation with compacted



FIGURE 52. *This wet and potentially unstable cut slope on a newly constructed road was stabilized using a buttress of large rock armor. To assure their effectiveness, rock buttresses and other retaining structures should be designed by a qualified engineer or engineering geologist.*

lifts of soil. Several layers of geogrid or geotextile are placed to provide additional lateral support.

Common maintenance grading or paving over cracks or small scarps does not stop or repair a fill slope settlement problem.

d. Through cuts

There are a number of road shapes and drainage structures or features that direct and control surface runoff on rural roads. These include rolling dips, waterbars, various road shapes (insloped, crowned or outsloped) and natural dips in the road alignment. Most of these are intentionally employed to direct road surface runoff to chosen locations where it will minimize potential impacts to water quality. **Through cuts are often an unintentional consequence of the initial road alignment, construction practices or subsequent maintenance activities.**

i. Location and characteristics There are two basic types of road cuts; sidehill cut and through cut (Figure 22). A sidehill cut is an

excavation across a hillside that leaves a cut only on the inside of the road. Cut-and-fill as well as full bench road construction creates a sidehill cut, and the road surface can be drained either into a ditch on the inside of the road or onto the adjacent hillslope on the outside of the road. In contrast, **a through cut is defined as a road cut into a native hillslope with excavated slopes on both sides of the roadway.** They are characterized by excavations that range from tens of feet high down to as little as several inches (Figure 53). **They are commonly found where a road has been excavated through a hillslope or ridge or, more commonly, straight down a relatively gentle ridge or hillside.** Through cuts are sometimes designed or constructed to reduce the grade (steepness) or curviness of a road, and in other cases to reduce the length of a new road.

Low volume forest, ranch and rural roads should be built to follow the topography as much as is possible, not cut through it. The exception occurs where a road is designed

FIGURE 53.

Through cut road reaches can be short or long, and the degree of cut can vary from several inches to tens of feet deep. The road in this through cut section is well drained using a crowned shape, with ditches on both sides of the road. The road surface and ditch should be drained at the beginning and the end of the through cut road reach to minimize erosion.



for high travel speeds or considerable commercial traffic is expected. In these instances, large sidehill cuts, or sidehill through cuts, are constructed to keep the alignment relatively straight and avoid having to weave in and out of the naturally undulating terrain. Everywhere a road is constructed through, rather than around, a ridge or hill, a through cut is often constructed (where there is a cut on each side of the road). Larger and taller ridges will have higher and longer cutbanks on each side of the road.

Other through cuts are sometimes unintentionally developed when a road is constructed straight down a gentle ridge or hillslope to reach a lower level or the valley bottom. These through cut road segments are typically constructed to shorten the road from one point to another (a road down a gentle or moderate fall-line gradient slope is much shorter than constructing a broad switchback that traverses back and forth across the hillside to get to the lower elevation point). When a road is constructed straight down a gentle ridge or hillslope, a shallow through cut is naturally formed.

All through cuts behave similarly, with runoff flowing straight down the excavated roadbed. The key component is that there is an excavated cut on both sides of the roadbed and road surface drainage is confined between the two cutbanks, either along the sides of the roadbed (usually ditches) or down the road surface itself where roads are flat in cross sectional shape. **Poor drainage is a characteristic of virtually all through cut roads and the longer the through cut, the greater will be the volume of water that collects within and concentrates along or on the road surface.**

Similarly, the steeper the grade of the through cut, the greater will be the erosive force of the water that is contained within it during runoff events. Long and/or steep through cut

road segments can produce extensive rills, road ruts or gullies on or alongside the road surface, and this concentrated runoff and eroded sediment is discharged off the road at the end of the through cut. In addition to their potential to impact water quality, through cut road segments are locations requiring high levels of road maintenance.

ii. Treatment Several treatments can be employed to reduce the impacts of through cut roads. These include:

- Relocate or realign the road segment on a sideslope so that it can be effectively drained along its length.
- For shallow through cuts, where one or both cutbanks are less than several feet high, it may be possible to refill the through cut and redevelop effective sidehill drainage.
- Surface (rock or pave) the road and ditches within the through cut to reduce erosion rates and lower long term maintenance requirements.
- Make sure the roadbed has a distinct road shape that drains the road to one or both sides (rather than down the center of the road).
- Construct (excavate) “cutouts” in the downslope road cut to regularly drain the through cut onto the adjacent, stable hillslope. These drainage cuts or lead-out ditches can be many 10s of feet long.
- Install rolling dips and/or ditch relief culverts with outlet energy dissipation (rock armor) both above and below the through cut road reach, to drain the road surface before and after the through cut.

Fall line roads that are aligned straight down a hillslope, even if the hillslope

gradient is relatively gentle, are almost impossible to effectively drain. Runoff water wants to run straight down the road surface, creating rills and small gullies. The eroded road surface is regraded each year, and then re-erodes every wet season. **It is a self-perpetuating cycle of erosion and grading that slowly and persistently deepens fall line through cuts over time.**

If an alternative alignment is not available, the most effective treatment for shallow through cuts includes road shaping to keep the runoff to the side(s) of the through cut roadbed, in concert with long “cutouts” or side drains that divert runoff onto the adjacent natural hillslope (Figures 54, 55). The deeper the through cut, the deeper and longer these cutout drains have to be excavated and the more difficult this treatment becomes.

e. Operations and treatments for unstable soils

Both soils and areas can be classified as “unstable.” Typically, unstable areas are characterized by unstable soils, but the presence of unstable soils may not yet have been expressed on the landscape as an unstable area. Unstable areas are perhaps most easily and frequently recognized by expressions on the hillslope (cracks, scarps, leaning trees, etc.), while the presence of unstable soils may be masked by a number of site factors (e.g., gentle slopes, binding roots, rocky abutments, etc.) that have prevented the development of indicators of slope instability.

Location and characteristics—*Unstable soils* have various definitions depending on the use to which they are likely to be subjected. Sometimes these soils show natural instability in the undisturbed setting. More often (e.g., on soils maps), they are classified as

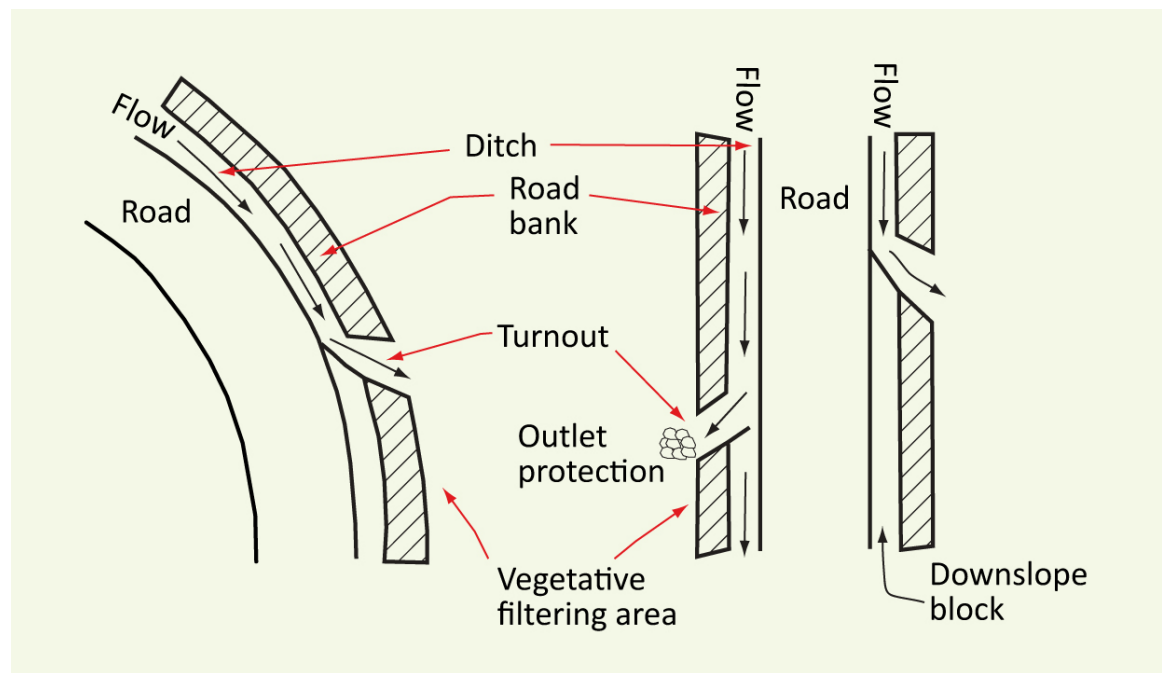


FIGURE 54. Typical locations for “turnouts” or lead-out ditches used to drain bermed or minor through cut road reaches. To be self-maintaining, lead out ditches must have a grade at least 2-3% steeper than the road surface or ditch that drains to them; otherwise they’ll plug with sediment deposits (U.S. EPA, 2000).



FIGURE 55. Steep roads that go straight up or down a hillside are very difficult to drain. This steep, fall line road developed a through cut cross section that was drained using lead out ditches to direct runoff off the road and onto the adjacent, vegetated hillside. The road was “outsloped” to drain runoff to the right side, and the lead out ditch was built slightly steeper than the road grade, to be self-cleaning. Four lead out ditches have been constructed at 100-foot intervals to the bottom of the hillside.

poor quality soils that become unstable when disturbed by construction (Figure 56). In the context of roads, unstable soils are less likely to support cutbanks without buttressing or special measures. Unstable soils are often characterized by weak, non-cohesive soils or colluvium containing sand, gravel, rock fragments or weathered granitics, as well as expansive clays.

Unstable areas are characterized by mass movement features, typically developed in areas of unstable soils. Unstable areas are often characterized by hummocky topography,

tension cracks and/or slope scarps, headwall and lateral scarps, and irregular bowl-shaped slopes suggesting previous slope failure. The hillslope may also exhibit indirect evidence (e.g., leaning trees) or contributing factors (very steep slopes) that can lead to slope instability. Many unstable areas are often found in combination with areas of emergent groundwater (springs and seeps) and zones of saturated soils that suggest impaired groundwater movement.

Water in and on hillslopes is usually

FIGURE 56. *This forest road was constructed through wet, unstable soils and subsequently experienced shallow slope failures and rapid erosion rates for a number of years following road building.*



a key contributing factor to the occurrence of slope instability and landslides.

Road construction and management activities that cause or increase slope instability in areas of unstable soil include undercutting (developing slope cuts), loading (including spoil disposal or sidecasting onto steep slopes), and the addition of water (road drainage diverted or discharged onto unstable or potentially unstable slopes). Roads intercept subsurface flow paths when they cut into the soil profile, with water either emerging from the cutbank (contributing to cutbank failures) or being blocked by overburden and uncompacted earthen materials disposed of where the road crosses (and fills) steep swales or where loose spoil is sidecast downslope off the road. Road building in wet areas may cause subsurface damming of groundwater that, in turn, contributes to fill slope failures and to larger debris slides and debris flows.

Avoidance—As with operations on or near wet areas, the first and best option is to locate the road to avoid sensitive areas such as headwalls, steep slopes (slopes >60%, especially those known to be prone to debris slides in nearby areas), and areas of known unstable soils and slope instabilities.

Road planning and road location are invaluable tools used to avoid unstable areas. Vulnerable slopes include those where roads cross geologically unstable or highly erodible materials, steep slopes or steep channels subject to debris flows, wet slopes, or areas subject to flooding. New roads should be planned to avoid these high hazard locations and unstable areas, such as slumps, landslides, debris flow tracks, earthflows and other instabilities, and to have a qualified geologist find another suitable alignment. Existing roads that cross this type of terrain will likely require high maintenance and be subject to regular and costly storm damage repairs.

Treatment—A variety of slope stabilization measures are available to solve road-related slope stability problems and to cross unstable areas. **In most cases, relatively gentle cut slopes, good compaction, minimal sidecasting and good surface and subsurface drainage will eliminate routine stability problems.**

General treatment strategies may be employed to minimize a road's impact on hillslope stability, but most problems are site specific and a qualified geologist or engineering geologist should be consulted for the best treatment design. The initial assessment and design of the road often requires continued professional observation and

guidance as the road construction, road upgrading or road decommissioning project progresses.

Roads built in steep and/or unstable areas should contour the landscape, minimizing cuts and fills, and be kept as narrow as possible.

Where possible, design minimum standard roads as outsloped with no ditch. Road runoff should be drained away from known unstable areas and unstable soils. Sidecasting should be avoided on steep slopes, and roads should be built using either full bench endhaul construction techniques, or benched construction to minimize sidecasting.

Roads themselves often develop cut slope or fill slope instabilities when constructed on steep slopes or through unstable soils. Minor cutbank instabilities can be treated using a variety of buttressing, drainage and revegetation measures. Unstable fill slope treatments can range from the direct excavation of unstable fill materials to more complicated, deep patch embankment repairs.

Because it may not be feasible to build, mitigate, or maintain a road where slopes are steep and the rock or soil material is weak, alternative road locations should be considered. Existing roads built on steep, unstable inner gorge or

streamside slopes should be considered for permanent decommissioning. Consult with a qualified geologist or engineering geologist to determine the best decommissioning design.

f. Operations and treatments for wet areas

Constructing, maintaining or decommissioning forest, ranch and rural roads becomes significantly more challenging when you operate on wet or unstable soils. If at all possible, wet areas, especially large wet areas, should be avoided when constructing or relocating low volume roads. Avoidance is always the preferred option. Road crossings in wet areas are problematic and undesirable, usually requiring special designs to remove water, stabilize the road surface and prevent road damage.

Not only are many wet areas ecologically valuable and should be avoided if at all possible, they are challenging places to build and maintain roads for logging, ranching or other operations where commercial traffic, heavy loads or high levels of vehicle traffic are common. Soils in these areas are often weak, quickly deteriorate under traffic, and require considerable subgrade reinforcement to guard against damage and deformation (Figure 57). Not all treatments



FIGURE 57. *This seasonal road was built on fine grained soils that exhibited poor drainage and high rates of soil erosion. Even minor traffic during the wet season caused damage to the roadbed and rapid erosion clogged and filled ditches, waterbars and rolling dips.*

are effective and road reaches built across wet areas generally require a long term commitment to continued maintenance and repair.

Location and characteristics—Wet areas may be wet because of long term snow cover, long rainy seasons, or because of emerging groundwater (springs and seeps). Slopes with abundant slope instabilities and high fractured geologies are locations where emerging groundwater is likely to be common. Wet areas are also prevalent in lower slope, riparian and valley bottom areas, where groundwater is near or at the soil surface and expressed as wetlands, marshy areas, or by the presence of water loving plants. Soil maps can be used to help identify the location of wet and poorly drained soils.

Road design and construction in areas of wet soils is typically more difficult and expensive than in dry soil conditions. The road may require intermittent or continuous subsurface drainage and thicker surfacing to support traffic without deterioration and rutting. Wet, fine grained soils are susceptible to deformation, rutting and erosion and have low shear strength. Expansive, clay rich soils are difficult to work and cannot be easily driven in wet conditions. Wet conditions on cutbanks and fill slopes are also likely to cause stability problems and high maintenance requirements, and make road construction and maintenance more expensive. Similarly, cut-and-fill road construction may bury springs and seeps; thereby causing elevated subsurface pore water pressures and triggering fill slope failures.

Avoidance—Road cuts and fills are highly susceptible to springs, seeps and saturated soil conditions. Roads should be located or realigned to avoid sensitive areas such as headwalls (steep bowl- or swale-shaped depressions near the headwaters of small watershed areas), wet areas and unstable soils. In addition to avoiding obvious obstacles, like rock outcrops and landslides, roads should be located to avoid riparian areas; saturated, unstable soils; expansive soils; wetlands;

bogs; marshes; springs; and other environmentally sensitive wet areas. These should be identified as control points along a road alignment that are mapped during field layout and avoided during construction. Roads should be located where road construction costs and stability can be achieved, and where the impact on streams, water quality and aquatic habitat can be kept to a minimum.

Treatments—If wet areas must be crossed and cannot be avoided, special drainage or construction methods should be used to reduce impacts from road construction and use. Localized wet zones usually require comparatively low gradient cut slopes of 2:1 or gentler to reduce the risk of failure. Experience shows that a stable wet slope angle may be roughly half the angle of the same stable dry slope. Low, gentle cut slopes will show less instability and lower erosion rates.

Simple slope buttressing can also be employed along the base of a wet, unstable cut slope (Figure 52), but unless it involves a mainline road, the more expensive engineering measures are rarely used on low volume forest, ranch and rural roads. Soil buttressing and armoring of small slumps, planting, and other simple erosion control techniques can be employed on cutbanks but instabilities will continue to occur until the slope has naturally stabilized. Maintenance of the cut and the ditch will be a continuing requirement for some time.

Subdrainage is used to carry subsurface or emergent subsurface water from the roadway. Seepage can occur along the cutbank, beneath the roadbed and/or beneath the road fill along the outside edge of the road. This can cause several problems if subsurface water is not drained from the road prism and construction area, including 1) excessively wet fills and subgrade materials, leading to road surface rutting or the need for large quantities of rock as base-course, 2) cutbank slumping, 3) mass wasting of the fill due to unrelieved pore water pressures, and 4) continual mud pumping at the road surface,

leading to failure of the surfacing and the need for regular re-surfacing, possibly with filter fabric.

Special subsurface drainage measures (subdrains) are not frequently used on forest and ranch roads, but it is important they be employed where needed. Some relatively simple subdrain techniques can be used to drain water before it adversely affects roadbed strength and integrity or causes slope stability problems (Figure 58). Ditches and French drains (sometimes called trench drains) excavated along the

inside edge of the road, at the base of the cutbank, are common methods of draining emergent, upslope groundwater before it can saturate roadbed materials. Horizontal drain pipes can be installed to drain water from within the cutbank, but this stabilization technique is expensive and not always effective.

If the roadbed crosses an intermittent or perennial spring, soils beneath the road surface may need extra drainage. For water which will emerge beneath the road, gravel drainage

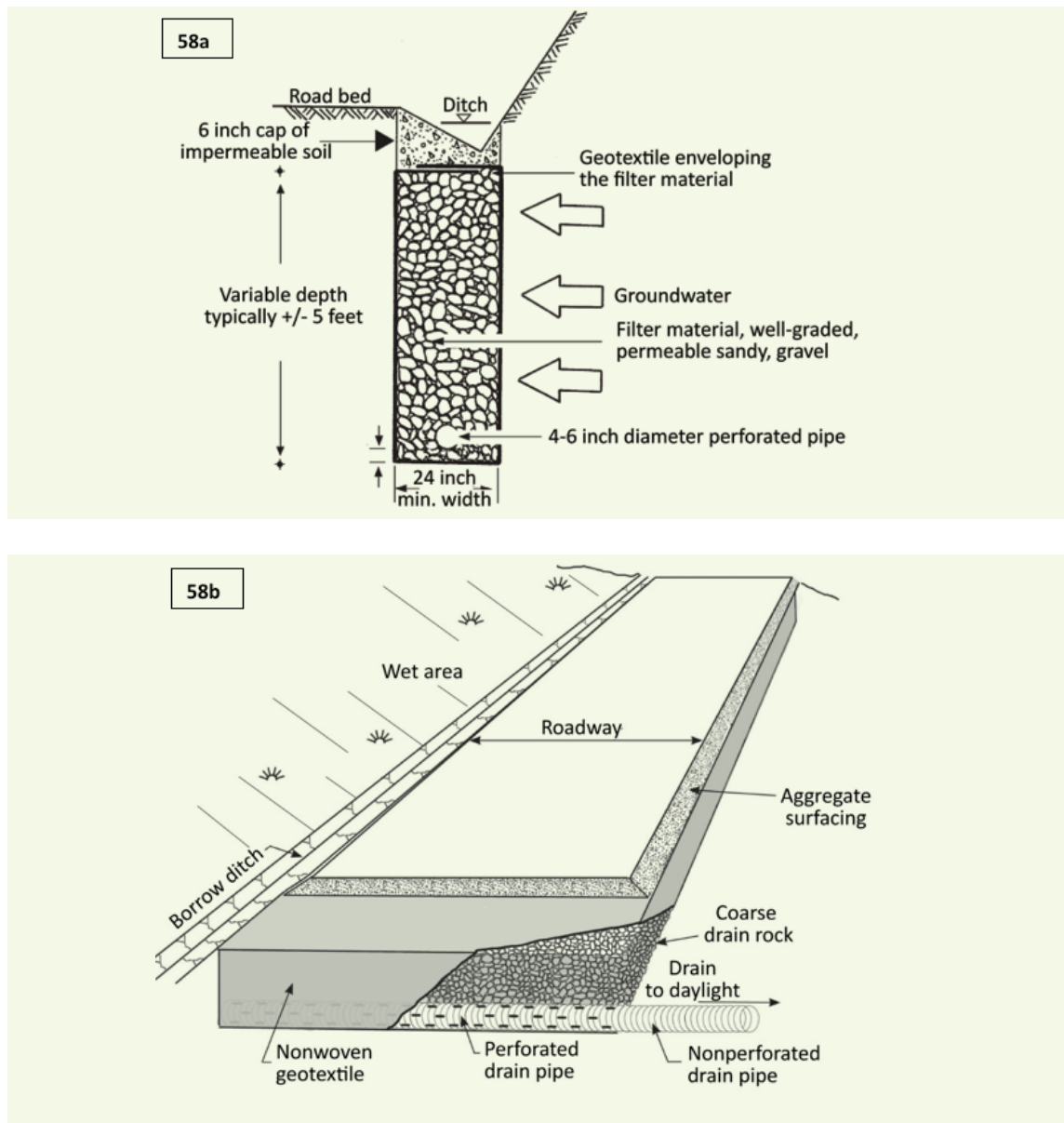


FIGURE 58.

Roads which are built across small springs, seeps or wet areas can be kept dry and stable by the use of subsurface drainage techniques. Vertical underdrains or French drains (a) and horizontal drainage blankets (b), using graded rock and synthetic fabrics (geotextiles), are two common methods for draining or dewatering wet subgrades (subsurface soil and rock materials) (Modified from: Keller et al., 2011).

blankets can be used to drain the water laterally to the toe of the fill slope (Figure 58a). Filter fabrics (geotextiles) are used to maintain separation between the native hillslope materials and the overlying base course or surface course materials (Figure 58b). Where fills are thin, and where surfacing is placed directly on native soils, geotextiles can also be used on the subgrade to maintain soil separation and prevent soil pumping into the surfacing materials.

5. MATERIALS AND MATERIAL SOURCES

a. Road rock and riprap

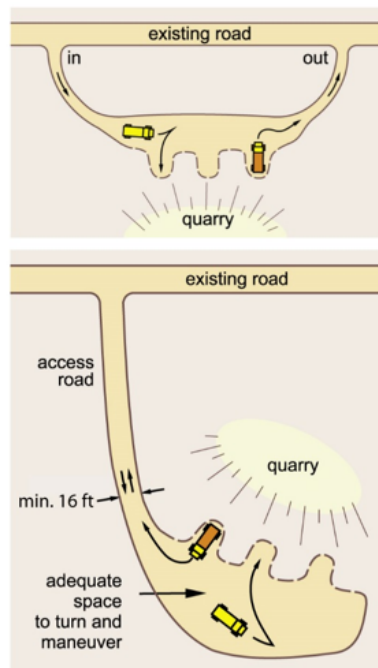
i. Rock quarries, rock pits and borrow sites Quarries, rock pits and borrow sites are developed to obtain rock for various uses on rural roads (Figure 59). A **quarry** is an open excavation site where stone, riprap, aggregate, and other construction materials are developed and extracted from a bedrock surface or rock outcrop. Rock material is usually developed by ripping or blasting and often needs to be processed by crushing, sorting or screening to produce the desired stone sizes for a

project. In a **rock pit or borrow site**, soil or rock is mechanically ripped or excavated to produce construction materials or fill for use on a project, such as rock from outcrops for armoring or road surfacing, aggregate from river deposits, or fill material from native soils. Screening and/or crushing may be required to produce the needed shapes and size grades.

Regulations—Local development, use and abandonment of quarries and rock pits/storage areas in California, and in many other states, normally follow regulatory requirements for forest management (e.g., California's Forest Practices Act and Rules) or mining. The rules for developing rock sources for forestry generally focus on maintaining stable slopes and protecting water quality. Where quarry operations involve relatively large areas or where commercial products will be sold for use off-property, more stringent surface mining regulations may apply. State and/or federal regulatory agencies usually oversee surface mining operations. For example, California's Surface Mining and Reclamation Act of 1975 (SMARA) provides a comprehensive surface mining and reclamation policy to minimize environmental impacts and to make sure mined lands are reclaimed to a usable condition (California Office of Mine Reclamation, 2013).

Anyone engaged in surface mining operations, including quarrying, borrow pitting or gravel skimming from river beds, is affected if the disturbed area exceeds one acre in size or the cumulative volume of material mined exceeds 1,000 cubic yards per location.⁴ Most other states have similar regulations.

FIGURE 59. Access roads are required in new quarry locations or borrow sites that allow for efficient transport into and out of the rock development area. Sufficient space must be provided for quarrying, processing, loading and transport. The drawing shows two possible quarry access routes that maximize efficiency (Johannessen, 2008).



4 In California the mining site is exempt from SMARA where the excavation is done exclusively for obtaining materials for use on timber harvest roads or in forest management activities on the property where forestry is occurring, and if the footprint of surface mining disturbance is further than 100 feet away from any Class I watercourse or 75 feet away from any Class II watercourse. If any part of the mining disturbance falls within the stipulated stream buffer, or any portion of the material produced at the site is used for commercial purposes, the mining activities are subject to SMARA. Mining for on-property forest operations is regulated by the California Forest Practice Act and Rules.

Naturally occurring asbestos, common in ultramafic rocks and soil throughout the U.S. and globally, can pose serious health risks when airborne and inhaled. In areas where naturally occurring asbestos is present, road construction activities, as well as the development of quarry, borrow, or rock pit locations can generate airborne dust that must be mitigated for air and water quality, and worker safety. Asbestos emissions are regulated by federal, state, and local laws for construction, earthwork, and mining. Contact your state air quality regulatory agency (e.g. California Air Resources Board; Oregon/Washington/Montana Air Quality Program) for regulatory compliance requirements.

Rock source development and management—

After the need is determined, and a possible rock source has been identified, projects are normally developed in four stages: reconnaissance, feasibility, design, and construction.

1. *Reconnaissance*—Initial exploration involves field reconnaissance using topographic maps, geologic maps and reports, and aerial photographs. Any projects that have previously used the rock source should be examined and evaluated in the field. You will need both an adequate quantity and quality of rock for your project!
2. *Feasibility*—Feasibility includes determining the size and physical character of the rock outcrops and rock materials, including general hardness and likely fragment sizes that could be made. Feasibility is analyzed to prepare preliminary designs and cost estimates for permitting, mining, processing and transportation, as well as other factors required for quarry or pit development.
3. *Design*—Rock pit or quarry design is needed to assure that the developed rock will meet your needs, including quantities, rock sizes, rock quality and expected waste. Field tests or service records of the same rock

used elsewhere may be used in conjunction with, or instead of, laboratory testing.

4. *Construction*—Investigations during actual excavation of the rock materials provide field and design personnel with detailed information for how to best develop the rock source.

The use of local rock sources, such as borrow pits and quarries, can produce major cost savings for a project compared to the cost of hauling materials from commercial sources or distant locations. However, the quarry or borrow pit material quality must be adequate for your needs.

ii. Evaluating rock quality **Use of local high quality materials, even in small amounts from a variety of sites, can be very desirable and cost-effective, but only if it performs well.** Poor quality materials will require more road maintenance and may break down quickly; eroding, polluting water sources, affecting air quality and requiring re-surfacing. Haul distance strongly affects the delivered cost of rock so it is best to use small, high quality local quarries or borrow pits whenever possible.

Rock quality can be determined or judged from both in-situ characteristics and conditions of the rock mass, as well as from field and laboratory tests of the actual rock material.

In-situ tests of rock suitability—

- Naturally durable rocks are often identified and defined on geologic maps. Most rocks that are durable and resistant will form prominent outcrops that stand above the surrounding landscape. These often include massive igneous, metamorphic and well cemented sandstone rock types. Clay rich siltstones, shales and other thin bedded sedimentary rocks, or rapidly weathering rock (e.g., deeply weathered, decomposed granitics) usually do not make good, durable rock.

- Past performance is a good indicator of rock quality. **Nearby or similar rock that has been quarried and used in the field for an extended period of time can provide an excellent measure of future rock performance on a newly opened quarry or pit.** This may be a better indicator of future rock performance than many field and laboratory tests, although both measures are preferred.
- **Simple field tests can be used to gauge basic rock strength and suitability.** For example, sandstones can be examined using a hand lens to see if the grains are hard and shiny or dull and soft. Finally, a rock hammer is a good tool for field testing. If you break off a piece of rock, and the break actually fractures the cement and mineral grains, then it is well cemented and likely to be durable. **The hardest and most durable rock will have a distinctive “ring” when struck with a hammer and the hammer will quickly rebound.** Rocks that give a lower pitch “thud” rather than a higher pitch ring will likely be softer and less durable. These are qualitative indicators, so it is useful to try this on rocks of known durability so you can gauge the relative responses.
- Rock particle sizes needed for your project (e.g., road rock versus riprap) must also be readily available, or easily produced, from the pit or outcrop without excessive effort or development of large volumes of waste material.

Laboratory tests of rock suitability—

Laboratory tests or field results can be used to quantitatively determine rock quality, and to predict a rock material’s suitability for use as a base course or surfacing material. Laboratory tests center around those designed to determine resistance to abrasion, freeze-thaw cycles, and strength in relation to durability. However, laboratory tests for forest, ranch

and rural road applications are costly and not frequently used in these applications.

If laboratory testing is to be employed, the most marginal quality rock should receive the greatest number of tests. **The ultimate goal of all testing is to accurately predict durability and prevent erosion hazards. That’s why performance in the field under actual conditions and for extended periods may provide a more accurate picture of rock suitability than field or laboratory tests that are designed to predict performance.** Qualified geologists and engineering geologists can provide guidance on the suitability of rock aggregate for various road uses, and local road managers and maintenance crews often have excellent knowledge of the suitability of local aggregates.

iii. Rock development and production Rock is most frequently developed from a quarry or pit by blasting, or ripping and excavating.

Blasting—Production methods that include drilling, blasting, hammering, ripping, excavating, processing, and hauling play an important role in the sizes of rock that can be obtained. When blasting solid, unfractured bedrock, make sure to obtain any required permits and employ only qualified, trained and licensed experts. Rock quarried from blasting is often the best material available and is not severely fractured or weathered, but it is likely to require further processing and sorting before it can be used.

Ripping and excavating—Where bedrock outcrops contain sufficient natural fractures, you can usually excavate rock materials by ripping or hammering instead of blasting. **Hydraulic rippers mounted on larger crawler tractors, or hydraulic hammers on excavators, are frequently used to generate rock from fractured bedrock outcrops.** In-channel gravel deposits or river terrace deposits are often used as material sources for fill and road

surfacing. They are produced by direct excavation of gravels using heavy equipment. The river rock is often screened and crushed to develop more angular material from the largest rounded rock particles. **Ideally, unless these gravel sources are permitted, deposits in or near streams or rivers should not be used. Instead, geologic river terrace deposits are often used to produce river-run gravels for road surfacing and other road-related uses, and they are often located farther away from active river channels.**

iv. Rock waste It is important to estimate and plan for the amount of waste that can be expected from rock production, whether by blasting, or ripping and excavation. Waste material from quarrying and borrow operations should be endhauled and placed at an approved, stable location where it will not enter a watercourse or adversely affect the environment (Figure 60). Simple sidecasting of waste debris at the excavation site is generally not acceptable. A qualified geologist may be required

to identify appropriate spoil disposal sites and to evaluate sites for stability before they are developed or used. The waste debris and original groundcover soils should be recycled and reused during reclamation of the rock pit or quarry.

v. Rock riprap Riprap, used along roads and where roads cross streams, most commonly consists of an arrangement of large rocks, typically graded with smaller rocks filling in the voids. Riprap is generally used to protect a slope from erosion. Sometimes referred to as rock slope protection (RSP), it works by absorbing and deflecting the energy of flowing water and is installed for energy dissipation and for preventing erosion along shorelines, streambeds, bridge abutments, stream crossings and at culvert inlets and outlets. It is employed in various sizes for these project types, and is designed to resist the forces it is expected to encounter. In forest, ranch and rural road applications, riprap is often “field designed” by experienced personnel, but consulting with a qualified engineer or engineering geologist will take the guess work out of



FIGURE 60. *This rock pit is easily worked by an excavator, but the material contains abundant fine grained particles. Here, a Grizzly rock screen is used to separate high quality rock armor from fine grained waste materials. As in this photo, waste materials should be endhauled to a stable spoil disposal site rather than sidecasting onto steep, unstable or streamside slopes.*

the design, ensure the rock sizes are appropriate for the intended purpose, and likely save time and money. Large rock is also designed and used to buttress potentially unstable fill slopes or cut slopes against failure and, because of the large earth forces involved, these designs are also best developed by a qualified professional.

Rock for riprap should be hard, dense, durable, and resistant to abrasion, displacement by flowing water or exposure to various environmental conditions. Like other rock products, the best tests of rock suitability are those in which the rock materials have been successfully in use for long time periods in similar conditions. Riprap stones should not be thin and platy, nor should they be long and needle-like. “Angularity” is often used as a qualitative descriptor of shape, because it improves the ability of rock armor particles to “lock together” and be stable on a slope.

vi. Road rock (base-course and surfacing) The pavement of a forest, ranch or rural road is a structural system comprised of a surface course and a base course, all overlying the prepared subgrade (native) soil. Ideal aggregate has hard, dense angular fragments with at least 3 sharp edges, but not sharp enough to puncture vehicle tires. It is well graded (contains a variety of particle sizes) with a compact, blocky (not elongated or platy) shape.

Road surfacing rock must be hard enough (not brittle and not soft) to withstand vehicle tire pressure without fracturing and with minimal wear under repeated tire loads. The aggregate should also contain sufficient fines to fill voids and allow for good compaction. River gravel, sometimes known as “river-run,” is often too rounded to compact adequately. It can be crushed to improve the angularity of the largest particles but still contains mostly rounded particles and is less suitable.

Durable aggregate road surfacing must be used for active roads and road segments that drain to streams so as to minimize erosion, fine sediment production and transport, and turbidity (muddy water).

Marginal, lower durability aggregate that will break down and erode should not be used as a surface course, especially on high traffic roads and on road segments that drain to streams.

While surfacing can double the cost of a road (Table 22), the rock or gravel cover provides a stable surface that can be used to extend the operating season while limiting damage to water quality. For rural residential roads, a good rock surfacing is required for all-season traffic. However, if water is reaching the roadbed from subsurface flow beneath the road fill (rather than from rainfall), measures in addition to surface rocking will likely be required to maintain surface stability and control erosion.

TABLE 22. Estimated cost distribution for constructing a typical low volume road¹

Construction phase	Average cost (%)
Equipment and material	10%
Clearing grubbing, slash disposal	20–25%
Excavation	20–25%
Culverts	10%
Rock surfacing	30–40%

¹USDA - SCS/USFS (1981)

vii. Reclamation (rehabilitation) of quarry and borrow sites Reclamation is the process by which adverse impacts of mining are minimized so that mined lands can be used for a beneficial land use after they are closed and reclaimed. Some key components of reclamation include slope stabilization, erosion control, flood and drainage control, avoidance or mitigation of impacts to sensitive species and habitats, minimizing water and air degradation, revegetation and safety. The reclamation process may extend to affected lands surrounding mined lands, and may require backfilling, grading, re-soiling, soil compaction, stabilization, drainage control, erosion control, revegetation, or other measures.

Reclamation consists of activities and treatments that reclaim, repair, or improve part or all of an existing road, borrow pit, quarry or disturbed area and restore it to its original or some desired final condition. Site reclamation is typically needed after materials extraction, and regulations usually dictate how reclamation is conducted and the final configuration and restoration of the site. Reclamation work on larger sites may be dictated by regulation (e.g., SMARA) and should always be defined in a *Reclamation Plan*. Small pits and quarries may not need a plan but will still benefit from certain restoration practices that ensure it will not adversely affect the environment.

Reclamation usually consists of discrete steps, starting with salvage and stockpiling topsoil from the initial site clearing work. Unused top soil and subsequent waste products from rock development can be stockpiled or temporarily stored so they can be used to fill and reshape the final pit or quarry site. The recontoured site is designed with either a dispersed internal drainage system or external drainage that prevents eroded sediment from discharging to nearby streams or lakes. Once the final topography has been achieved, the site is capped with salvaged or imported topsoil, treated with temporary and permanent

erosion control measures including seeding and replanting, and required safety measures (e.g., restoring the site to minimize danger from overhangs, loose rock and waste material heaps; installing gates, barriers, signs, etc.).

b. Geotextiles

Geotextiles are synthetic, permeable fabrics which are used to separate, filter, reinforce, protect, and/or drain rock, soil and other related materials. They are usually made from synthetic polymers which do not decay under biological or chemical processes. This makes them useful in road construction and maintenance.

Geotextile fabrics come in three basic forms: woven, needle punched (felt-like), or heat bonded (ironed felt). Woven geotextile is a sheet made of two sets of parallel strands interlaced to form a thin, flat fabric. Non-woven geotextile fabric is more likely to stretch than woven geotextile and has the increased ability to let water flow through or along the plane of the geotextile. **For general road applications, the two most important geotextile specifications are permeability and strength.** Woven fabrics have a high tensile strength, but they have a lower abrasion resistance, less permeability and lower frictional resistance than non-woven fabrics. **In contrast, nonwoven fabrics offer superior resistance to abrasion damage and provide excellent characteristics for soil separation, as well as filtration and drainage.**

Geotextile variants include geosynthetics and geomembranes. Geosynthetic composites such as geogrids, mats, webs, nets, meshes or formed plastic sheets have been developed primarily for structural reinforcement and/or to contain particles. A geogrid is a non-woven geosynthetic with large holes on a rectangular layout used to constrain internal particle movement and consequent rutting, while stiffening the soil mass over its complete depth

so as to improve (spread) the load distribution from vehicles. A geomembrane is a continuous membrane-type liner or barrier that acts as a complete moisture barrier, but allows lateral transmission of water within the membrane so that it can be transmitted away from the site.

i. Geotextiles for common road applications Geotextiles and geosynthetics have a number of applications in the forest, ranch and rural road setting. For example, geotextiles keep the layers of subgrade and base materials separate and manage water movement through or off the roadbed (Figure 61). Other uses include:

- drainage and filtration, including trenched or French drains;
- underdrains and filter blankets, to capture spring and seepage flow beneath a road;
- subgrade reinforcement, to provide additional tensile and compressive strength;
- subgrade or base containment, to resist lateral displacement of surfacing materials;
- structure reinforcement, to provide lateral tensile strength to soils;
- in retaining walls and reinforced soil walls, to provide lateral strength to emplaced and engineered fills; and
- erosion control, including sediment traps (silt fences, silt curtains, etc.), riprap bank protection, diversion ditches, and slope protection.

Manufacturers of these products will usually provide expert professional advice on the proper use and installation of their products and this advice should be sought.

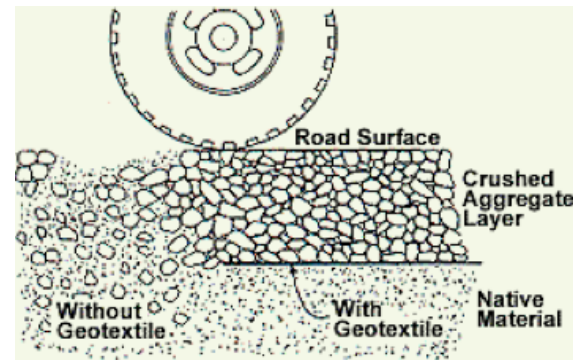


FIGURE 61. Geotextile in separation application (Wiest, 1998).

In forest, ranch and rural road systems, geotextiles have four basic functions (Figure 62):

- *Separation* is the main benefit of stabilization work with geotextiles. Inserting a properly designed geotextile will keep layers of different sized particles separated from one another, thereby preventing intermixing of the two soils and preventing fine subgrade soils from pumping up into and contaminating the overlying, clean base rock.
- *Filtration* is the process of allowing water to pass through the fabric while preventing soil migration. Water can be transmitted either downward (drainage) through the geotextile into the subsoil, or laterally (transmission) within the geotextile.
- In *reinforcement*, a geotextile can actually strengthen earth materials. Under load, non-woven fabric typically exhibits high tensile strength and broadens (spreads out) subgrade loads.
- Geotextiles can also provide aggregate *confinement* above the fabric (keeping road rock in place) and good frictional resistance (so aggregate won't slide off the fabric). Geotextiles with superior frictional characteristics, such as needle punched unwoven fabrics, aid in "locking" the aggregate in place.

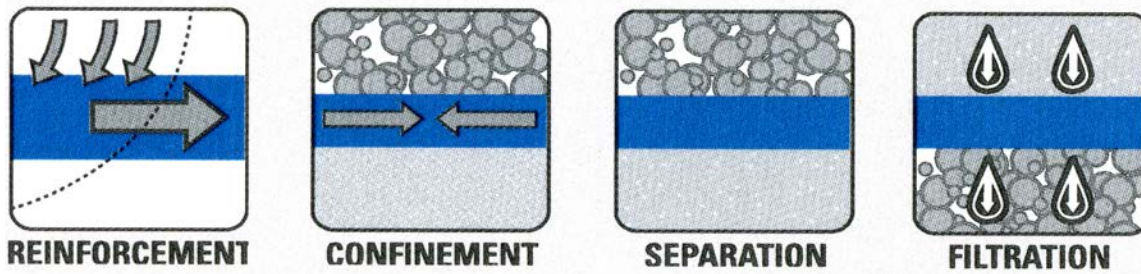


FIGURE 62. Four basic functions of geotextiles (TenCate Geosynthetics).

Where aggregate is unlikely to remain in place even under normal traffic (e.g., on a steep road grade, within a ford, or where you have rounded “river-run” aggregate) a geomatrix or geogrid can be used to physically contain soil materials (containment), add tensile strength and prevent lateral movement of the aggregate. However, these specialized geosynthetics do not have the ability to separate materials or to provide filtration.

When using geotextiles, you can often reduce the thickness of required road aggregate by up to 30% because of its strengthening properties. This is important

and can save money if you don’t have a nearby or affordable source of high quality road rock.

ii. Geotextiles for erosion control Geotextiles can be used in many ways for erosion control. One of these is with riprap along stream banks, lake shores, and other bodies of water to keep finer soils beneath the riprap from eroding (Figure 63). Geotextiles are also employed in protecting the sloped banks of diversion ditches, and in controlling surface erosion (erosion control blankets) or retaining eroded sediment in the project area (e.g., silt fences). Geotextiles recommended for erosion control should have permeability, resistance to abrasion, and high resistance

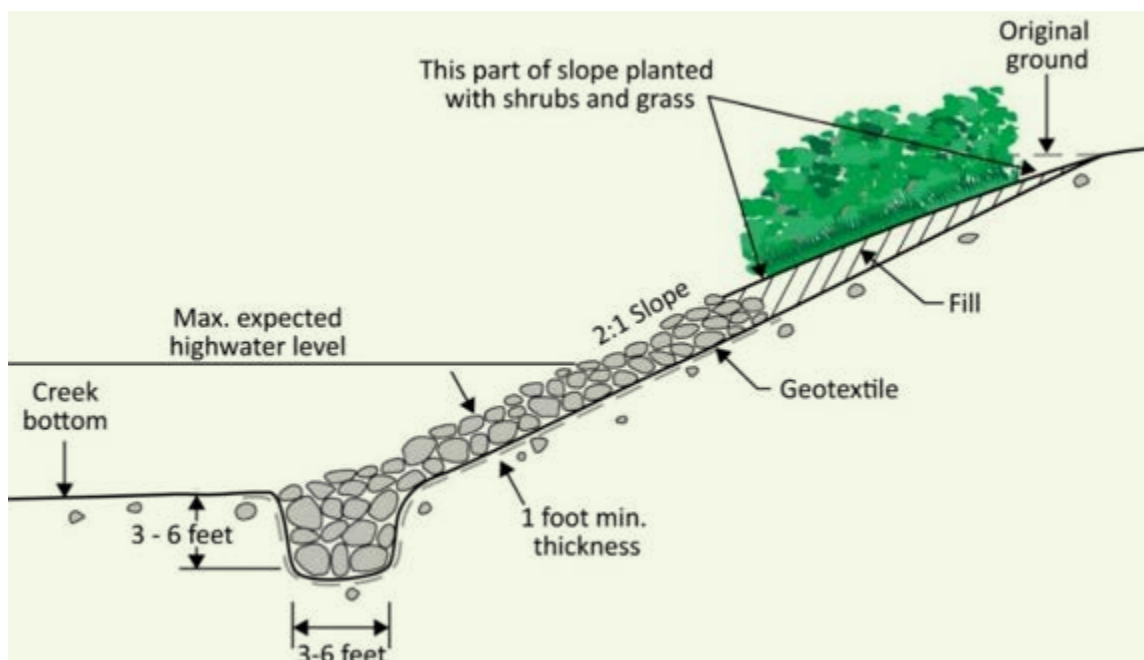


FIGURE 63. Geotextile used beneath riprap for erosion control, filtration and material separation. Whether in a streamside, lakeside or slope buttressing application, the permeable fabric protects fine grained soils beneath the armor from erosion and sapping, and allows soil water to filter through the fabric and into the armored area without increasing pore water pressures (Modified from: USDA—NRCS, 2007).

to ultraviolet rays as primary considerations. Erosion control covers a variety of conditions from high velocity stream flow to heavy wave action, to less severe conditions.

C. STREAM CROSSING DESIGN

Where a road crosses a natural watercourse, provision must be made to carry the water under or across the road. The selection of the best and most appropriate stream crossing design depends on a number of factors, and a poor design choice can result in a costly installation that is subject to failure and significant environmental damage.

Streams can be crossed with bridges (including arches) or culverts (flow beneath the roadbed), or armored fills or fords (where streamflow travels over the road surface). Culverts are the most common stream crossing structure and bridges and arches are best for large streams or where migratory fish are present. Fords work well on small to medium sized streams where there is a stable stream bottom, vehicle traffic is light, and fish passage is not required, but their use can cause persistent downstream turbidity and fine sediment pollution. Armored fills, where the stream flows over the top of the fill and down the protected outside fill face, are employed on relatively small, non-fish bearing streams that flow only occasionally during the wet season. Because they cannot plug with debris, they are used in places where winter or wet season maintenance is difficult or impossible.

1. LEGAL REQUIREMENTS

All private landowners constructing temporary or permanent stream crossings need to obtain proper permits and follow applicable laws and regulations of state and federal agencies. Prior to conducting road building or timber operations, or to modifying the bed or banks of a stream channel for any purpose,

it is important to determine the legal requirements of your work (see Chapter 1, Section I).

All states and countries have regulatory requirements regarding working in or around streams and lakes, and most have standards and/or suggested best management practices (BMP) for stream crossing installations and for road building operations in these areas. These often include culvert sizing requirements, requirements for removal of temporary stream crossings, limits on equipment operations near stream channels, road construction standards, and a variety of other road building and erosion control requirements (e.g., see Appendix B).⁵ You will need to check with regulatory agencies to determine the requirements in your area before undertaking similar project work. Such regulations always have the same broad goals: provide for sustainable forest or land use operations while providing maximum feasible protection to the environment.

It will be less expensive and certainly more effective to learn what best management practices (BMPs) are applicable and required in your area before planning, designing and conducting a road construction, road upgrading or decommissioning project that involves stream crossings. Thus, in California most federal and state water pollution regulations are administered and enforced by the California State Water Resources Control Board, through their Regional Water Quality Control Boards. A wrong choice in stream crossing method can result in major damage to both the immediate site and to downstream water quality. There are strict legal requirements for protecting water quality. **Stop-work orders, clean up and abatement orders, and heavy penalties for pollution can delay or terminate your project and be very expensive. Do it right the first time!**

⁵ Information on the complete Forest Practice Act and Rules in California can be obtained from Ranger Unit offices of the California Department of Forestry and Fire Protection.

No matter where you are located, ask your local regulatory agencies for assistance in determining what permits you may need and what practices are required before initiating a proposed project. In California, ask your local California Department of Fish and Wildlife biologist, a forester from the California Department of Forestry and Fire Protection, a geologist with the California Geological Survey, your Regional Water Quality Control Board inspector or a Resource Conservation District (RCD) specialist for assistance and information about requirements for your project. **Prevention is always the best course of action in conducting progressive land stewardship and resource conservation.**

2. STREAM CROSSING DESIGN AND REDESIGN CONSIDERATIONS

Classifying the stream (e.g., California Class I, II, III or IV watercourses) and the road (temporary, seasonal or permanent all-weather) is the first step in defining the type of stream crossing to be installed. **Stream crossings should be designed (or redesigned) for adequate fish passage (even where fish could be seasonally present), minimum impact on water quality, and to handle peak runoff and flood waters.** Fish passage is now expected and required in most areas of the country, and you must consider and provide for passage requirements for all life stages of migratory and resident fish encountering the crossing site. Stream crossings can be classified as either “permanent”⁶ or “temporary.”

⁶ There is really no such thing as a “permanent” culverted stream crossing. Culverts are subject to a variety of processes which guarantee their eventual failure unless they receive regular, periodic and storm maintenance, and they are replaced and rebuilt at the end of their normal life span. Metal culvert pipes have a limited life span and will eventually wear down and fail. In addition, since culverts are designed to pass a “design flood,” a larger flood may eventually occur which exceeds culvert capacity and washes out the stream crossing.

There are three basic subcategories of both permanent and temporary stream crossings: 1) bridges and arches, 2) fords and armored fills, and 3) culverts. Culverts include not only the traditional corrugated metal pipe (CMP), but also includes plastic HDPE pipes, concrete culverts, log/culvert temporary crossings, and other temporary structures that pass stream-flow through or beneath the road fill.

The type of crossing facility selected will depend on a number of factors. Each of these elements should be considered before selecting the final design or location for the stream crossing installation. Design considerations include:

- whether fish, amphibians or other wildlife of any life stage use the channel as a migration route at the crossing site,
- whether the crossing will be temporary (used for only a single entry) or permanent (to be used for more than a single season or a number of years),
- the types of vehicles that will use the crossing,
- the slope, configuration and stability of the natural hillslopes on either side of the channel (soil foundation conditions),
- the slope of the channel bed,
- the orientation of the stream relative to the proposed road,
- the expected 100-year flood (peak) discharge (i.e., stream size),
- the amount and type of sediment and woody debris that is in transport within the channel during flood conditions,
- the installation and subsequent maintenance costs for the crossing,

- the expected frequency of use, and
- limitations and designs imposed by permits and other legal requirements.

These and other site-specific factors play a role in determining the best crossing location and most suitable type of stream crossing to be used.

As recently as the 1960s and 1970s, culvert sizing and simple stream crossing design on low volume roads was often done by subjective methods, using the best knowledge and experience available from the crews actually performing the work. This was most common on non-public forest and ranch roads where public safety was less of a concern. For public roads it was once standard practice that when a stream crossing failed and washed out during a large flood event, federal emergency monies would be made available to reconstruct the crossing or failure. Unfortunately, reconstruction was required to be to the same standards as existed in the original facility,

thereby “reloading” the gun for the next storm of equal or greater magnitude. This has largely been corrected so new installations can be designed to current standards, making future failures less likely to occur.

a. Reducing stream crossing vulnerability

Culverted stream crossings are naturally susceptible to failure. That is why it is somewhat of a misnomer to call culverted stream crossings “permanent.” In reality, a fill crossing is really an earthen dam, placed across a stream channel, that has a small hole (culvert) in the bottom. If the culvert is too small, or if it gets plugged with sediment, vegetation or wood, the “dam” (stream crossing fill) may be overtopped and wash out. **That’s why culverted stream crossings need to be properly designed, constructed and maintained to prevent loss of the fill and discharge of large volumes of eroded soil into the stream.**

FIGURE 64. *Eroding stream crossing after a single storm on an unmaintained road. The culvert plugged and flood flow overtopped the fill, initiating a head-cut. In addition to being undersized, the culvert was installed at a flat gradient that is more prone to inlet plugging with debris. If left uncorrected, the crossing fill would continue to erode and deliver the eroded sediment downstream.*



Washed-out stream crossings are a common occurrence on abandoned, poorly maintained and/or improperly designed forest, ranch and rural roads (Figure 64). However, culvert plugging can result in much more damage than a washed-out stream crossing fill. If flow from a plugged culvert is diverted down the adjacent road (instead of flowing over the fill and immediately back into the stream channel), the diverted streamflow can create large gully systems, cause natural stream channels receiving the diverted flow to greatly enlarge, or trigger landslides as it flows over nearby unprotected hillslopes.

Stream crossings with a diversion potential (DP) occur wherever the road climbs through the crossing site and one approach slopes away from the stream crossing (Figure 65). If the culvert plugs, the backed up flood waters will be diverted down the road alignment (Figures 66a, 66b). If the crossing has no DP, backed up flood waters will flow onto the road surface, over the low point in the fill and back into the natural channel (Figure 67).

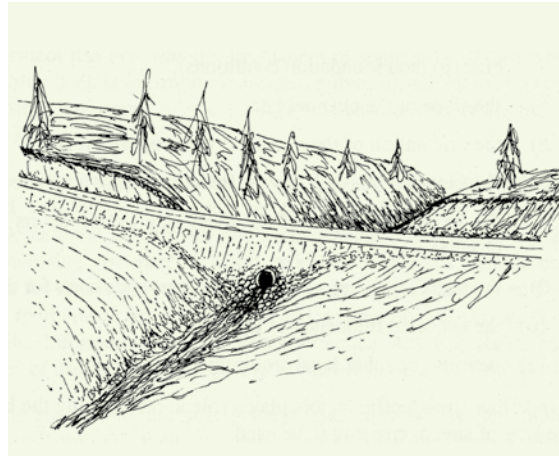


FIGURE 65. Stream crossing with diversion potential. Stream-flow would be diverted down the road toward the right side of the picture if the culvert inlet plugged and streamflow reached the road surface.

The fill may be partially eroded or completely washed-out, but streamflow is not diverted out of the channel and onto adjacent, unprotected roads and slopes. **Flood research in mountainous areas of the western USA has shown that, on average, stream diversions cause from 2 to 10 times the volume of erosion and downstream sediment delivery (through gullying and landsliding) compared to simply eroding and washing out a stream crossing fill.**

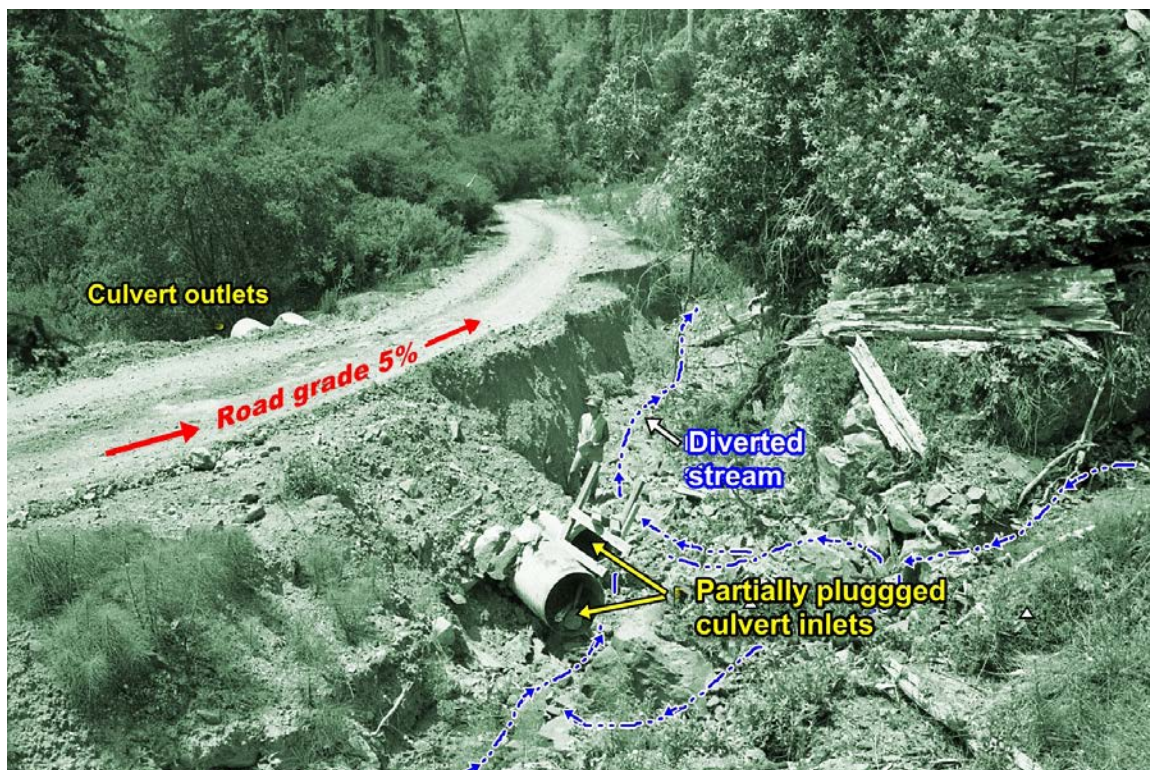


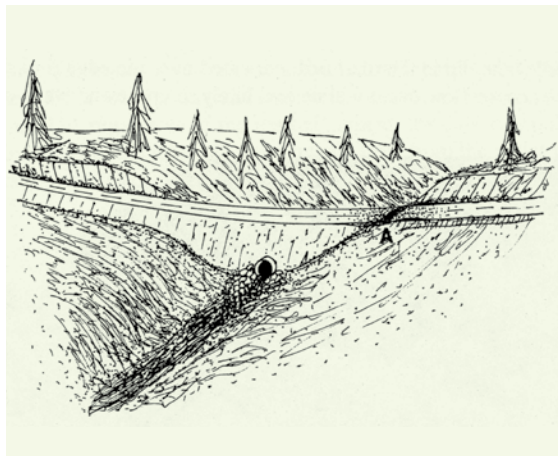
FIGURE 66A. Double culvert stream crossing showing the result of a stream diversion that occurred during a winter storm. The road slopes to the distance at about 5 percent. When the culverts plugged with debris, streamflow diverted down the inboard ditch and created the large diversion gully. Note the person for scale.

FIGURE 66B.

This large hill-slope gully was created during a single storm event when a culvert plugged and a stream diverted at a stream crossing located 400 feet up the road to the left of the vehicle. The eroded sediment from this gully was delivered to the same stream channel downslope.

**FIGURE 67.**

Stream crossing with no diversion potential. If the crossing was overtopped, flood flow would reach the road surface and flow back into the channel at location “A,” where the road changes grade. This is called the hinge line of the fill, where the crossing fill intersects the natural slope.



i. Reducing the risk of stream crossing failure and stream diversion

Stream crossings fail by one of two mechanisms: 1) they partially or completely erode or gully (washout) when they are overtopped by floodwaters, or 2) floodwaters are diverted down the adjacent road alignment instead of flowing over the road and washing out the crossing fill. Either way, significant environmental damage can occur when flood flows exceed the ability of a stream crossing

drainage structure to pass the required design streamflow and material in transport.

Although bridges and arches may be locally undersized and prone to failure, culverted stream crossings are the most common, and most susceptible, type of stream crossing likely to fail during flood events. Most of these failures result from culvert plugging, and the subsequent ponding of flood flows behind the stream crossing fill.

Reducing the risk of culvert and stream crossing failure—In-channel and drainage structure treatments can be applied to existing culverted stream crossings to reduce the chance that a culvert will become plugged, with subsequent flood flows overtopping or diverting down the road. They are aimed at reducing the likelihood of culvert plugging rather than physically preventing a subsequent stream diversion, but both techniques reduce the vulnerability of a stream crossing to failure and to possible stream diversion. These measures are often

employed on steep road grades where it may not be physically possible to dip the road or construct a critical dip on the road surface to prevent stream diversion (e.g., see [Figure 68](#)), but they are appropriate as preventive measures on most culverted stream crossings.

The most common measures used to reduce the risk of culvert and stream crossing failure include:

- upsizing the stream crossing culvert beyond the 100-year flood design diameter (e.g., by one or two sizes) so that floating woody debris is less likely to plug the inlet;
- installing debris barriers (also called trash racks) to capture floating woody debris slightly upstream of the culvert inlet before it can plug the culvert;
- installing wing walls and/or a flared culvert inlet to either direct wood and sediment more easily through the

culvert inlet or to cause it to be trapped above or before reaching the inlet;

- installing an emergency overflow culvert higher in the fill (above the main culvert) as a “relief valve” in case the main culvert becomes plugged; and/or
- removing the road fill and replacing the culverted stream crossing with a bridge.

Reducing the risk of stream diversion—

Reducing the risk of culvert failure is not enough, as there are times when culvert failure will occur despite the best design. **Except where physically impossible or where not compatible with existing traffic types, all new and reconstructed (upgraded) stream crossings should be designed and built to prevent the diversion of flood flows if (when) the culvert becomes plugged.**

If the designs and treatments are done correctly (i.e., they can accommodate the 100-year peak flow), these preventive treatments can



FIGURE 68.

Culverted stream crossing with a diversion potential. If this culvert inlet plugs with sediment or floating debris during a flood event, streamflow will be diverted down the road into the distance. Because the culvert is close to the road surface in this shallow fill, a critical dip could be installed immediately to the right of the fill, to direct flood flow back into the channel.

completely eliminate the risk of future stream diversions, and their erosional consequences.

With new construction, the most effective road prism design is to dip the road into and back out of the stream channel (a dipped crossing), so that when the culvert plugs flood flow will spill over the low point in the fill and back into the natural stream channel. The erosion prevention treatments for road upgrading are similar to those for new construction; either physically lower the existing fill over crossing or construct a deep, broad rolling dip to prevent flood flow from ever diverting down the road (Figure 69). Where the stream channel is not incised into the landscape (i.e., it can't be dipped) or the culvert has a thin overlying fill and is too close to the road surface, the new road can be constructed, or the existing road can be reconstructed, with a broad, deep rolling dip on the down-road side of the crossing (over the fill's hinge line) to direct flood flows over the fill and back into the channel (Figure 67).

This dip in the road is called a “critical dip” because of its critical importance in protecting the watershed and its streams from storm impacts. Although somewhat like a rolling dip, it has to be designed to have sufficient capacity (width and depth) to carry flood flows from the stream without itself overtopping and diverting down the road. Stream crossings with no diversion potential are said to be designed as “diversion-safe” because a dip in the road fill, or a critical dip in the road grade, prevents flood flows from ever flowing down the adjacent road to do damage elsewhere. The placement of this dip on the fill's down-road hinge line also minimizes the volume of erosion that is likely to occur when and if the fill is overtopped.

Preventing future stream diversions is one of the most important and cost effective measures that can be applied to the existing road network to protect downstream water quality and aquatic habitat from catastrophic damage. The steeper the hillslopes, the more erodible the soils, and the larger the diverted streams, the greater will be the potential for

FIGURE 69. A gradually climbing road changes grade over the small stream crossing, thereby eliminating the possibility for future stream diversion. The dip is broad and gentle to accommodate all traffic, and designed to carry peak flood flows across the road and back into the channel with minimal erosion and sediment delivery.



significant erosion and downstream impacts from a diversion. However, even small streams, when diverted onto steep, unstable hillslopes, can cause large debris slides and debris flows that can severely impact rivers and streams in downslope areas far removed from the actual diversion site. In some locations (such as valley bottoms and low gradient basal slopes) culvert plugging and stream diversion is less likely to cause significant erosion or water quality impacts. Some judgment is required to correctly identify these low threat settings.

ii. Reducing the magnitude of stream crossing failures When a stream crossing culvert plugs, and flood waters overtop the stream crossing fill, the road prism and fill will begin to gully as the streamflow cascades back down the outside fill face. The magnitude of stream crossing erosion (partial or complete washout) depends on the volume, velocity and duration of the overflow event, as well as the erodibility of the fill materials.

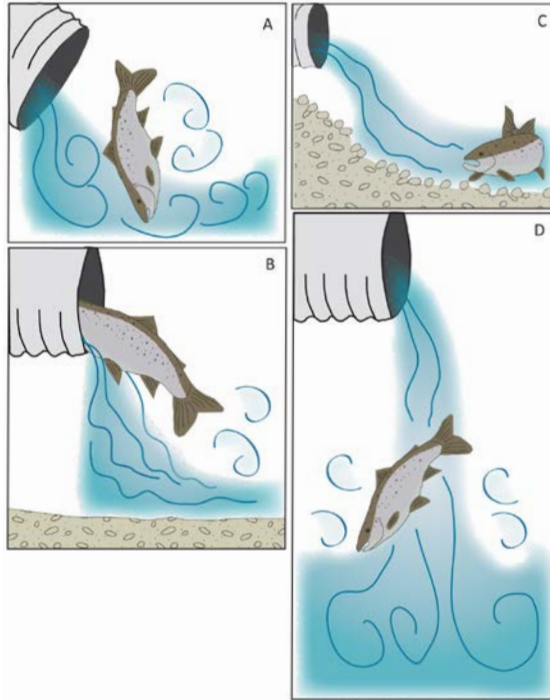
Three basic treatments can be designed into a stream crossing to minimize the magnitude of the erosion that will occur during an overflow event.

1. *Minimizing erodible fill volume:* **Minimizing the erodible fill volume is done by dipping the road grade into and out of the stream crossing, rather than having the road run at a smooth, even grade across the crossing fill.** For shallow fills (e.g., [Figure 69](#)), or for steep road grades which cross a fill (e.g., [Figure 68](#)), you might be able to dip the road only a small amount. For deep stream crossing fills with gentle road approaches, the amount of the dip that can be constructed (excavated) is controlled by the steepness of the resulting road grade on each approach. Deeply dipped stream crossing fills means there is less fill to erode in an overtopping event and guarantees that the stream will not be diverted down the adjacent road when overtopping occurs.
2. *Minimizing overtopping erosion rates:* **To minimize the amount of erosion that would occur in an overtopping flood event, and to minimize damage to the crossing, flood overflow can be intentionally directed to a hardened or more resistant location on the fill.** By locating the axis of the deep road dip, or the critical dip for shallow fills, on the down-road hinge line of the crossing fill, only a small amount of fill will erode until denser native soils or bedrock is encountered. This will minimize the rate and volume of erosion created by the overtopping event. If the dip were located over the center of the stream crossing fill, erosion would proceed more quickly down through the easily erodible fill and potentially exposing the culvert.
3. *Armoring the overflow spillway:* Finally, in channels where debris flows or other culvert plugging events are relatively common, an armored overflow channel can be constructed on the outside fill face across the axis of the road dip. The armor will protect the underlying fill from erosion during an overflow event. Although it is difficult to correctly design the required armor size for use on a steep fill slope, the rock can also be grouted or locked in place with concrete. It is important to design a channel cross sectional form to contain the predicted flood overflow and prevent it from flanking the rock armor. This type of spillway armoring treatment will be needed on only a small percentage of stream crossings, where overtopping is a common occurrence, or where failure is likely (e.g., the basal culvert is greatly undersized), erodible fill volume is high and downstream resources are especially sensitive or valuable.

Overtopping events are rare, so you have to balance the expense of the protective design with the probability of its occurrence. **Properly located**

FIGURE 70.

Incorrect culvert installation can impede or prevent fish passage through a stream crossing. Culvert conditions that block fish passage include: A) water velocities too great, B) water depths too shallow, C) insufficient resting area or jumping pool depth at culvert outlet, and D) culvert outlets that are too high above the streambed (Modified from: Furniss et. al., 1991).



and designed stream crossing dips (the most cost effective design change) will minimize erosion and damage to stream crossing fills in most overtopping events. The armoring and construction of an overflow channel to convey flood waters is not usually required.

b. Fish passage designs

For fish bearing streams, designing crossings with proper fish passage is equally as important as sizing the stream crossing for the 100-year design flood flow and to pass sediment and debris.⁷ Stream crossings that are not properly designed for the upstream and downstream migration of anadromous or resident fish species can combine to result in the overall loss of important fish habitat and ecological productivity.

Of all the types of stream crossing designs and structures, culverts are most commonly identified as impeding fish passage.

Compared to the natural channel, poorly designed culverts in fish-bearing streams often result in

(1) replacing natural spawning gravels with pipe materials, (2) straightening and shortening stream channels, thereby resulting in reduced natural channel complexity and increased stream velocities, and (3) impeding fish passage due to channel scour at poorly designed culvert outlets (Figure 70). In addition, construction activities in fish bearing streams can also result in the modification of stream channel hydraulics and release fine sediment, resulting in embedded spawning gravels and reduced pool depths.

There are obvious benefits, but also potential impacts, to removing a barrier to fish and organism passage. Impassable crossings may occasionally provide an ecologically beneficial function. For example, elevated culverts provide elevational (grade) control by creating a rigid boundary against the upstream migration of channel incision in an unstable channel system.

Removal of a culvert that controls base level could allow channel incision to progress upstream, contributing to reduced habitat quality throughout the upstream reach. In a few instances, it may even be preferred to install or maintain a fish passage barrier. Thus, a culvert that is impassable to an invasive species protects upstream native species from predation and unwanted competition. You should consult a qualified fisheries biologist, and the appropriate regulatory agencies, before deciding to remove a known fish migration barrier.

Proper fish crossing design should be aimed at minimal impact on habitat while improving “ecological connectivity” for salmonid and other native fish, amphibians, reptiles, macroinvertebrates, insects, and other organisms that make up the aquatic food web. Fish require the ability to move throughout a watershed to access spawning grounds, to migrate in the summer to avoid warm water temperature and low flows and to escape to side channel refugia during winter flood flows.

⁷ See Appendix C for specific California Forest Practice Rule language for this requirement.

i. Fish passage at stream crossings Many forest, ranch and rural roads were constructed decades ago, before fish passage was considered an important design consideration. Even on small fish bearing streams, old culverts are typically undersized, installed at steep gradients or installed high in the stream crossing fill so as to partially or completely block passage. These sites are increasingly becoming the focus of road improvement projects, to make the stream crossing more resilient to storm damage and flood flows, while also reestablishing or improving fish passage.

The National Marine Fisheries Service (NMFS, 2001) has suggested the following alternatives and stream crossing types/structures for fish bearing streams, in the order of preference:

1. **Preferred:** *No stream crossing structure in a fish-bearing stream.* The best design for fish passage is not to install a stream crossing that disrupts the nature stream channel characteristics. Decommission or permanently remove existing stream crossings that act as fish barriers and realign roads to avoid crossing the stream.

2. *Bridge* that spans the stream to allow for long term dynamic channel stability. Bridges are an expensive option, but when installed properly, they are the best crossing structure for maintaining stream integrity and natural channel characteristics, as well as preserving ecological connectivity.
3. *Bottomless arch, embedded culvert, embedded ford, or ford* that simulates the natural streambed characteristics. These crossing designs incorporate the natural streambed at the base of the structure and across the entire width of the road.
4. On low gradient channels, use a *non-embedded culvert or "hydraulic design"* that incorporates more traditional culvert design.
5. **Least preferred:** on steeper gradient channels, install *baffled culvert* or a structure with a designed fishway.

When culverted stream crossings are upgraded for fish passage, they can be replaced with bridges or bottomless arch installations. For existing stream crossings, **bridges that do not affect the channel bed and have their**



FIGURE 71. This 45-foot railroad flatcar bridge was installed to replace an undersized culvert that had been a barrier to fish migration. The channel width was maintained and a minor amount of armor was used to protect the abutments from erosion.

abutments outside the channel are the least likely to adversely affect fish and organism passage. In replacing a culverted stream crossing, a bridge installation is generally a highly effective but potentially costly project. On private, low standard roads, use of salvaged rail flatcars and affordable I-beam bridges can be a highly cost-effective option (Figure 71).

Bottomless arches, with natural channel beds and abutments at least as wide as the channel, are also considered generally favorable for providing or improving aquatic passage (Figure 72). Because of their high rate of success, and not having to precisely design grade control and culvert embedding at the crossing site, a number of commercial timber companies have made it

FIGURE 72. *This bottomless plate arch was installed to provide fish access through the stream crossing. Each abutment is comprised of a concrete foundation and the stable stream-bed ensures continuous aquatic passage.*



FIGURE 73. *Embedded culverts are another type of stream crossing structure that allows continuous fish passage. This 10-foot diameter embedded culvert has a natural gravel and cobble streambed. It was installed to replace a small diameter culvert that was a barrier to fish migration.*



their policy to upgrade to bridges rather than install embedded culverts or arch structures.

The simplest fish-friendly culvert installation is the embedded culvert that contains a natural streambed through a wide, oversized pipe (Figure 73). For many landowners, this is the most cost-effective solution. The old culvert is removed and replaced at channel grade with a culvert that is embedded in the stream channel gravels. An embedded culvert can be any shape, but is most often a circular, box or pipe arch that has been buried into the ground typically 20–40% of its height (Figure 74).

Ideally, embedded fish passage culverts are wide and as close to the natural channel width as possible, so flows are not accelerated through them and downstream scour is avoided. Embedded culverts are typically installed in stable, low gradient stream channels that are unlikely to experience significant channel changes (i.e., heavy aggradation or channel downcutting). One advantage of an embedded culvert is the culvert invert (bottom) can provide grade control and protection against extreme scour compared to an open-bottom arch.

Many existing low-water crossings (fords) and culverts create passage problems for aquatic organisms. However, like other crossing structure types, low-water crossings can be effectively designed to: (1) enable passage of aquatic organisms, (2) protect endemic species from invasive competitors, and (3) provide grade control in an incised stream system for protection or restoration of upstream reaches. Fords, particularly vented fords, can be constructed to pass large flows and large amounts of debris, and still provide suitable aquatic organism passage.

The passage conditions and obstacles for ford crossings are similar to those of a culvert, except at higher water conditions when passage over the structure is unimpeded. There should be at least one culvert set deep into the streambed of a hardened ford structure so that passage during low flow conditions is possible. For fish or aquatic species passage, uniform stream channel gradients and acceptable flow velocities must be achieved and maintained through the crossing. Just as wide, embedded culverts are preferred for fish passage, a high Vent-Area Ratio (VAR) structure for a vented ford is much better for

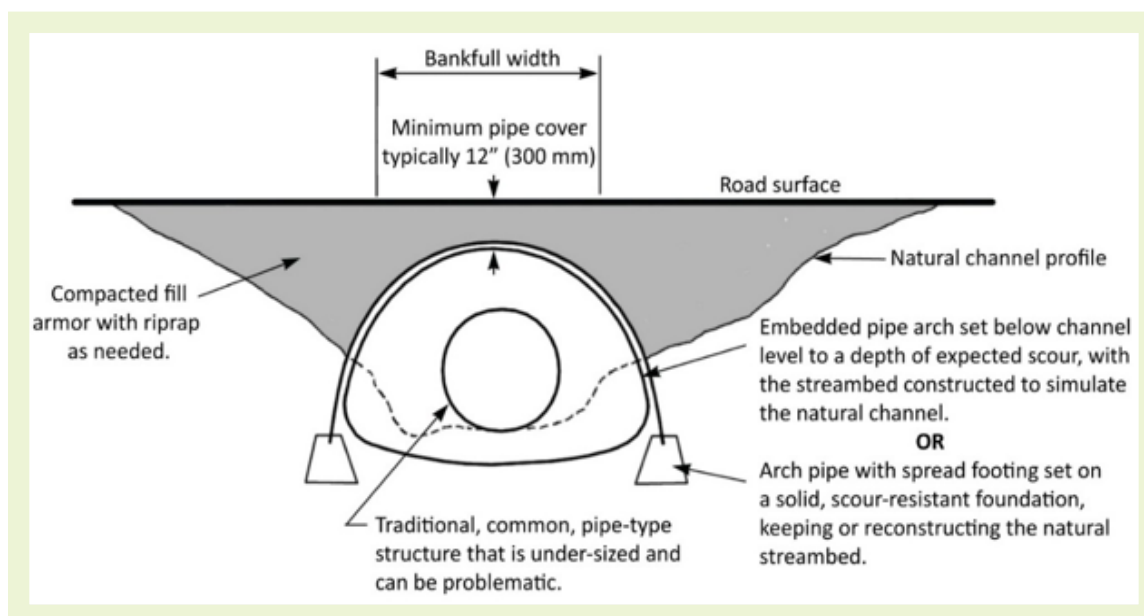
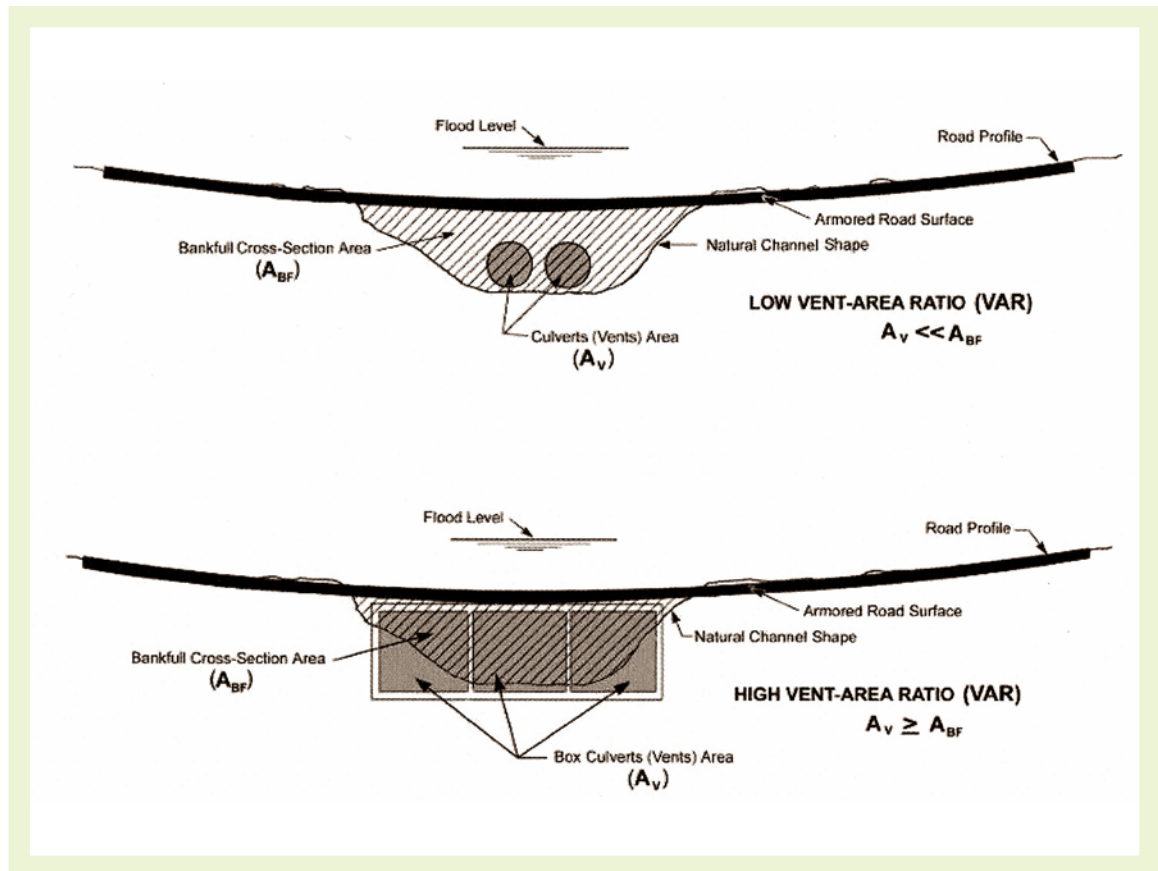


FIGURE 74.
Example of a stream simulation culvert (showing preexisting round culvert, embedded arch culvert and bottomless arch or plate arch) (Modified from: Keller et al., 2011).

FIGURE 75.

Examples of fords with low and high Vent-Area Ratio (VAR). The high vent-area crossing is preferred for fish passage (Keller and Ketcheson, 2012).



aquatic organism passage and to maintain the natural function of the stream (Figure 75).

In general, unstable, eroding stream channels should not be chosen for stream crossing arches, fords or low water crossings, especially where fish passage is required. In a degrading reach, hardened fords and other fixed-bottom crossing structures (like culverts) may be undermined when an advancing headcut reaches them, and this could eliminate fish passage. At the same time, low-water crossings and culverts can function as grade-control structures, preventing the headcut from moving headward and protecting the stability and aquatic habitat of upstream reaches. It may be necessary to install a bridge or an open bottom arch, or otherwise provide alternative passage (such as a roughened channel) for aquatic organisms if impassible grade drops occur on the downstream side of a ford, or if energy dissipation structures

cannot accommodate passage. This is especially important for concrete slab ford crossings.

ii. Grade control for fish passage When installing or replacing stream crossing culverts, fords, vented fords and other in-channel stream crossing structures in fish bearing streams, channel grade (slope) and channel structure (roughness and drops) become important design elements. Installation techniques that might be applicable and effective for non-fish bearing channels may no longer be suitable. For example, 1) wide, flat bottom box culverts may not provide for low flow juvenile passage; 2) rock armor at the outlet of a culvert may not allow passage or provide for an adequate holding or jumping pool; and 3) downstream cutoff walls, roughened energy dissipation slabs, splash aprons, or energy dissipation pools might reduce outlet erosion and channel scour, but such measures can also create fish

passage barriers. Likewise, simply removing or replacing an existing culvert with a larger culvert could trigger channel downcutting and the creation of a new fish passage barrier.

Grade control structures may be necessary upstream and/or downstream of a newly installed or removed drainage structure (especially culverts) to control the longitudinal profile and water surface elevations, and thereby provide for continuous fish passage (Table 23). Channel grade controls may be needed to provide for steepened or stepped fish passage through the affected channel reach. Channel grades can be stabilized using a series of small grade control structures to produce small steps in the channel to raise it to the required level or elevation. Alternately, the channel can be “roughened” with coarse rock to provide for a continuous steepened section that will not erode and yet can still provide for

fish passage. In essence, roughened channels are permanent features designed to resist channel changes during the design, 100-year flow event.

Designing grade control to provide for unimpeded fish passage in a stream will likely require special permitting and/or the use of a qualified, experienced professional (hydraulic engineer or engineering geologist). These projects need to accommodate passage of all life stages (e.g., juvenile and adult salmonids) and still function well during both low flow periods and during flood flows. Designs require an uninterrupted, uniform (or acceptable) gradient, natural bottom stream bed at the crossing site, extending from the natural channel bed below the stream crossing to the same natural channel bed above the drainage structure.

Grade control may be required to control the integrity of the longitudinal profile and water surface elevations through the

TABLE 23. Comparison of channel profile design structures used to control grade either upstream or downstream of a stream crossing culvert for fish-bearing streams¹

Grade control	Advantages	Disadvantages	Limitations
Log sills	Downstream bed elevation control	Limited to <5% final gradient (affects length to catch channel grade).	Minimum spacing of 15 ft. Limited to <5% gradient. Allowable drop depends upon fish requiring passage. No wet/dry cycles between.
Baffles	Increase hydraulic roughness	Turbulence, hydraulic profile raised, debris and structural problems. No small fish passage.	Slope $\leq 3.5\%$
Plank sills	Hand labor	Less durability	Limited to streams with <5% gradient; small streams.
Roughened channel	Natural appearance, flexible, can provide passage for all fish	Technical expertise required. Technical fish-passage analysis required.	Limited to <3% gradient streams.
Boulder controls	Flexible, allowing channel to regrade slowly	Should only be used for downstream use if culvert is sufficiently embedded.	Maximum drop of 0.75 ft.
Fishway	Can provide passage for most fish	Expensive. Technical expertise and site-specific, flow-regime data required. Debris and bedload problems.	Narrow range of operating flow. Difficult to provide passage for all fish, all of the time.

¹Hotchkiss and Frei (2007)

stream crossing and, where necessary, trained personnel should be consulted.

iii. Design guidelines **In most cases, fish passage is designed for juvenile fish, considered to be the most vulnerable and “least able” life stage of migratory and resident fish.** Designing crossings with proper fish passage for juvenile fish is more difficult, but ensures that all life stages, and ultimately the health of the watershed’s fisheries, will be maintained. This handbook is not a guide to designing fish passage and organism passage at road stream crossings, but knowledge of the basic criteria and elements of grade control is provided so that users can determine when and where they may need to consult with specialists about their particular project or site.

Determining the proper fish passage design for your stream crossing requires a site-specific assessment by qualified and experienced fish biologists, civil engineers, and engineering geologists or geologists.

Designs are developed utilizing federal and state-accepted methodologies to identify the species at risk, quality and quantity of existing or potential fish habitat, potential or existing fish barriers, physical environmental conditions, and hydraulic and hydrologic conditions upstream and downstream of the proposed stream crossing. Contact your local state fish and wildlife office, Resource Conservation District or similar organization to obtain a list of fish passage design professionals in your area.

Federal and state agencies have developed specific guidelines for evaluating the site suitability of fish passage crossings and specific design techniques. **It is important to re-emphasize that the evaluation and design of fish passage stream crossings should be conducted by qualified professionals, as defined by federal or state laws.** It is important that the landowner understand their responsibility and role in proper road design in

fish-bearing streams. **Table 24** provides a list of available reference documents that may be used to inform landowners, road project managers, and road design professionals about federal and state guidelines and techniques for proper fish passage stream crossing evaluation, design, and construction. At the same time, there is no substitute for qualified, experienced professionals.

c. Designing stable stream crossing fill slopes

i. Slope gradient Slope gradient is one of the key factors that influence the stability of fill slopes. **Stable fill slopes are a product of stable fills, and that requires good compaction.** Properly designed culverted stream crossings also require careful attention to design fill slope gradients that will not structurally fail and will stabilize and revegetate quickly. Stream crossing fill slopes should be designed and constructed at gentle angles (e.g. maximum 2:1 (horizontal:vertical) slope ratio) unless that is infeasible or cost prohibitive. Stream crossing fill slopes constructed with a 2:1 slope ratio are typically stable and not prone to fill slope failure (if they are compacted under proper moisture conditions), and respond the best to revegetation (**Figure 76**).

Obtaining a stable fill slope gradient is dependent on:

- *The type of fill used to backfill crossing.* **To ensure stable crossing fill slope gradients, avoid using clay-rich soils, or cohesionless soils such as fine sands and silts.** Aim for backfill materials that are moist but not excessively wet or unstable (see also “Chapter 5: Construction, Section I (3). Culvert Installation” and **Table 17**).
- *Compaction measures applied during backfill.* Uncompacted fill materials allow water to fill the soil pore spaces, thereby reducing soil density and shear resistance. Lack of soil shear strength makes it difficult to

TABLE 24. List of federal and state fish documents and handbooks related to fish passage stream crossing evaluation and design

Agency	Title	Year published	Citation
Federal			
USDA Forest Service	Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings	2008	Stream-Simulation Group, Forest Service. 2008. Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings. 0877 1801P. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center
Federal Highway Administration (FHWA)	Culvert Design for Aquatic Organism Passage	2010	FHWA, 2010, Culvert Design for Aquatic Organism Passage, Publication No. FHWA-HIF-11-008, U.S. Department of Transportation, Federal Highway Administration, Office of Infrastructure Research and Development, McLean, VA, 234 p. Available at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/11008/hif11008.pdf
National Marine Fisheries Service (NMFS)	Guidelines for Salmonid Passage at Stream Crossings	2001	NMFS, 2001, Guidelines for salmonid passage at stream crossings, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Available at: http://swr.nmfs.noaa.gov/hcd/NMFSSCG.PDF
State			
California Department of Fish and Wildlife	Fish Passage Design and Implementation	2009	Love, M., and Bates, K., 2009, Chapter XII: Fish Passage Design and Implementation, in California Salmonid Stream Habitat Restoration Manual, Third Edition, Inland Fisheries Division, California Department of Fish and Wildlife, Sacramento, CA, 189 p. Available at: http://www.dfg.ca.gov/fish/resources/habitatmanual.asp
California Department of Fish and Wildlife	Chapter IX: Fish Passage Evaluation at Stream Crossings	2003	Taylor, R.N. and Love, M., 2003, Chapter IX: Fish passage evaluation at stream crossings, in California Salmonid Stream Habitat Restoration Manual, Third Edition, Inland Fisheries Division, California Department of Fish and Wildlife, Sacramento, CA, 100 p. Available at: http://www.dfg.ca.gov/fish/resources/habitatmanual.asp
Oregon Department of Forestry (ODF)	Fish Passage Guidelines for New and Replacement Stream Crossing Structures	2002	ODF, 2002, Fish Passage Guidelines for New and Replacement Stream Crossing Structures, Forest Practices Technical Note No. 4, version 1.0., Oregon Department of Forestry, Salem, OR., 14 p. Available at: http://www.oregon.gov/odf/privateforests/docs/fishpassguidelines.pdf
Washington Department of Fish and Wildlife	Design of Road Culverts for Fish Passage	2003	Bates, K., Barnard, B., Heiner, B., Klavas, J. P. and Powers, P. D., 2003, Design of Road Culverts for Fish Passage, Washington Department of Fish and Wildlife, Olympia, WA, 112 p. Available at: http://wdfw.wa.gov/publications/00049/wdfw00049.pdf



FIGURE 76. This newly upgraded 36-inch diameter culvert was installed in-line with the natural channel and at the base of the road fill. The road fill was graded to slightly less than 2:1 (50% slope) that was easily and rapidly revegetated. The culvert outlet extends at least 6 feet beyond the fill and discharges into the natural channel bed.

construct or maintain proper fill slope gradients. **Stream crossing fill materials should be compacted during optimal (moist, not overly dry or wet) soil conditions in 6" to 12" lifts (layers) to increase soil density and shear resistance and reduce the potential for fill and fill slope instability.**

- *Compaction equipment.* A variety of compactors can be used for various soil types and site conditions, including: *sheepsfoot rollers* (which are usually towed); *pneumatic-tired rollers* (which use rubber tires to “knead” the soil or subgrade); *vibratory rollers* (smooth drum) (typically used for granular and mixed soil materials); and *tamping foot compactors* (which combines the advantages of a vibratory roller with a sheepsfoot). All compactors are used in building up a stable fill. **Vibratory rolling compactors should be used on cohesionless soils, such as sand and gravel while sheepsfoot rollers are best suited for cohesive soils such as silts and clays.** True compaction equipment usually produces the best results but **field compaction using rubber tired heavy equipment or even dozer tracking can often provide adequate soil strength if done uniformly and under proper soil moisture conditions.**
- *Compaction of the fill slope faces.* Compaction is most easily obtained on horizontal surfaces; it is much more difficult to obtain proper soil compaction on the slanting outer fill slope faces. **Ideally, if the design stream crossing fill slope is to be steeper than 2:1, the fill should be built slightly wider than desired and compacted in thin vertical lifts. The excavator can then use its bucket to excavate back the fill slope face to remove the outer 6" of loose, uncompacted soil material until the internally compacted soils are exposed. This provides the best compacted fill slope.**

Even under ideal moisture conditions, only moderate compaction on angled fill slope faces can be attained using a sheep’s foot roller winched up and down the fill slope, or an excavator fitted with a quick-release sheep’s foot roller attachment used to compact the fill face. Short, gently sloping fill faces can often be mulched, either with small diameter angular rock (road rock) or with a straw mulch to control erosion until the surface has naturally compacted and stabilized with vegetation.

For locations where stream crossing fill slopes require steeper gradient design (e.g., steeper than 2:1 or 1½:1), a qualified civil engineer, engineering geologist, or geologist should be consulted. They will help you determine if simply rock armoring will help stabilize the fill slope surface, or if other slope revetment measures need to be applied to prevent potential fill slope instability. Slope revetments might include riprap blankets keyed into the base of the stream crossing fill slopes; gabion structures⁸; engineered fills; or other fill slope retaining structures (Figures 51 and 77).

ii. Culvert outlet extensions Stream crossing culverts should be installed so that both culvert ends extend sufficiently beyond the base of the fill slope to prevent erosion or undercutting of the fill, and that the culverts are long enough to allow construction of a gentle and stable fill slope. **Preferably, the culvert outlet should extend at least 6 feet beyond the base of the fill (Figure 76), and the inlet approximately 2 feet upstream of the base of the fill, to protect the stream from soil erosion or soil movement off the newly constructed fill slope.** If stream crossing culvert installations require riprap protection at the inlet or outlet, several additional feet of culvert can be added to protect the exposed pipe from crushing or burial.

8 Gabion wire baskets should not be used in fish-bearing streams.



FIGURE 77. Road crossings of steep stream channels require fill slopes that often exceed a 2:1 slope gradient. This steep fill slope was stabilized with coarse rock armor embedded in a basal keyway.

Landowners have sometimes tried to save money by minimizing culvert length during construction, by installing short culverts, constructing steep fills and “shot-gunning” culvert outlets near the top of the fill. A culvert installed too short in the fill can cause culvert inflow or outflow to scour and potentially undercut and destabilize the fill. The additional pipe length beyond the base of the fill ensures that streamflow is transported beyond the fill slope and is released into the natural channel. In addition, the extended pipe length is added insurance that the pipe inlet/outlet will not be buried or blocked in the case of small fill failures, sidecast during grading, or culvert damage during maintenance activities.

iii. Armoring and riprap

Introduction—Rock armor and riprap can be used at stream crossings to provide erosion control at the inlet and outlet of culverts, on fill slope surfaces, along stream channel bottoms and stream banks, and along ditches leading to stream crossings. As an erosion control measure, riprap is effective for energy dissipation by providing roughness that slows water velocities or turbulent flow along stream channels, at culvert inlets and outlets, and along ditches. Finer rock

materials can also be applied as non-erodible “mulch” on fill slopes that lack vegetation and will not respond well to vegetative erosion control measures (e.g., in arid or semi-arid areas). Used as mulch, riprap prevents surface erosion by protecting the soil surface from raindrop erosion and by dispersing and slowing concentrated surface runoff. It also acts to trap eroded sediment within rock particle spaces.

Riprap is also used as a stabilization measure for steep fill slopes or along unstable stream banks; although, riprap can become unstable when placed on slopes steeper than 2:1 if it is not properly selected and installed. For this reason, the landowner or road project manager should consult with a qualified professional for design specifications and installation instructions when riprap is planned as a stabilization or revetment measure.

Riprap specifications—The effectiveness of rock riprap as an erosion control measure is based on (1) stone or particle size and weight, (2) stone durability, (3) slope gradient, (4) thickness of riprap application, and (5) its use in conjunction with underlying filter fabric

or geotextile. At stream crossings, riprap should be sized according to expected stream velocities and slope gradients. Riprap that is undersized for site specific stream velocities and slope steepness will be subject to particle erosion, where the riprap cannot withstand the stream hydraulic forces and becomes dislodged or the slope steepness exceeds the riprap angle of repose.

Riprap should consist of a well-graded mixture of larger and smaller hard rock sizes in order to minimize void space and create a dense layer of interlocking rock. Interlocking riprap forms a flexible, yet durable and self-adjusting erosion resistant surface. Avoid using uniformly sized riprap due to its reduced frictional resistance, large pore space voids and sensitivity to individual particle movement. However, recent published documents suggest that a coarse, uniformly sized riprap surface may be advantageous along stream environments to create increased roughness and flow resistance, improved diverse habitat, suspended sediment deposition and increased oxygenation. **Table 25** provides ten of the standard riprap classes and the associated gradation by size and weight.

In general, riprap should be installed with an underlying layer of geotextile or gravel separating the riprap from compacted fill material. Geotextiles are used to prevent winnowing of fines, scour, slumping, piping, or the movement of fill or subgrade soils into the overlying riprap. Care should be taken when using equipment to place riprap on geotextile so that it is not damaged or torn.

Culvert inlet and outlet armoring, and energy dissipation—Rock armor at culvert inlets and outlets has three functions; 1) as inlet and outlet protection used to protect the base of the fill from splash and surface erosion, 2) to trap sediment eroded from the upper portions of the newly constructed fill slope before it is delivered to the stream, and 3) as energy dissipation below the culvert outlet to protect the channel against high velocity flood flows.

Riprap installed to protect the inlet and outlet of a stream crossing culvert from erosion or for energy dissipation should be keyed into the natural channel bed and banks to an approximate depth of about 1.5x the maximum rock thickness (**Figures 78, 79**).

TABLE 25. Standard classification and gradation of riprap by size of rock¹

Riprap size class	Median particle weight ²	Median particle diameter ² (in)	Minimum and maximum allowable particle size (in) ²						
			D ₁₅		D ₅₀		D ₈₅		D ₁₀₀
			Min	Max	Min	Max	Min	Max	Max
Class I	20 lb	6	3.7	5.2	5.7	6.9	7.8	9.2	12.0
Class II	60 lb	9	5.5	7.8	8.5	10.5	11.5	14.0	18.0
Class III	150 lb	12	7.3	10.5	11.5	14.0	15.5	18.5	24.0
Class IV	300 lb	15	9.2	13.0	14.5	17.5	19.5	23.0	30.0
Class V	¼ ton	18	11.0	15.5	17.0	20.5	23.5	27.5	36.0
Class VI	3/8 ton	21	13.0	18.5	20.0	24.0	27.5	32.5	42.0
Class VII	½ ton	24	14.5	21.0	23.0	27.5	31.0	37.0	48.0
Class VIII	1 ton	30	18.5	26.0	28.5	34.5	39.0	46.0	60.0
Class IX	2 ton	36	22.0	31.5	34.0	41.5	47.0	55.5	72.0
Class X	3 ton	42	25.5	36.5	40.0	48.5	54.5	64.5	84.0

¹Lagasse et al. (2006)

²Equivalent to spherical diameter

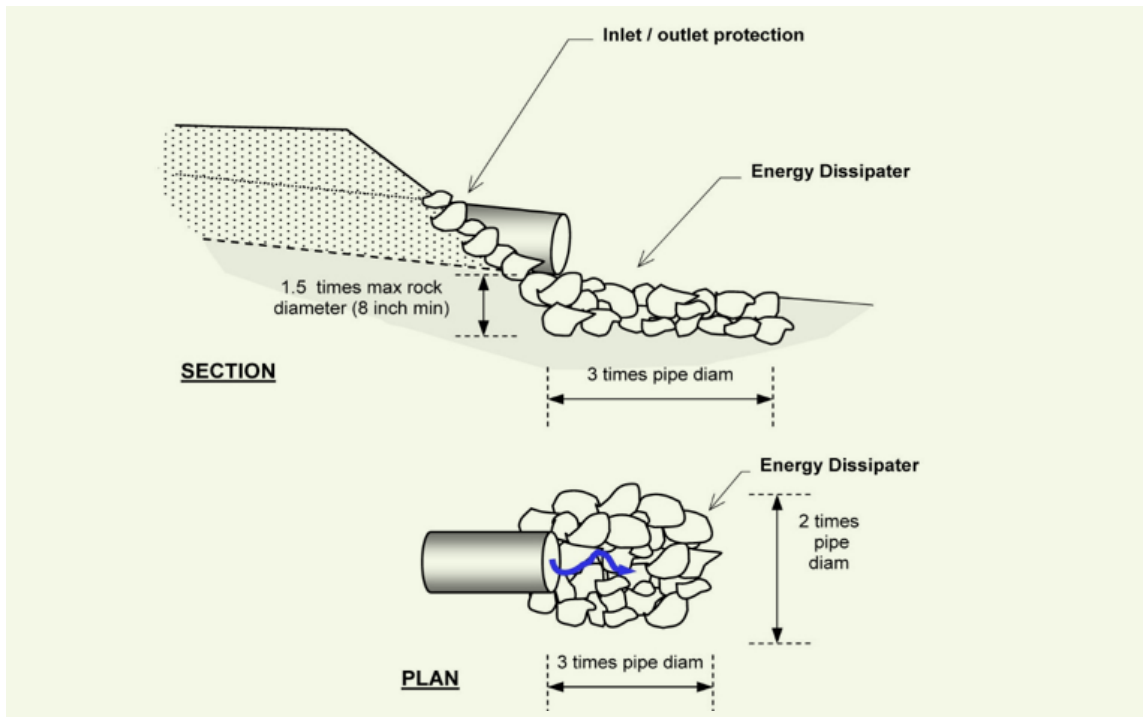


FIGURE 78.
Riprap as outlet
energy dissipation
(Best, 2013).

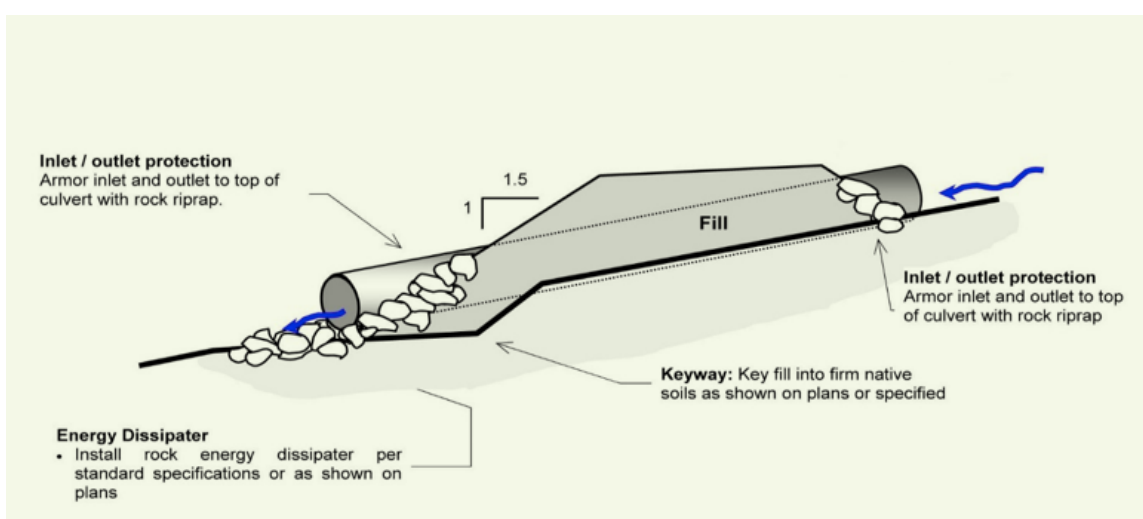


FIGURE 79.
Riprap as inlet
protection and
outlet energy
dissipation
(Modified from:
Best, 2013).

Riprap should be placed at least up to the top of the culvert at both the inlet and outlet to protect them from splash erosion and to trap any sediment eroded from the newly constructed fill slope above (Figure 79).

Rock armor used for inlet and outlet protection (i.e., not as energy dissipation) does not have to be sized to protect against high velocity scour. If the culvert is properly sized and its length is adequate, it should be able to

transmit flood flows without scouring the inlet or eroding the outlet around the culvert. Armor here is designed to protect the culvert outlet and basal fill from splash erosion and from occasional submergence and currents within standing water (at the inlet) when the culvert plugs. Importantly, inlet and outlet armor also serves to trap sediment that has been eroded or slides down the new constructed fill face in its first several years, until the slope becomes well vegetated (Figures 73, 80).

FIGURE 80. Rock armor placed around this culvert where it emerges from the fill slope was used to protect the stream from unexpected erosion of the new, erodible fill slope until it stabilized with vegetation.



If energy dissipation is necessary below the culvert outlet, rock armor size should be designed for the peak flood flow. The riprap apron should extend a length of about three culvert diameters downstream from the end of the outlet and in line with the natural channel, and span a width of at least two culvert diameters in order to reduce the potential for outlet scour or flanking of the rock armor during flood flows (Figure 78). Riprap size should be based on the design stream velocities to ensure rock will stay in place and not be mobilized, causing potential erosion and destabilization of the stream crossing. However, outlet velocities are not easily estimated for sloping culverts at peak flood flows.

Armored fills and armored spillways—Riprap armor is employed to protect the outer fill slope of an armored fill (see Armored fills, below) and less frequently as overflow “chutes” for culverted stream crossing fills that are prone to overtopping during flood events. Both designs require rock armor to be centered at the low point in the stream crossing fill, where the flood

flow would overtop the fill and flow down the fill face during any storm or culvert plugging event. The spillway should be constructed with a broad overflow dip (like an armored channel; with a bed and two gently sloping banks and sufficient capacity to contain flood overflows) directly over the low point in the crossing.

Some general design parameters for rock placement on an armored fill might include the following: Riprap should be keyed in to the fill slope or overflow channel to an approximate depth of 1.5x the maximum rock thickness. Riprap should be placed with a minimum of 2x the D50 thickness and extend to the top of the fill slope. In general, the width of the spillway should be at least 5x the design stream bankful stage width. We would also suggest a range of rock sizes be used in order to lock the rock riprap together, and a geotextile fabric beneath to protect the underlying erodible fill. Riprap placed on a steep fill slope can not be guaranteed against erosion during a flood flow or overtopping event. For this reason, the rock can be grouted or secured with concrete as a stabilizing measure.

Slope revetment—Anything but the smallest slope revetment (such as a small boulder pile) require specific designs that are best developed by a licensed professional so as to provide the most stable, functional and safe structure. A qualified and experienced engineer or engineering geologist evaluates existing site conditions, geology, and soils to determine the best design that will provide critical slope stabilization. In general, building stream crossing fill slopes at slope ratios greater than 1½:1 is discouraged. In some cases, steep fill slopes are buttressed using riprap blankets or gabion baskets that are keyed into the channel bed and extend upslope. Because of the variable nature of fill materials and the difficulty of attaining stable and consistent compaction, a qualified professional should be consulted for design advice before constructing steep stream crossing fill slopes, road and cutbank fill slopes, bridge abutments or engineered fills.

Streambank stabilization—In some cases, it may be necessary to protect steep streambanks upstream, downstream or, in the case of bridges, through the entire length of a stream crossing, from high velocity stream flows that may cause bank instability or scour. Riprap can be used alone in riprap blankets or gabion baskets, or it may be used in combination with live plants and structures (biotechnical measures) or dead vegetation (root wads, large woody debris, etc.) (Gabion baskets are not recommended for fish bearing streams).

Wherever rock armor has to resist flowing water, the size and weight of riprap is based on the stream velocity and channel slope. The nomograph illustrated in **Figure 81** provides the relationship between riprap particle diameter, particle weight, stream velocity, and slope ratio. It is a useful tool for helping you estimate the proper size riprap for the design stream crossing or stream bank stabilization project. Advice from an experienced and qualified hydraulic engineer or engineering

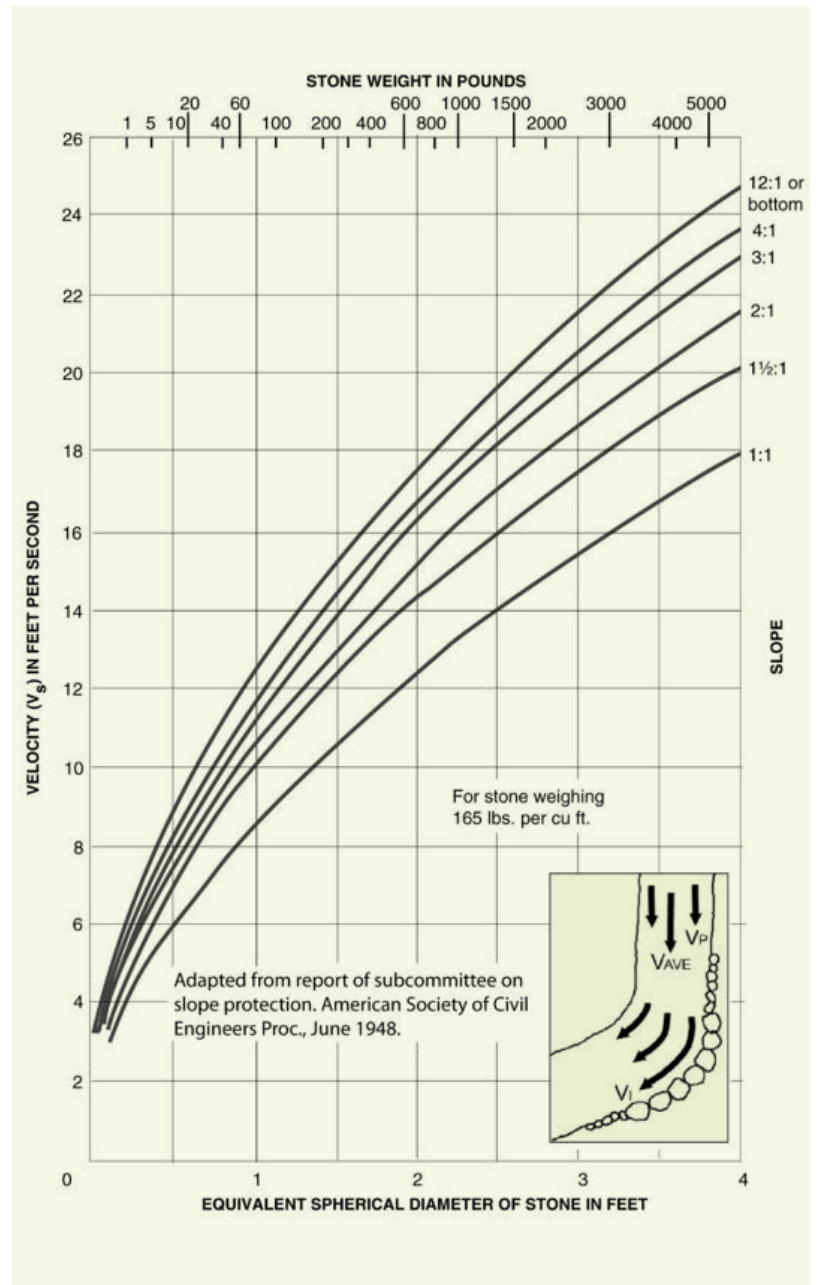


FIGURE 81. *Nomograph for determining riprap stone size and weight based on velocity and side slope steepness. While this nomograph provides an estimate of the required stone sizes, a qualified engineer or engineering geologist should be consulted for specific design work prior to constructing a streambank protection structure (Johnson and Stypula, 1993).*

geologist should be sought when designing streambank stabilization works that are protecting roads, buildings or other infrastructure.

Riprap should be installed on top of geotextile fabric or a clean mixture of coarse gravel and sand. The riprap should be keyed into the streambed and extend below the maximum expected scour depth with an adequately sized key base width at a thickness of a minimum of 2x the median (D50) rock diameter with the largest stone sizes placed at the base of the riprap structure. The armor should be set into the streambank so it does not significantly protrude into, or constrict, the natural channel, or otherwise reduce channel capacity. The riprap should extend along the length of unstable or oversteepened bank and up the bank sufficiently to encompass the existing bank instability and/or design flood elevations. Site-specific conditions will dictate the exact specifications and installation techniques that are chosen for your site. Because of environmental restrictions, regulatory (permitting) agencies may also provide specifications or restrictions on riprap installation at most sites.

iv. Road surface drainage Uncontrolled chronic road surface drainage can produce and deliver significant amounts of fine sediment to streams via ditches and road surfaces, and if it is discharged onto a stream crossing fill slope it can deeply gully or destabilize the fill. In general, roads over and adjacent to stream crossing fills should be designed to disperse runoff quickly and not allow concentration of runoff. **Designing roads to disperse and shed water on stream crossing approaches, before the road runoff reaches the crossing, can help maintain slope stability, reduce erosion and minimize sediment delivery.**

Road surfaces can be de-watered before reaching the crossing utilizing a variety of road shaping treatments including outsloping, insloping, and crowning; or road drainage

structures such as rolling dips and ditch relief culverts (Refer to “Chapter 4, Section B: Road Prism and Road Surface Drainage” for specific information regarding road drainage techniques, design, spacing, and construction). Depending on site and road conditions, a rolling dip and/or ditch relief culvert installed just up road (e.g., 50 to 100 ft) from the stream crossing can help reduce the amount of road surface runoff reaching the crossing, as well as drain the runoff onto stable terrain away from the stream crossing fill slope. If the ditch is wet and flows water, ditch relief culverts (not rolling dips) should be used to drain the ditch.

In addition to de-watering the road approaches to a stream crossing, it is important to drain the roadbed through the crossing so runoff does not threaten the fills with erosion or instability. As long as the road has been hydrologically disconnected before reaching the stream crossing, local road surface drainage can be controlled by outsloping, insloping and/or berms. To minimize erosion, make sure any fill slope that receives local runoff is stable and mulched with vegetation or rock. If slopes are long, steep or susceptible to surface erosion, a low earthen berm can be used to take local runoff beyond the crossing fill and then discharge it onto stable terrain alongside the crossing (Figure 82). In some instances, rock armor or a flume may be required to carry flow to the base of the fill. When the fill face has completely revegetated the berm can be removed. **Insloping the road fill and road surface is probably the preferred method for controlling road surface runoff over the crossing and maintaining a stable fill**, especially where commercial truck and trailer traffic is common. If the road is insloped to drain onto the shorter inboard fill slope of the stream crossing, light surface armor or heavy mulch may be all that is required to prevent erosion until it is revegetated.



FIGURE 82. This newly upgraded stream crossing fill was protected from road runoff and erosion by the installation of a drainage berm along the road. Once the fill is vegetated and stabilized, the berm can be safely removed.

v. Erosion control Stream crossing construction results in the removal of vegetation and the creation of a bare road surface and two bare fill slopes that are highly susceptible to erosion. Although vegetation will usually reestablish over time, it is important to mulch and rapidly re-vegetate the bare fill slopes immediately after construction to establish a protective vegetated surface prior to the wet weather season. **All bare soil surfaces at newly constructed stream crossings should be straw mulched and seeded, or covered with an erosion control blanket.** The hydrologically connected road surface should be rock surfaced, or paved. If revegetation is not likely to develop quickly, the fill surfaces can be covered with a thin rock mulch to control raindrop impact and rill erosion.

In order to properly seed and mulch bare soil areas, make sure to use local, native seed with two or more shade tolerant, well rooted, aggressive perennial grass, forb, legume, or woody species. Seed should be applied to fill slopes immediately after construction when

seed will have direct contact with soil and weed species have not had time to establish. After seeding, cover the slope with protective mulch, such as weed-free straw, wood chips, bark, or other similar materials to protect and encourage seed growth and reduce the potential for surface erosion. Cover the surface uniformly, but not too thick or you may inhibit germination and growth.⁹ For additional protection on steeper fill slopes (steeper than 1½: 1), it may be necessary to tack erosion control netting (e.g., jute or coir netting) over the seeded and mulched surfaces in order to protect the slopes from surface erosion and provide a stable environment for vegetative growth.

vi. Critical dip placement A critical dip should be constructed at newly built or upgraded stream crossings that would exhibit a diversion potential.¹⁰ If a stream crossing culvert plugs and flood flow overtops the

⁹ A good rule of thumb is “no bare soil visible.”

¹⁰ See Appendix C for specific California Forest Practice Rule language for this requirement.

road fill, a properly constructed critical dip can convey flow over the crossing and back into the natural channel, usually with far less erosional impact than if it had been diverted down the road and into another stream or onto an unprotected hillslope (Figure 83).

If road conditions allow, critical dips should be built on the down gradient side of the crossing (near the stream crossing hinge line) and not along the centerline where the fill is the deepest and the where a culvert is typically aligned. If the culvert plugs and the crossing fill is overtopped, a critical dip installed over the centerline of the crossing risks the development of a deep gully that would likely compromise or damage the existing culvert. A critical dip installed along the stream crossing hinge line would result in a smaller gully (shallower depth of fill at the crossing hinge line) and would not likely damage the existing culvert, thereby causing less environmental

damage and making crossing reconstruction less difficult or costly (Figure 84).

The critical dip should intercept the ditch and the ditch should be physically plugged at the down road side to prevent any diverted flow from discharging down the ditch. For additional protection, and for use only at stream crossings with a history of frequent culvert plugging and overtopping, an armored overflow channel can be constructed at the outfall of the critical dip extending down to the stream channel (Figure 84). This will ensure that the fill slope is protected from potentially erosive streamflows.

A second strategy to prevent stream diversions is to dip the entire stream crossing fill, with the low point in the dip at the down-road hinge line (Figure 84). This prevents the stream from diverting and flowing down the adjacent road, and also reduces the volume of erodible fill in the crossing itself.

FIGURE 83.

Critical dip at a stream crossing. Note reverse grade that directs flow over the road and back into the natural channel in this climbing road grade. Prior to installation of the critical dip, the culvert plugged and the stream diverted down the road and completed washed out the road in the foreground.



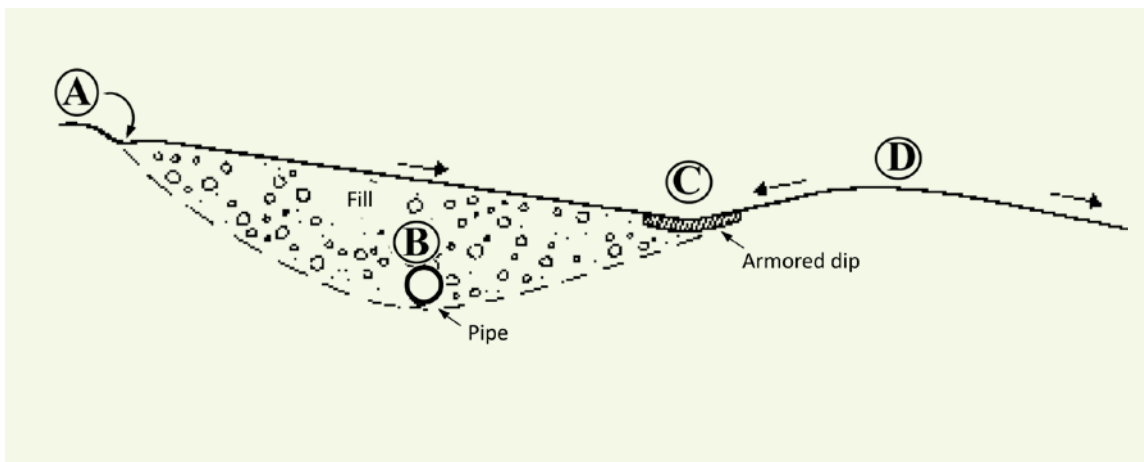
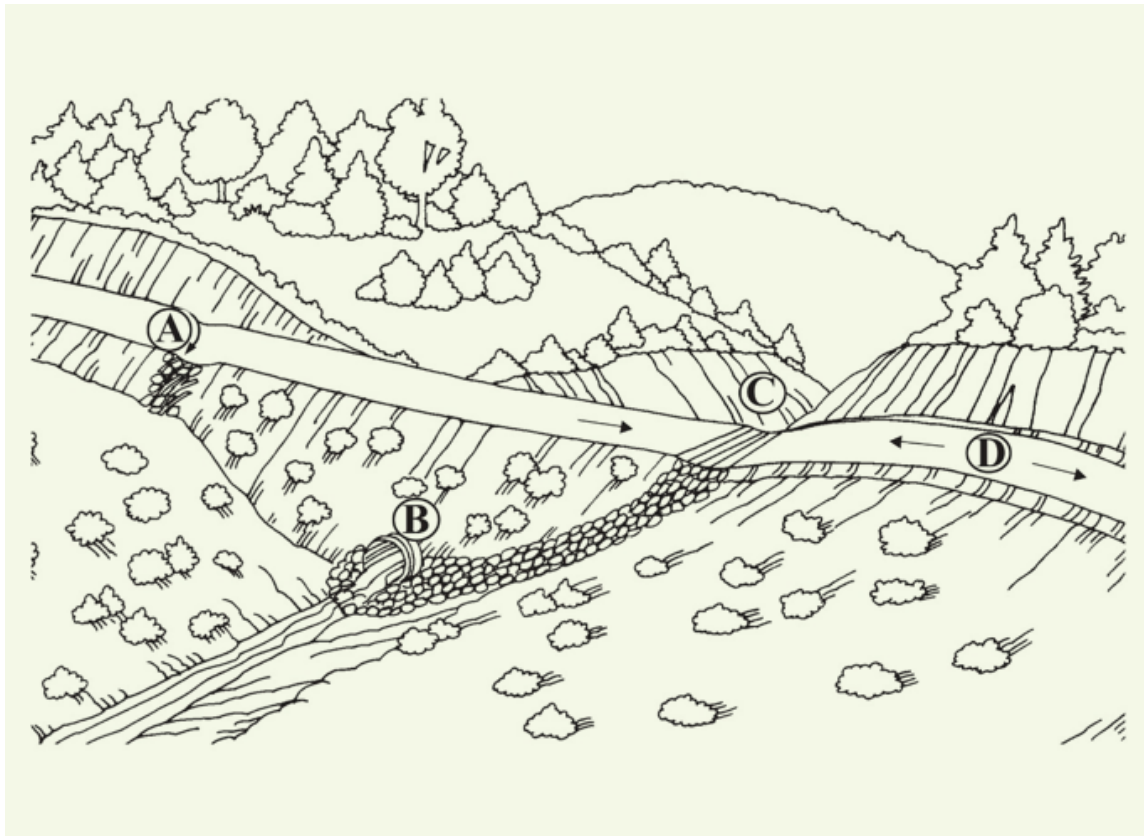


FIGURE 84. Critical dips or dipped crossing fills should be centered near a stream crossing's down-road hingeline, not over the centerline of the crossing where overtopping could cause washout or severe erosion of the fill. If the stream crossing culvert (B) plugs, water will pond behind the fill until reaching the critical dip or low point in the crossing (C) and flowing back down into the natural stream channel. The down-road ditch must be plugged to prevent streamflow from diverting down the ditch line. For extra protection in this sketch, riprap armor has been placed at the critical dip outfall and extending downslope to the stream channel. This is only required or suggested on stream crossings where the culvert is **highly likely** to plug and the crossing fill overtopped. The dip at the hinge line is usually sufficient to limit erosional damage during an overtopping event. Road surface and ditch runoff is disconnected from the stream crossing by installing a rolling dip and ditch relief culvert just up-road from the crossing (A) (Keller and Sherar, 2003).

d. Treating hydrologically connected stream crossing approaches

For maintained forest, ranch and rural roads, hydrologic connectivity can rarely be completely eliminated. Unless recently constructed, most untreated road systems have connectivity values ranging from 30% to 50%. Preferably, the goal should be to have <10% hydrologic connectivity along your roads.¹¹

Stream crossings usually represent the most common location where road reaches are hydrologically connected to adjacent streams. A reasonable goal would be to have no more than a total of 200' of connectivity at each stream crossing (less would be better) and ideally less than 100' of connectivity per approach (Figure 85). Some situations will allow you to achieve

¹¹ See Appendix C for specific California Forest Practice Rule language for this requirement and TRA #5 for additional information on this topic.

even less connectivity, where road approaches can be outsloped with no inside ditch and almost none of the road drains to the stream.

Minimizing hydrologic connectivity depends on having frequent road and ditch drainage structures collecting and discharging runoff onto stable slopes where it can infiltrate into undisturbed forest soils before it reaches a watercourse (Figure 85).

Insloped roads with ditches are the most common way in which roads are hydrologically connected to streams in a watershed. Most hydrologic connectivity typically occurs on the approaches to stream crossings and secondarily at ditch relief culverts with gullies below their outlets. Thus, insloped roads should be frequently drained onto the adjacent, stable hillslope using ditch relief culverts or rolling dips, where runoff will not enter a stream channel.

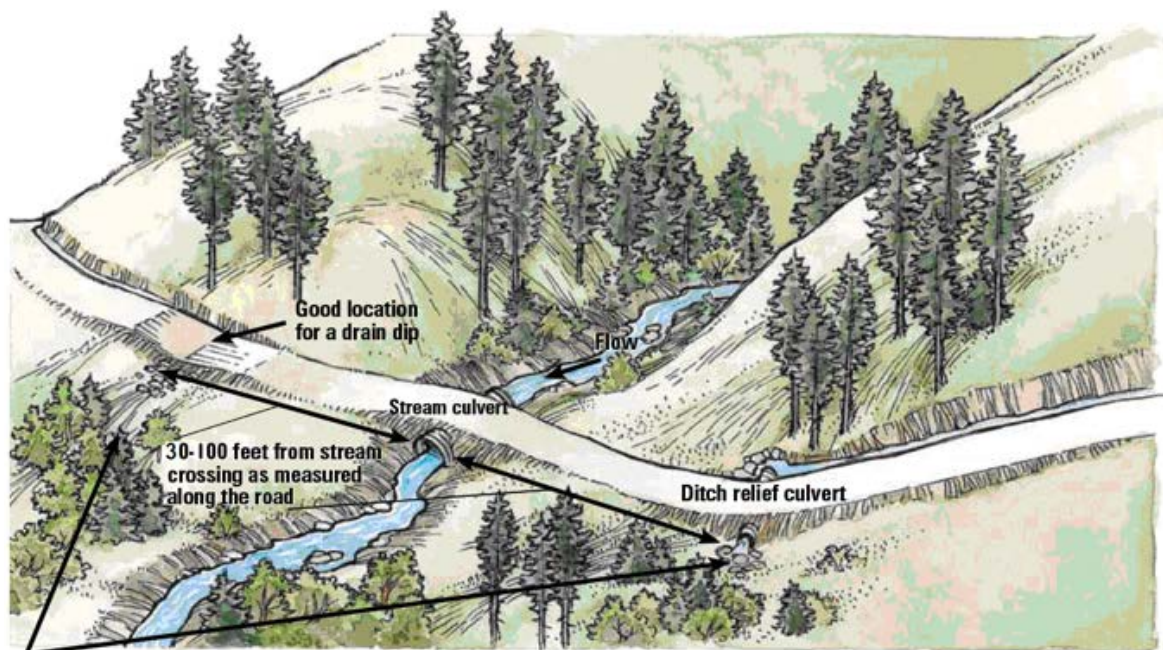


FIGURE 85. Diagram showing hydrologic disconnection on the approaches to a stream crossing. Note the absence of an apparent critical dip at the crossing. (Modified from: Adams and Storm, 2011; see Appendix C for use in TRA #5).



FIGURE 86.
Rolling road grade is one method used to effectively drain a road and disconnect road runoff from streams. This road was dipped and then rises to the bridge crossing, ensuring that road runoff is drained off the road and onto the vegetated hillslope prior to reaching the crossing.

Choose from a variety or combination of surface drainage techniques including berm removal, waterbars, road surface shaping (outsloping, insloping or crowning), ditch relief culverts, rolling dips, and other measures that effectively disperse road surface runoff (Figure 86). It is critical that all road surface drainage techniques adequately drain the road surface while still being drivable for the expected traffic.

A number of road drainage tools or practices can be employed to cost-effectively reduce hydrologic connectivity of forest, ranch and rural road systems. These include:

Road Shaping (outsloping, crowning and insloping)

- Road outsloping, with or without an inboard ditch, is the preferred method of road surface shaping for protecting water quality, reducing hydrologic connectivity, and minimizing fine sediment delivery to streams.
- The degree of outslope is typically at least 2% for low gradient roads (<4% road grade) but increases up to about 5% as road grade steepens.
- Outsloping alone is insufficient to drain the roadbed unless it is paved. The road surface must be drained with rolling dips or waterbars.
- Outsloped roads may or may not have an inside ditch. If the cutbank is wet or has seasonal springs, a ditch is used to drain emergent water to a ditch relief culvert or rolling dip that intercepts the ditch. The road surface can be, and still should be, outsloped.
- Steep roads (greater than about 14%) are difficult to drain, so crowned or insloped road shapes are employed. Ditch relief culverts and rolling dips must be frequent to prevent road and ditch gullyng.
- Crowned roads drain both to the outside fill slope and to the inside ditch. The crown or high spot is often the center of the road, but it can be shifted to the inside third of the road to reduce road runoff delivered to the ditch.
- Insloped roads normally need a ditch to carry road runoff and spring flow to the nearest ditch relief culvert or rolling dip where it can be discharged to a stable hillslope.

- Insloping is typically 3% to 4% towards the ditch, but the degree of inslope will increase as the grade of the road increases to quickly drain road runoff off the road and into the ditch.
- Insloped roads can be converted to outsloped roads to reduce hydrologic connectivity.
 - ▶ For roads needing a ditch, outslope the road so runoff drains off the outside road edge while the ditch drains relatively clear spring flow to the nearest stream crossing or ditch relief culvert.
 - ▶ If there is no spring flow in the ditch, the ditch can be filled (eliminated) while the insloped road is ripped and regraded to drain to the outside half of the road.
- Insloped roads are used where water cannot be discharged over the outside fill slope because of soil erodibility, fill slope instability or the proximity of a stream. This often includes newly constructed stream crossing fill slopes.
- ▶ For mainline roads less than 7–10% grade if used by lowboys or other low clearance vehicles or trailers. Rolling dips must be broad and shallow.
- ▶ For logging roads with log trucks, rolling dips are generally suitable on road grades up to 12% to 15%.
- ▶ On road grades up to 10 to 12% when in the snow zone or where unsurfaced roads are used when wet and/or slippery.
- ▶ On road grades up to 18% or more used by pickup trucks or other high clearance or 4-wheel drive vehicles.
- Ditch relief culverts or other road/ditch drainage structures that currently have gullies at their outlets, even if those gullies are stable, should be closed and relocated. Existing gullies are highly efficient corridors for continued connectivity, even if the gullies themselves are not actively eroding.
- Spacing of road surface and ditch drainage structures should be partially based on proximity to the watercourse, not just on road grade and soil erodibility. **The closer you are to a stream, the more closely spaced will be the drainage structures—so that no single drainage structure carries enough flow to connect to the nearby stream during a design runoff event.**
- **The closest drainage structure to a stream crossing is important, but the location of the next structure up the road is equally important. That spacing determines how much road and/or ditch runoff reaches the closest drainage structure, and hence its ability to connect to the watercourse.**

Road drainage structures

- Use rolling dips and road shaping to drain the road surface. Even if you increase the frequency of ditch relief culverts, you *must* also drain the road surface (using rolling dips or waterbars) and either get the road runoff into the ditch where it can be delivered to a ditch relief culvert, or drain it to the outside of the road (using rolling dips or waterbars) so it is discharged onto a stable, buffered hillslope. **In hydrologically disconnecting roads from streams, you must account for BOTH road surface runoff AND ditch flow.**
- Rolling dips on outsloped roads are recommended:

Other methods and considerations

- Install sediment retention basins where a connected ditch is likely to carry substantial runoff and eroded sediment. The sediment basins require maintenance.
- Road reaches that cannot be disconnected (e.g., the immediate approaches to stream crossings) should be well rocked, paved or otherwise surfaced. This is especially important for roads with significant traffic (they generate the most fine sediment) but is also important for native surfaced roads that are easily eroded.
- The connected road surfaces (i.e., road approaches) of native surfaced roads can be stabilized with mulch and grass as long as there is little or no traffic during the wet weather season. Otherwise, rock surfacing should be employed.
- Erosion and sediment delivery on seasonal roads can be further reduced by utilizing seasonal closures or traffic restrictions.

Connectivity goals should be established for individual driveways, as well as large ownerships, complete watersheds, and entire road systems. Everyone, from small landowners to large property owners, is responsible for reducing man-caused cumulative watershed effects. The ultimate goal would be to have roads where there was no hydrologic connectivity; hence, ridge roads or upper slope roads with no stream crossings and no connected road drainage structures. That's unrealistic in most areas. **Set a goal of 10% to 15% (or less) connectivity in a watershed or over a road network. Set targets of having 1) no more than 100 feet of connectivity (ideally 50 feet) per connected approach to each stream crossing wherever possible, 2) disconnecting all ditch relief culverts and rolling dips, and 3) surfacing (rocking, paving, etc.) those road reaches that are to remain connected.**

3. STREAM CROSSING CULVERTS

a. Culvert materials and durability

Culvert materials—The selection of culvert material type should be based on a combination of factors that will determine its suitability and longevity for the environment where it will be used. These factors include:

- durability (service life),
- structural strength,
- hydraulic roughness,
- bedding conditions,
- durability and abrasion resistance,
- corrosion resistance,
- expected wildfire frequency, and
- water-tightness requirements.

The pipe material used in a project may also depend on cost, required span, discharge, topography, soil chemistry, and climate.

The four most common culvert materials include steel (including galvanized steel), aluminum, plastic (HDPE) and concrete. Each material has advantages and disadvantages.

- **Steel culverts** are the most common culvert material used in the field and are available in a large range of shapes, diameters, and lengths. They are used in both corrugated pipe and plate forms (e.g., multi-plate culverts assembled by bolting). Corrugated metal pipes (CMP) are constructed from a single piece of galvanized steel and can be custom made in many lengths; 20 to 30-foot lengths are standard and easily

transported. Single pipes with a diameter greater than 12 feet usually have special traffic requirements for delivery or shipping.

Steel culverts are strong, relatively lightweight, easy to place, have a moderate service life (estimated 20–50 years) and are readily available. Sections are joined together by metal coupling bands with neoprene gaskets that provide good tensile strength. Their disadvantages include their susceptibility to corrosion (rusting) and abrasion, even with a galvanized coating. They have a shorter life than concrete. Steel culverts are also available as aluminized steel, where an aluminum protective coating is applied on both sides. The aluminized protective coating is more expensive but more resistant to corrosion than galvanized steel. Aluminized Steel can be considered equivalent to galvanized steel for abrasion resistance.

- **Aluminum culverts** are light weight (for a metal), have a long life, resist corrosion (do not rust) and are available as standard corrugated 20' sections. Aluminum culvert pipes are also corrugated and can be constructed as either structural plates or as pipes from a single piece of aluminum. Due to their high resistance to corrosion, aluminum pipes are often used in high corrosion environments such as saltwater applications. However, because of the "softness" of the metal they require special care when backfilling and can be damaged during handling (loading, unloading, etc.). Under similar conditions, aluminum culverts will abrade faster than steel culverts, so aluminum culverts are not recommended in highly abrasive environments with angular bedload and high stream velocities. Aluminum culverts have not been used as much since the mid-1980s because of their comparatively higher cost.
- **Plastic (HDPE) culverts** have the advantage of being lightweight, with the standard

20-foot section manageable by one person, and can be installed by smaller equipment than metal or concrete pipe. Because of its light weight, plastic pipe is easier to ship, handle, and install. Another advantage of plastic pipe during backfill is that it can be cut with a conventional chainsaw. Check locally to compare costs of plastic and steel culverts, as one may be preferable over the other in various size ranges. Currently, because of higher raw material costs, plastic pipe is more expensive than galvanized steel culverts for sizes over 24" diameter, but that could change over time.

Plastic pipe can be corrugated or double sided, although double sided pipe is greatly preferred for its strength. They are corrugated on the outside and smooth on the inside and commonly used for road projects with sizes (diameters) ranging from 24 to 120 inches (10 feet). The most common sizes are 18 to 48 inches diameter. Plastic pipe culverts exhibit good abrasion resistance and are virtually corrosion free (even in low pH soils), permitting a 50-year maintenance-free service life under most conditions. Plastic culverts are now available with steel reinforcing for extra durability and strength. Because of their smooth inside surface, they are hydraulically efficient (i.e., greatly increasing stream velocities in the pipe). Due to increased flow velocities, energy dissipation structures may be needed below steeply sloped HDPE pipes.

Plastic culvert sections are coupled by snap-on or slip-on bell ends, or strap-on coupling bands. These couplers provide adequate pull-apart resistance but are less secure than metal bands used for joining steel and aluminum culverts. Differential settlement under a new culvert can bend them and cause them to separate, so it is important to provide a well compacted foundation. Plastic culverts are problematic in areas subject to burning and wildfires because they can burn and melt while

in the ground if one end catches fire (Figure 87). End treatments using metal, concrete or masonry (flared end sections or headwalls) will limit the possibility of fire damage.

Solid wall HDPE pipe is a special-use culvert employed in trenchless culvert installations (pipe ramming) and a few other situations where strength is critical. This type of pipe is engineered to provide balanced properties for strength, toughness, flexibility, wear resistance, chemical resistance and durability. The pipe can be joined using several conventional methods, but the preferred method is by heat fusion (melting) which produces a leak-proof seal that is as hard as the pipe.

- Concrete** culverts are strong, resistant to corrosion, resistant to abrasion, and have the longest life span of common culvert materials (about 75 years). Concrete (reinforced) box culverts are commonly used on county- and state-maintained public roads. Circular pipes that are precast in segments and grouted together are sometimes used, but are more commonly employed as low flow drain pipes and sewer lines. Concrete and reinforced concrete pipes are composed of cement, aggregates, and possibly reinforcing material, and are available



in circular, arch, and elliptical shapes. Concrete arches are increasingly used for new projects designed for fish passage. The main disadvantages include their high cost, weight, and the requirements for special handling and careful placing. They require rubber O-ring gaskets at joints to prevent leakage. Concrete pipes require a uniform, well compacted bed and backfill because the joints are held together only by friction and are more easily disjoined. Concrete pipes are not as readily available in all areas and typically come in maximum 8-foot sections because of their heavy weight.

FIGURE 87. This plastic culvert was melted and burned out during a forest fire in central California. In fire-prone areas, metal culverts may be more suitable, or plastic culverts can be fitted with metal inlets and outlets that prevent burning (Pete Cafferata, Calfire).

TABLE 26. Abrasion and corrosion potential of common culvert materials

Material	Abrasion Potential	Corrosion Potential	Comment
Steel	Low to Moderate	Low to High	Low abrasion potential assuming zinc galvanizing is present and steel is not exposed. Once exposed, steel will corrode in most environments. Corroded steel is subject to accelerated abrasion. Aluminized steel is more resistant to abrasion and corrosion. Coatings decrease abrasion and corrosion potential. Corrosion is high in acidic environments.
Aluminum	Varies	Low	Aluminum generally does not corrode easily. Its abrasion potential is relatively low but highly dependent upon velocity and discharge as well as amount, size, shape and hardness of bedload.
Plastic	Generally Low	Low	HDPE and PVC may experience greater abrasive wear in an acidic environment. Both are relatively corrosion resistant.
Concrete	Low to High	Generally low	Abrasion potential for concrete is dependent upon the quality, strength, and hardness of the aggregate and density of the concrete as well as the velocity of the water flow coupled with abrasive sediment content. There is a correlation between decreasing water/cement ratio, increasing compressive strength and increasing abrasion resistance.

TABLE 27. Estimated increase in metal pipe service life based on metal thickness¹

Gauge	Multiply life by this factor
16	1.0
14	1.3
12	1.7
10	2.2
8	2.9

¹Johansen et al., 1997

Culvert durability—Pipe durability and corrosion resistance can be enhanced by several techniques, including protective coatings and treatments (Table 26), as well as increased gage thickness (Table 27). Under most conditions plain galvanizing of steel pipe is all that is needed; however, the presence of corrosive or abrasive elements may require additional protection. The metal pipe invert may be buried in the streambed or under concrete and other lining materials to reduce or eliminate the impact of heavy sediment loads that can cause abrasion and subsequent corrosion. To use a round pipe with a buried invert, the size of the round pipe should be

selected so that its capacity will be equivalent to that of the required unburred pipe-arch.

Corrugated steel pipes are typically the most susceptible to the combined actions of abrasion and corrosion, and this has led to a wide range of protective coatings. Some protective coatings meant to protect metal culverts from abrasion and corrosion can be abraded and discharged into the stream and therefore may not be allowed for culverts in perennial, highly abrasive or fish bearing streams. A variety of special coatings have been developed to extend pipe life under various environmental conditions.

Metal pipe may be protected with an asphalt coating to insure corrosion resistance throughout the pipe design life, and research has shown this can add 15 to 35 years of life in certain conditions. However, highly abrasive bedload can remove the asphalt coating relatively quickly, eliminating any corrosion resistance benefit. As an alternative to asphalt protective treatments, the thickness (gage) of corrugated steel pipes can be increased to compensate for loss of metal due to corrosion or abrasion. **While increasing the pipe's metal thickness to offset corrosive or abrasive effects can be specified, coatings are typically more cost effective.**

Abrasion is a metal culvert's worst enemy. Abrasion is the wearing away of pipe material by water carrying sands, gravels, and rocks (Figure 88). This also exposes steel culverts to increased

FIGURE 88.
Abrasive bedload transport has worn through this aluminum culvert invert.





FIGURE 89. Steel plates have been welded onto the lower 25% of the invert of this 6 ft diameter galvanized culvert. The steel provides protection against abrasion by coarse bedload transport.

corrosion when galvanized and aluminized coatings are worn off. However, all types of pipe material are subject to abrasion and can experience structural failure around the pipe invert if not adequately protected (Table 26).

A liner or bottom reinforcement utilizing excess structural material is one option to repair or extend culvert life with minimal reductions in flow capacity. **Welded steel plate is one viable alternative for use as an invert lining to extend culvert life (Figure 89). Concrete or bituminous lining of the invert of corrugated metal pipe is a more commonly employed method to minimize abrasion.** Sometimes, an asphalt coating can be used in combination with an asphalt or concrete paved invert. Simple repairs might include protecting the invert of the culvert with reinforced concrete. **Invert linings should cover the lower 25% of the periphery of circular pipes, and about 40% of pipe arches (Figure 90).** Visual examination of the size of the materials in transport in the stream bed and the average stream slopes will give you some idea of the expected level of abrasion and the paving you might need. You can also learn a lot by observing the condition of culvert inverts in similar streams nearby.

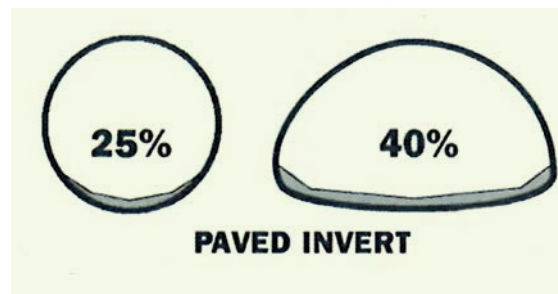
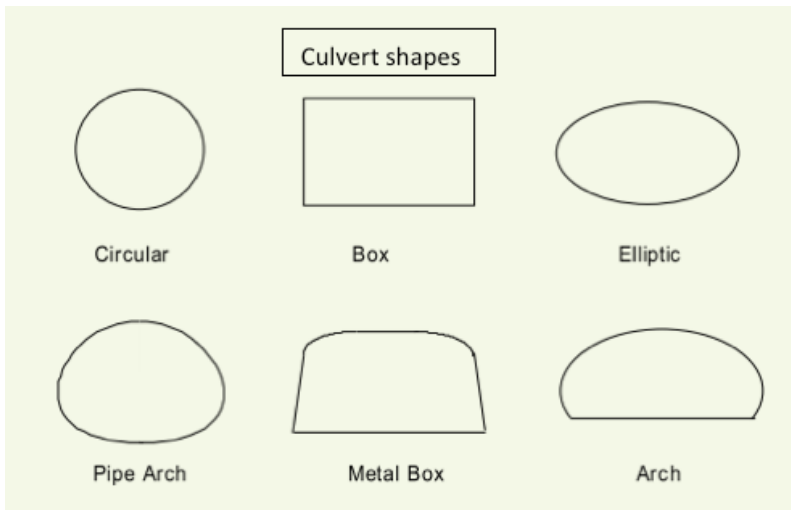


FIGURE 90. A paved culvert invert can add protection and extend culvert life in an abrasive stream environment without causing much reduction in flow capacity.

Where fish passage is required, culverts are often embedded into the alluvial streambed. This effectively covers the invert during most flow conditions and may help protect the invert from abrasion. However, in streams with significant bedload, placing culverts on flat grades (<3%) to encourage bedload deposition and protection against abrasion may also increase the failure potential of the pipe. The deposited sediment can substantially decrease the hydraulic capacity, ultimately leading to plugging or potential roadway overtopping on the upstream side of the culvert. **As a standard practice, culvert diameters should be increased two or more standard sizes over the required hydraulic opening in situations where abrasion and bedload concerns have been identified and the culvert has been embedded.**

**FIGURE 91.**

*Common culvert cross-sectional shapes. Each shape has advantages and specific uses that reflect their hydraulic capabilities and site conditions. Circular culverts are described by their diameter. Box culvert shapes are described by their width and depth. The other four culvert shapes are defined by a **span** (widest dimension) and a **rise** (tallest dimension). The **crown** is the top of the culvert and the **invert** is the bottom of the culvert.*

b. Culvert shapes

Selection of culvert size and shape should be based on engineering, stream morphology, biologic requirements, site conditions and economics. For example, migratory fish passage may indicate use of a specific culvert shape (e.g., an embedded, flat bottom arch) that conforms to passage requirements rather than round culverts. While round shapes are strongest, other shapes are sometimes required for specific designs or situations.

Culverts come in a variety of shapes, but the six depicted in **Figure 91** are the most common. By definition, culverts are completely enclosed forms, with tops and bottoms. A circular culvert is the most efficient shape because of its higher ratio of cross sectional area to the wetted perimeter, relative to other shapes with identical cross-sectional areas. **Circular culverts are by far the most common culvert shape. They are the most easily manufactured and usually the lowest in unit price (price/foot).** They are available in multiple sizes and materials, with a variety of thicknesses (gage). Circular metal culverts are usually ribbed or corrugated (annular or spiral) to increase strength; are structurally sound with no directional weaknesses; and are easy to handle, load, transport and install.

A narrow but high rectangular culvert is less expensive than a wide, low culvert of the same area. However, **the wider culvert has several advantages that are very important. The wider culvert spreads the outlet flow more; the outlet flow is shallower and has slightly slower velocity, causing less outlet erosion damage. The lower culvert is necessary where clearance is minimal and headwater depths are limited. However, a wide shallow culvert may not be suitable for fish passage during low flow conditions.**

Box culverts are usually made from concrete. Multiple box culverts are sometimes secured together, side by side, and partially embedded in stream channel sediments to act as a vented ford. Unless embedded, box culverts have relatively wide bottoms with shallow flows and are not suitable for fish passage during low flow conditions.

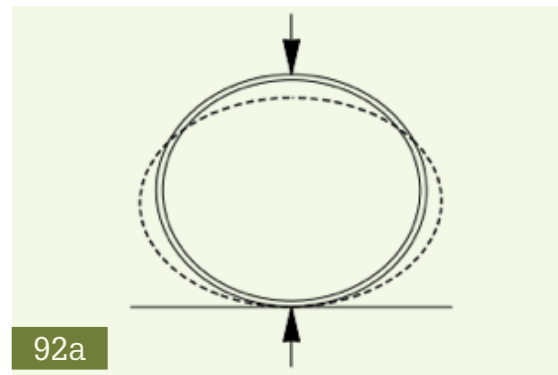
Elliptical culverts are often used where the road fill is shallow and a circular culvert of the correct diameter would not fit. They have a squished cross section and are wider than high. **Because of their shape, elliptical culverts are not as strong vertically as circular pipes.** Their structural strength requires thorough compaction of the bed and the sides of the pipe to provide confining pressures to counter vertical loads of the overlying fill and traffic.

Pipe arches, arches and metal box culvert shapes are designed to provide a wide cross section and a maximum span near the channel bed. Often, these culvert types are embedded into channel gravels to provide a natural substrate channel bottom within the pipe. These culverts are commonly used where fish passage is a requirement. They are also used to maximize culvert width and thereby allow larger floating debris to pass through the structure. While time consuming to assemble, multi-plate culverts are easier to transport and are generally used for culverts that have a diameter greater than 12 feet.

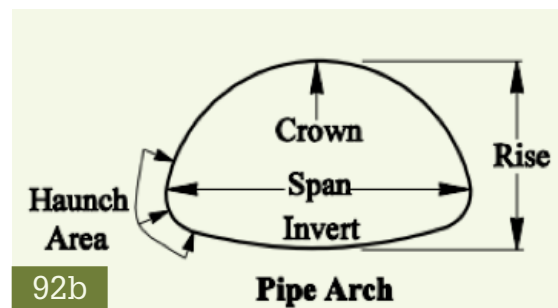
Except when concrete is used, each of these culvert designs are considered flexible pipes. As vertical loads are applied, a flexible culvert attempts to deflect. The vertical diameter decreases while the horizontal diameter increases (Figure 92a). **A flexible pipe will be stable as long as adequate soil support is achieved around the pipe.** When using flexible pipes, the bedding should be shaped to provide support under the haunches of the pipe (Figure 92b). The foundation must be able to uniformly support the pipe at the proposed grade and elevation without concentrating the load along the pipe. Establishing a suitable foundation requires removal and replacement of any hard spots or soft spots that would result in load concentration along the pipe. Bedding is needed to level out any irregularities in the foundation and to insure adequate compaction of the backfill material. In addition to providing structural support for a pipe, the bedding and backfill must be installed properly to prevent piping from occurring (Figure 92c).

Another type of stream crossing structure is sometimes called a bottomless arch culvert, open bottom arch or plate arch (Figure 93) as it is typically assembled on-site from individual plates bolted together to form the arch. In reality, it is an arch supported by lateral foundations and not a true culvert.

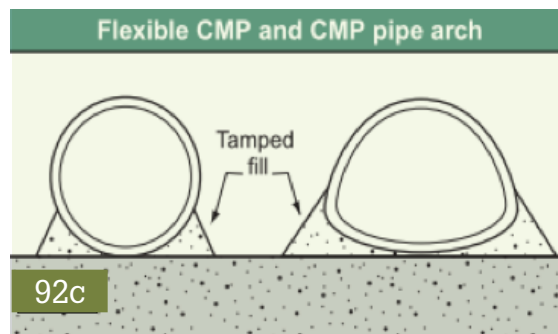
A prefabricated or poured concrete foundation is usually used to secure the arch within the streambed. It is actually more like a short span bridge than a culvert, although its "feet" are usually in or alongside the channel bed. It is often used in situations where fish passage is a requirement because the stream flows on the natural streambed beneath the arch, and the bed can contain the same type of channel complexity as upstream or downstream from the crossing. Bottomless culverts can fail by undermining if the concrete footings are not placed on a solid rock base or below the expected depth of scour, and if the streambed is unstable and subject to scour.



92a



92b



92c

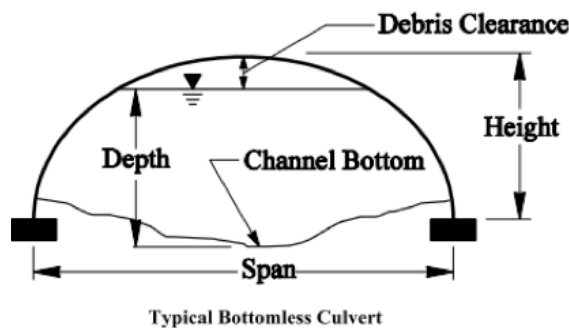


FIGURE 93. A "bottomless culvert" or plate arch is often used to meet fish passage requirements. Not a true culvert (culverts are closed conduits), it has lateral foundations that support the span and the natural channel bed carries streamflow through the structure.



FIGURE 94. The inlet of this 30-inch diameter culvert shows considerable rust where bedload abrasion has worn away the galvanized coating and exposed the steel to corrosion (rusting). A rule-of-thumb for evaluating culvert sizing in the field is if the rust line in a galvanized steel culvert is higher than about 20% of the culvert diameter (i.e., active bedload transport is occurring high up in the culvert), then the culvert is probably undersized. This culvert displays a 50% rust line, suggesting it is very undersized.



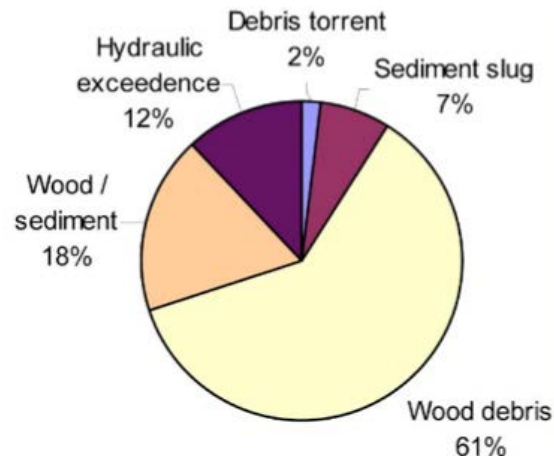
FIGURE 95. Woody debris does not have to completely plug a culvert inlet to significantly reduce its flow capacity. This culvert is at increased risk of plugging because of the large inlet basin that was excavated and because the inlet is not aligned with the approaching stream channel. These conditions encourage debris to float against the inlet rather than pass through it.

c. Culvert sizing

Flow capacity is one of the most important factors in stream crossing design, especially when using culverts. Culverts need to be large enough to meet design flood discharge requirements, not just normal flows (Figure 94). Permanent stream crossings to be built as a part of forestry operations in many areas are now required to pass at least the 100-year flood flow for that channel, including debris and sediment loads, even if they are to remain in the channel through only one winter season.¹² However, even a 100-year flood flow design does not mean that a culvert will not fail. **Woody debris and sediment transported down a stream channel can substantially increase the risk and likelihood of culvert plugging and failure occurring (Figure 95).** Stream crossing design should account for the possibility of culvert failure from both flow exceedance and inlet plugging. **However, research has clearly shown that culvert plugging by wood and/or sediment, and not flow exceedance, is by far the most common cause of stream crossing culvert failure (Figure 96).**

Culverts are typically sized using the estimated 100-year design flood flow and a culvert sizing nomograph that relates culvert size to design discharge, culvert inlet type, and headwater depth ratio. Methods for determining the 100-year design discharge include the Rational Method, USGS Magnitude and Frequency Method, and Flow Transference Method (Table 28).

The accuracy of each method is dependent on the size of the design watershed, and available precipitation and runoff data. Prepared culvert sizing tables may already be available for your area where someone has calculated peak flows and appropriate culvert sizes using one or more of these or other methods and culvert nomographs. Weather



conditions change quickly, especially in mountainous terrain, so it is often useful and more accurate to perform the calculations and size culverts yourself. Culvert sizing methods are described in more detail in Appendix A.

Except for the very smallest of crossings (<5 acres), it is generally not sufficient or adequate to estimate (guess) culvert sizes for stream crossings along forest, ranch and rural roads. Most field personnel have little personal experience or expertise with which to correctly estimate or visualize a 100-year flood flow, and many stream channels may no longer display physical evidence of large floods which may have occurred decades ago.

The culvert sizing methods used to determine culvert size for a given peak flow are based on culvert hydraulic flow capacity, and do not consider the influence of woody debris and sediment. Even small streams have the potential to transport debris and sediment and smaller culverts, such as 12" or 18" diameter culverts, are easily plugged with sediment and woody debris. **In addition to invaluable local observations and experience, there are several guidelines or measures that can be employed to reduce the risk of culvert exceedance and/or culvert plugging during peak flow events:**

FIGURE 96. Failure mechanisms for culverts occurring along forest roads in northwestern California associated with storm events with recurrence intervals less than approximately 12 years (Flanagan 2004; n = 57). Note that the specific distribution of failure mechanisms will vary depending on factors, including storm intensity and watershed characteristics. For example, see Furniss et al. (1998) for additional information on failure mechanisms following very large floods in the Pacific Northwest (Cafferata et al., 2004).

¹² See Appendix C for specific California Forest Practice Rule language for this requirement.

TABLE 28. Methods for calculating the 100-year design discharge.

Culvert sizing method	Suggested watershed area limit	Advantages	Disadvantages	Reference
Rational Method	<200 acres (preferred 100 acres or less)	Commonly used Uses local data	Local precipitation data may be difficult to obtain Accuracy is limited to drainage areas <200 acres	Kuichling, 1889 Dunne and Leopold, 1978 Cafferata, et al., 2004
USGS Magnitude and Frequency Method	>100 acres	Easy to use Equations are tailored to specific geographic areas Designs for rain-on-snow events Required data is readily available	Generalizes geographic areas Accuracy is limited to drainage areas >100 acres	USGS, 2012 Cafferata, et al., 2004
Flow Transference Method	Accuracy limited to distance (climatic differences) between gaged & ungaged streams	Easy to use More accurate than other methods if local stream data is used	Requires >20 years of gaging data Less accurate if ungaged stream is in different location or watershed	USGS, 2012 Skaugset and Pyles, 1991 Cafferata, et al., 2004

- Where possible, install culverts whose diameter or span is equal to, or greater than, the active channel width.
- Design culverts for no more than barrel-full capacity ($HW/D = 1.0$) in the design flow event (100-year flow), provided there is *no* significant floating debris or bedload sediment.
- Design culverts for no more than 2/3 barrel-full capacity ($HW/D = 0.67$) wherever debris and bedload sediment are likely to be present.
- Alternatively, where debris is present, it has been suggested that culvert diameters be increased one or two size diameters (12 to 24 inches) over the barrel-full design capacity to reduce the risk of plugging; and crossings of small streams should be designed with a minimum 24" diameter culvert (nothing smaller) to reduce plugging potential.

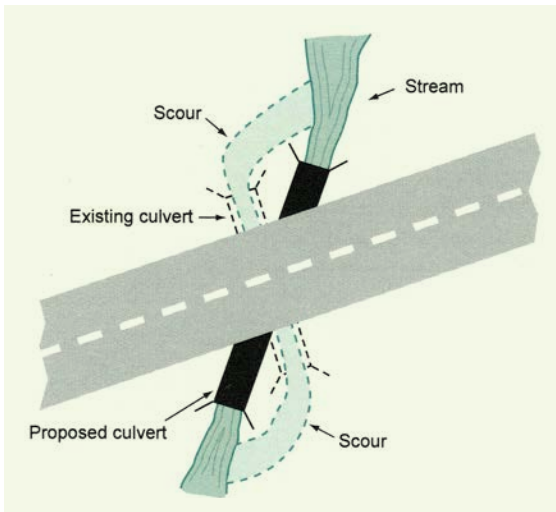
d. Culvert alignment and length

In the past, forest, ranch and rural road managers often attempted to minimize stream crossing costs by installing the shortest possible culverts

needed to take streamflow across the road. These culverts were often installed at a narrow point in the road, and set at a flat gradient, rather than sloping a long culvert down to the base of the fill. Gently sloped stream crossing culverts are easier to install and replace, but they require more maintenance, cause extensive gullyng of the fill slope and have a higher likelihood of plugging and washing out or diverting down the road.

Culverts should be aligned vertically with the natural channel. During construction, culverts are generally installed on or close to the natural stream bed so the outlet exits the fill at the level of the natural channel downstream from the crossing (i.e., mimic the natural channel gradient). **Steep channels will have steeply sloped culverts.**

To function properly, culverts should also be installed in-line with the channel's natural orientation. It is best for the road to cross at right angles to the stream channel, but regardless of the road alignment, the culvert should be placed parallel to the natural channel. In this manner, the inlet naturally receives the flow, plugging potential is reduced and flow from the outlet is directed



back into the natural channel and not against either of the channel banks (Figures 97 and 98).

Culvert length should also be estimated so that correct quantities of pipe will be available on the job site when stream crossings are being installed, and so the culvert can be installed to the base of the fill with the recommended barrel extension lengths (Chapter 5). Culvert length can be estimated based on the slope of the stream channel and the designed width of the road. A procedure for determining the correct length of culvert needed for stream crossings or ditch relief drains is outlined in Appendix E. Culverts that are too short for the crossing cause erosion of the fill and severe sediment pollution in the stream channel.

e. Culvert inlet and outlet treatments

i. Trash barriers and screens Even if a culvert is correctly sized for the design flow, small amounts of debris lodged against the inlet can significantly reduce its flow capacity. Debris may consist of anything from limbs and sticks or orchard prunings, to logs and trees floating down the channel. Silt, sand, gravel, and boulders can also be classified as debris and can partially or completely block culvert inlets (Figure 96). Typically, especially in forested environments, woody debris that lodges against the culvert inlet slows

FIGURE 97. Culvert alignment should be in relation to the stream and not the road. It is important that the stream enters and leaves the culvert in a relatively straight horizontal alignment so streamflow does not have to turn to enter the inlet or discharge into a bank as it exits. This figure shows a redesigned culvert installation that replaces the bending alignment that previously existed. Channel turns at the inlet increase plugging potential because wood going through the turn will not align with the inlet. Similarly, channel turns at the inlet and outlet are often accompanied by scour against the channel banks (Wisconsin Transportation Information Center, 2004).

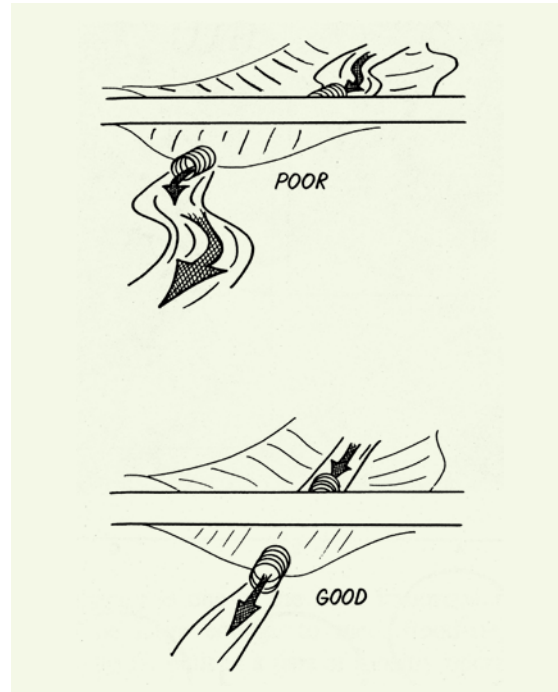


FIGURE 98. Culverts should be aligned with and placed in the bed of the natural channel so that flow enters and exits the culvert without having to turn or change gradient (USDA-SCS, 1983).

inlet velocities and sediment drops out of the water column and adds to or completes the blockage. The culvert site is a natural place for these materials to settle and accumulate.

Debris control structures (trash racks) at culvert inlets, and energy dissipaters at culvert inlets and outlets, are key components of stable culvert design, but winter maintenance of these structures is critical for success. The design of these protective structures is varied, and there are as many successful designs as there have been failures.

Debris control is best obtained by some type of grate or filtering structure of vertical or inclined poles dug into and built across the channel just upstream from the culvert inlet (Table 29). Creativity and experience can be used to develop a successful design. Drop inlet, slotted riser pipes have also proven to be effective in trapping debris without allowing the

culvert to plug. However, **care must be taken on fish-bearing stream channels to make sure passage is not blocked by such designs.**

Culvert trash racks should not be constructed right over or against the culvert inlet because they can easily plug and, in turn, prevent streamflow from entering the

TABLE 29. Debris classification and appropriate debris control structures¹

Debris classification	Debris deflector	Debris rack	Debris riser	Debris crib	Debris basin and dam
Light floating debris		✓		✓	
Medium floating debris	✓	✓			
Heavy floating debris	✓				
Flowing debris			✓		✓
Fine detritus			✓		✓
Coarse detritus			✓	✓	✓
Boulders	✓				

¹San Diego County DPW, 2012



FIGURE 99. This 6-foot diameter culvert with concrete head- and wing-walls has a trash screen built over the inlet to catch floating debris. The design is flawed because it screens and catches small woody debris that would otherwise easily pass through the culvert. During a flood event, debris will quickly cover the trash screen and effectively plug the drainage structure. Screen bars should be more widely spaced and the trash rack should be installed in the stream channel somewhere upstream of the culvert inlet.

culvert inlet (Figure 99). This is a common design flaw seen in culvert inlets on forest, ranch and rural roads everywhere. If constructed incorrectly, wooden crib boxes or metal grates built around or over the culvert inlet easily become clogged with debris and plug the pipe or significantly reduce its capacity to pass flood waters. **The most common problem with trash racks and screens placed over the culvert inlet is that small debris is often trapped rather than being allowed to pass through the culvert.**

Floating woody debris is one of the most common causes of culvert plugging and stream crossing failure during storm and flood events on forest, ranch and rural roads. Debris barriers and control structures can also be used to reduce the risk that floating debris will adversely affect culvert flow capacity. Both treatments reduce the risk of a culverted stream catastrophically failing. Debris control should be considered where experience or physical evidence indicates the stream transports a heavy volume of floating debris that could plug the inlet. **Not all streams are candidates for debris control structures, but active channels in steep mountainous areas, streams with tall, large volume fills, and stream crossing culverts that show evidence of past culvert plugging are places especially at risk.** Examining the maintenance history of each site is the most reliable way of determining potential problems, but maintenance records for both public and private low volume roads is usually sparse. Landowners, land managers, road managers and maintenance crews sometimes have the best local knowledge of the most problematic culverted crossings.

The most common treatments used to reduce the threat of culvert plugging include culvert upsizing so the culvert can pass larger debris, adding flared or mitered inlets, or constructing debris

screens or debris barriers that block large wood before it can reach the inlet area.

Debris Deflectors—A debris deflector is usually V-shaped and designed to deflect large floating debris or boulders carried as bedload in moderate to high velocity streams (usually found in mountainous or steep terrain) that might otherwise be trapped against the pipe inlet (Figure 100). It is located immediately in front of the culvert entrance with the vortex of the V placed upstream to deflect floating debris. **The horizontal spacing(s) of the vertical members should not exceed the diameter of a circular culvert or the smallest dimension of a non-circular culvert.** During large flood flows the culvert inlet is still susceptible to plugging if water and floating debris rises above the vertical members and debris is carried over the structure and into the culvert inlet. The addition of horizontal members on top of the structure can help prevent overtopping. Care must also be taken to ensure that woody debris

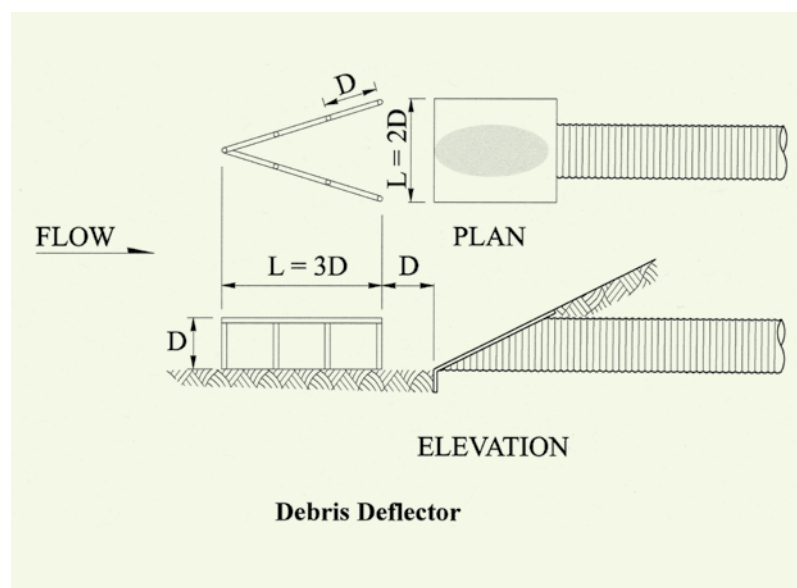


FIGURE 100. Debris deflector installed in front of a mitered culvert inlet with a sloping headwall. A deflector, by itself, cannot protect a culvert inlet from plugging with floating wood if the pipe is significantly undersized and flow ponds over the top of the deflector. The culvert should be properly sized for the design flow event (WDOT, 2010).

cannot float around the deflector and lodge against the culvert inlet. Frequent maintenance will be required to remove woody debris.

A recently developed alternative to the multi-post V-shaped debris deflector is a sturdy single-post debris deflector installed immediately upstream of the culvert inlet (Figure 101). Initial performance observations suggest this deflector is effective at turning debris so some can pass through the culvert and capturing the longest materials before the inlet can plug. A single metal post is embedded or pounded into the center of the streambed one culvert diameter distance upstream and directly in front of the culvert inlet. To be effective, it is important to increase the diameter and strength of the post, and the depth of installation into the streambed, because as stream size increases so does the size of the floating debris and the hydraulic forces. If necessary, the post can be strengthened using one or two support bars fastened to the top of the culvert or embedded back into the fill face.

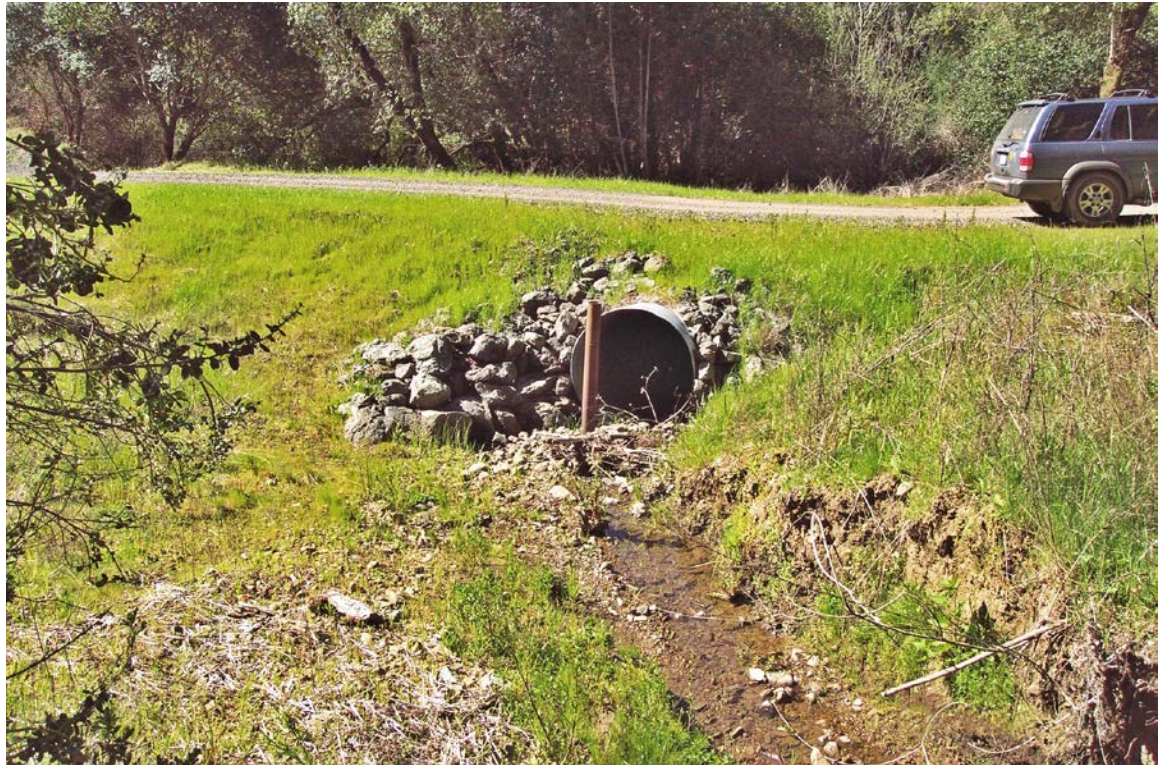
The vertical bar should extend at least one culvert diameter above the streambed. Floating debris that hits the post is turned lengthwise and parallel to the stream and culvert so that it will float into and through the pipe. If debris is longer than the culvert is wide, it will be turned and then be wedged between the post and the adjacent stream bank, fill slope, or the outside edge of the culvert. The inlet will remain open. Sediment will also stack up against the retained wood and behind the post, rather than directly against the culvert inlet. As with all styles of debris barriers and deflectors, the woody debris can then be cleaned out by hand or with heavy equipment after the storm is over to restore full channel capacity.

Although experimental, this design has shown promise for protecting all sizes of culvert installations and additional observations, case studies and research is needed.

Debris Racks—A debris rack is a screening structure placed across the stream channel upstream from the culvert inlet to be protected

FIGURE 101.

Single post debris deflector placed one culvert diameter in front of the culvert inlet is intended to turn short debris parallel to the stream flow, so it can pass through the culvert, while trapping long debris against the banks before it can plug the inlet.



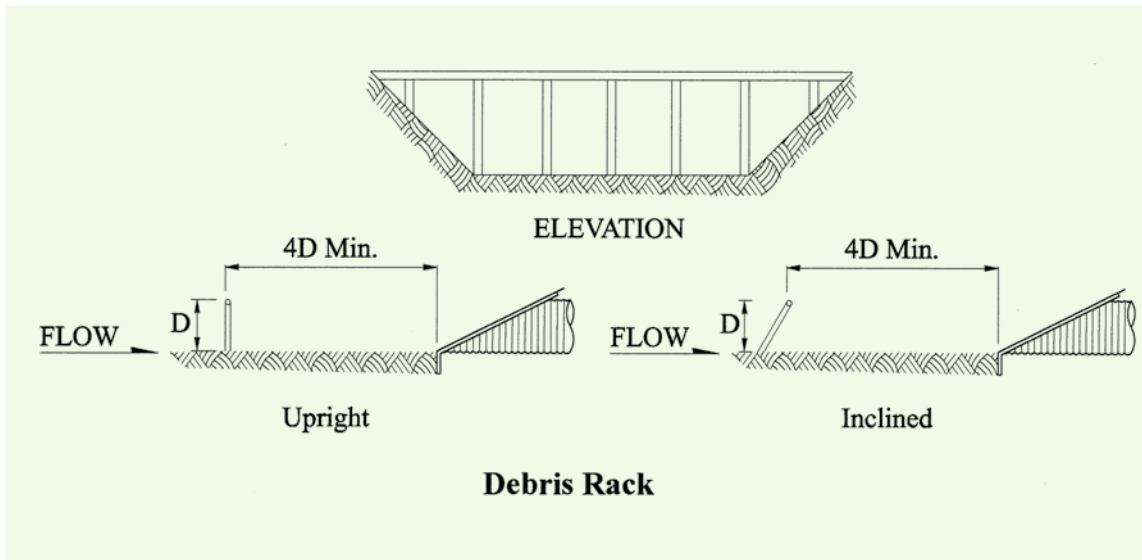


FIGURE 102. Multi-bar debris rack with vertical or sloping bars embedded in or wedged against the streambed. Bars should be spaced one culvert diameter apart (WDOT, 2010).

(Figure 102). It should be constructed with screening bars in an upright or downstream-inclined position attached to a horizontal support member. **The bars should be spaced at approximately the diameter of a circular culvert or the smallest dimension of a non-circular pipe.** The intent is to allow smaller debris to pass through the screen and through the culvert inlet while screening and retaining all longer pieces that would be more likely to plug the inlet.

Debris racks should be placed far enough away from the culvert entrance so that debris will not block the pipe itself and yet not so far that falling limbs and other debris sources could enter the channel between the debris rack and the culvert (Figure 103). Floating debris and sediment backed up behind it will frequently be trapped behind the rack and require cleaning after storm events (Figure 104). Preferably, there should be access for work crews and/or a backhoe to clean it and perform repairs. Like debris deflectors, debris racks trap most of the floating wood in the

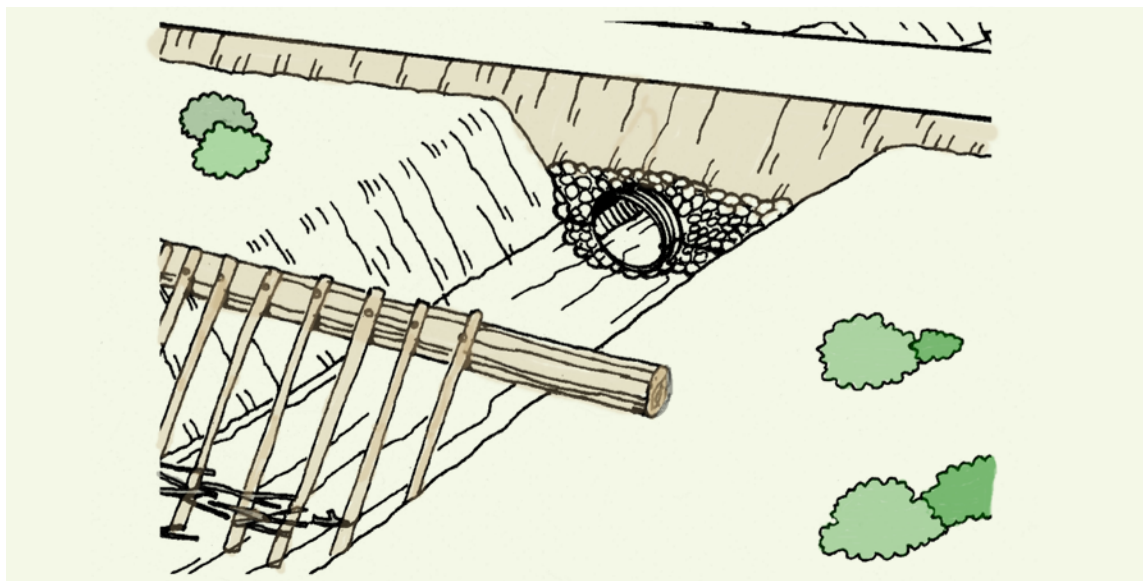


FIGURE 103. Sloping debris rack on a non-fish bearing stream channel (Keller and Sherar, 2003).



FIGURE 104. *The most effective trash rack or screen is one placed across the channel slightly upstream of the culvert inlet, with the spacing of the vertical posts approximately equal to the span or diameter of the culvert. Closer post spacing catches too much debris, and wider spacing lets large debris through that could plug the culvert inlet. The 4 posts on this debris rack are a little too closely spaced and one more post should be added to each side to prevent flanking during a flood event.*



FIGURE 105. *In larger streams, debris racks may need to be placed farther upstream from the culvert inlet. Limbs and branches floating down the channel are caught by the screen, but flow will back up and flood around the structure (as in this photo) if it is not extended into the bank. Debris racks or screens need regular maintenance to remove the accumulated debris. They should be made of durable metal posts and I-beams sized to resist the expected stresses and sunk deeply into the streambed for long term, secure installations.*

stream and will therefore require regular maintenance to prepare them for each storm event.

Debris control devices are often unsightly and expensive and they often require considerable maintenance after each flood occurrence (Figure 105). If the storage capacity of the debris trap is too small for a major storm, water may be diverted over or around the debris barrier and into the culvert entrance causing additional channel bank erosion and damage from stream crossing failure. Regardless, they can save a large stream crossing fill from failing, prevent loss of access and save thousands of dollars in reconstruction costs.

ii. Culvert Inlet Treatments The type of end treatment used on a culvert inlet depends on many interrelated and occasionally conflicting considerations. They can be designed to increase

culvert flow capacity and to provide some protection against culvert plugging. The designer must evaluate safety, debris capacity, hydraulic efficiency, scouring, and economics against the potential beneficial effects the end treatment might have on stream crossing stability.

The most common inlet treatments include the standard projecting barrel along with mitered inlets that are cut to the same slope as the adjacent fill, and flared inlets that are attached to the barrel of a standard culvert; each with or without rock armor along the fill slope (Figure 106). Flared inlets are available for most culvert shapes and culvert materials, but they are usually more expensive than mitered inlets.

Armor is also commonly used around the inlet and outlet of culvert pipes, where the ends emerge from the fill slopes (Figures 79,

FIGURE 106. Three common types of culvert inlet treatments include: projecting barrel, mitered or beveled inlet, and tapered or flared inlet. The most common, least costly, but least efficient inlet is the projecting barrel inlet.

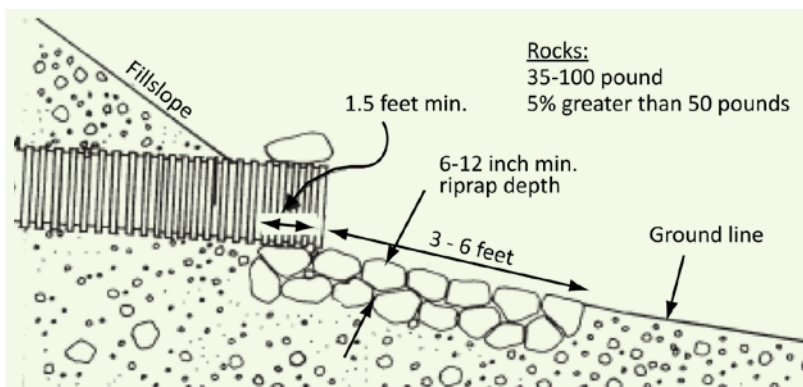
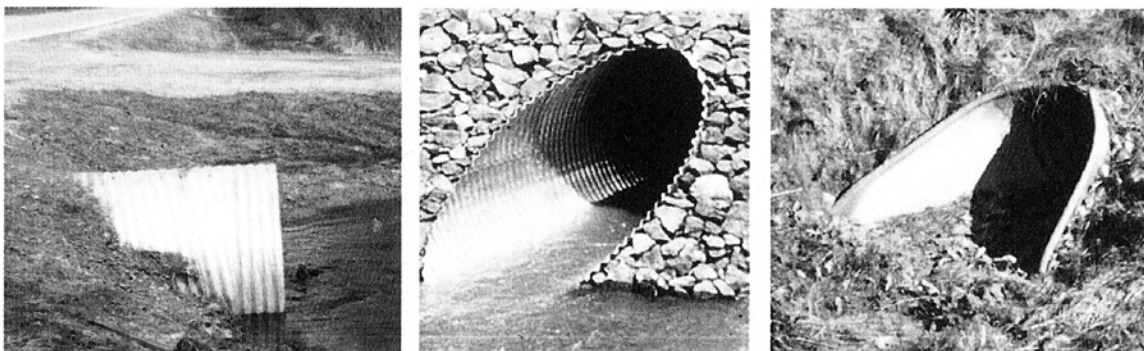


FIGURE 107A. Riprap armor at culvert outlet (Modified from: Kellar et al., 2011).

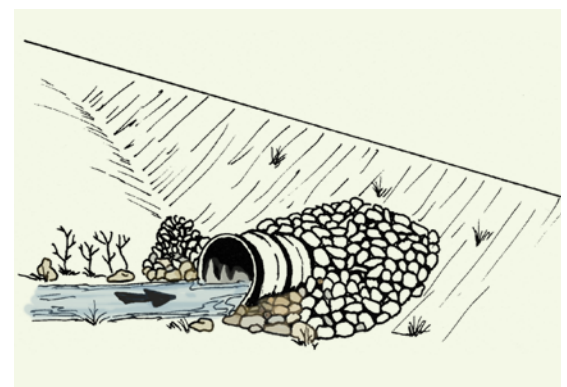


FIGURE 107B. Riprap armor at culvert inlet (Keller and Sherar, 2003).

106, 107a and 107b). This armor serves to protect the culvert from erosion during high water (at the inlet) and from splash erosion (at the outlet). Placed at the base of the slope it also serves to trap sediment that is eroded from newly constructed stream crossing fills until they revegetate and stabilize.

Projecting Ends—A projecting end is a treatment where the culvert barrel protrudes out of the embankment (Figure 108). It is by far the most common type of inlet configuration and works well for almost all stream channels. The primary advantage of this type of end configuration is that it is the simplest and most economical of all treatments. Projecting ends also provide excellent strength characteristics since the pipe consists of a complete ring structure out to the culvert opening. The simplest and least expensive way to fortify a projecting culvert is to apply rock armor to the fill slope around and above the inlet (Figure 107b)

There are several disadvantages to projecting ends. For metal, the thin wall thickness does not provide flow transition into or out of the culvert, significantly increasing head losses and reducing flow capacity. The projecting inlet is also considerably more susceptible to plugging with floating

debris or sediment, but this can be addressed with the installation of a debris deflector.

Tapered and Mitered Inlets—A **tapered inlet** is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section (Figure 109). It can be a side tapered inlet (where the culvert widens at the inlet) or a slope tapered inlet (where the bed slope increases into the culvert inlet). Tapered inlets improve culvert performance (discharge capacity) by up to 25% for side tapered culverts inlets, and up to 100% for vertical tapered inlets, by providing a more efficient control section (the throat). The wing walls deflect or trap large floating debris before it can plug the inlet and the concrete floor provides for a smooth surface that encourages rocks and sediment to pass through the culvert rather than be deposited at the inlet.

A **mitered inlet** consists of cutting the end section of a projecting culvert at an angle to match the embankment slope surrounding the culvert, thereby significantly increasing the effective area of the culvert inlet opening (Figure 106). It is relatively easy to either retrofit an existing projecting inlet and/or convert it to a mitered configuration.

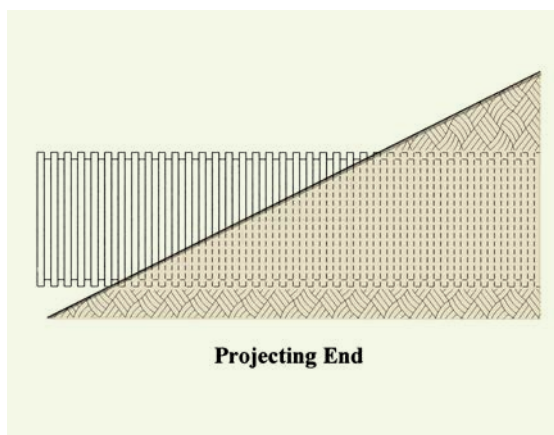


FIGURE 108. The projecting barrel inlet is the least efficient but the strongest, least costly and most common culvert inlet type.

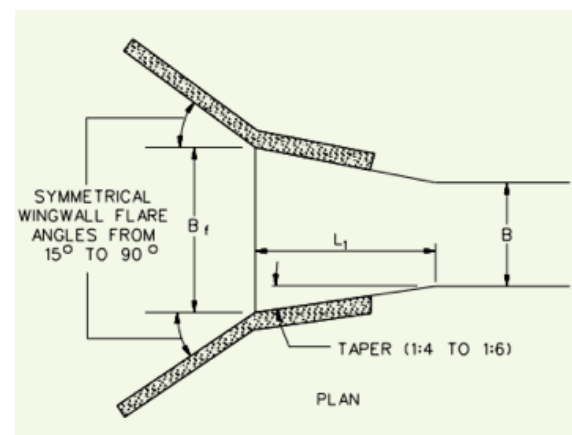


FIGURE 109. Side tapered culvert inlet with wing walls added.

A mitered end provides a larger, hydraulically more efficient opening than a projecting end, provides some measure of protection against plugging with floating organic debris, and is relatively cost effective to make. **Mitered ends should be considered for culverts about 6 feet in diameter and less, but can be constructed on larger diameter culvert ends if they are reinforced with a headwall, slope collar or fill slope armoring up to the height of the inlet** (Figures 103 and 107b). Unless they are of heavy gage steel, unsupported miters on larger culverts can weaken the inlet structure and make it susceptible to deformation during high flows.

The standard mitered end section should not be used on culverts placed on a skew of more than about 30 degrees from the perpendicular to the centerline of the road and fill. It is critical to have the mitered inlet be within about 6 inches of the fill face; a mitered pipe extending 1–2 feet has lost its hydrologic efficiency advantage by 25 to 50%. Wing walls may be needed to turn flow into the mitered inlet. Cutting the ends of a corrugated metal culvert structure to an extreme skew or miter to conform to a gentle embankment slope reduces the strength of the end section, in comparison to a round pipe. Headwalls,

riprap slopes, slope paving, or stiffening of the pipe may be required to stabilize the ends.

Flared End Sections—A metal flared end section, or flared inlet, is a very economical and easily installed, manufactured culvert end that is bolted to the culvert barrel and provides a simple transition between the culvert barrel and the streambed (Figure 110). Flared inlets increase culvert capacity the same as side tapered inlets (from 25% to 50% greater flow capacity than a projecting barrel inlet) by allowing flow to smoothly constrict into the culvert entrance. **Flared culvert inlets are often installed on culverts where the streams exhibit high rates of sediment transport that could otherwise cause culvert plugging.** The sheet metal bottom provides a very smooth surface at the inlet where sediment and rocks cannot come to rest and are easily flushed onto and through the culvert. Flared culvert inlets also act like mitered inlets by either wedging and trapping woody debris before it can plug the inlet, or allowing longer pieces of wood to ramp up over the inlet while streamflow enters the culvert barrel. Flared end sections are typically used only on circular pipe or pipe arches. Flared ends are generally constructed out of steel and aluminum to match the existing culvert

FIGURE 110. This 52-inch diameter culvert has been fitted with an attached flared inlet. Bolt-on, flared culvert inlets are available for most sizes and shapes of culverts, as well as for most culvert materials. The side flare improves hydraulic efficiency of the inlet, and the sheet metal bottom ensures that sediment is not able to accumulate or potentially plug the culvert entrance. The funneled sidewalls act to turn debris so it can enter the culvert, and its sloping sides causes larger debris to ramp up above the inlet, thereby reducing its plugging potential.



material. However, either type of end section can be attached to concrete or plastic pipe with special attachments. HDPE plastic inlets are available, but less common.

A flared inlet is usually the most feasible option in smaller pipe sizes and should be considered for use on culverts up to 48 to 60 inches in diameter. For larger diameters, end treatments such as beveled (mitered) openings, prefabricated or poured concrete headwalls, wing walls and aprons may be more economical than the flared end sections.

Headwalls and Slope Collars—A headwall is a rock, masonry or concrete frame around a mitered or barrel culvert inlet (Figure 111). It provides structural support to the culvert and eliminates the tendency for buoyancy. It also increases the hydraulic efficiency of the inlet, especially compared to projecting barrel inlets. A headwall is generally considered to be an economically feasible end treatment for metal culverts that range in size from 6 to 10 feet, but can be used on smaller culverts to shorten the fill slope and improve hydraulic

efficiency (Figure 111). Metal culverts smaller than 6 feet diameter generally do not need the structural support provided by a headwall. Headwalls are structurally beneficial on plastic culverts larger than 3 feet. A typical headwall on a mitered culvert is shown in Figure 112.

iii. Snorkels and risers The objective of culvert snorkels and riser inlets is to prevent sediment and floating debris from plugging culverts and causing subsequent overtopping, fill failure or stream diversion. Risers are also used to trap sediment, reduce sediment concentrations and sediment discharge, and protect downstream water quality. They are often used in recently burned watersheds where you expect significant soil erosion, and sediment and debris transport during a runoff event. They might also be used in retention basins downstream from a large earth moving project where unavoidable erosion and sediment transport is expected to enter the stream. Risers and snorkels are sometimes used where storm patrols and maintenance is uncertain and they serve as safety valves to alleviate the effects of culvert plugging.

FIGURE 111. This concrete vertical headwall was installed on a ranch road stream crossing. The headwall increases culvert efficiency compared to a projecting barrel inlet, but is still prone to plugging by floating organic debris.





FIGURE 112.

This sloping concrete headwall was constructed around a mitered culvert inlet. The mitered headwall inlet improves culvert inlet efficiency, and the concrete counters the potential buoyancy effects a weak plastic pipe would be subject to at peak flow events.

Snorkels are designed to provide a second inlet into the stream crossing culvert that will be used only when and if the main culvert inlet becomes plugged with sediment or woody debris (Figure 113). If that occurs, rising waters will eventually pour into the snorkel riser pipe through the slotted sides or into the open top. Snorkels are installed as a vertical riser welded over the top of the existing stream crossing culvert, usually at least several feet back from the current culvert inlet.

It is preferable for the vertical snorkel riser to have the same diameter as the main culvert so that it can accommodate design flood flows if the main inlet becomes completely plugged. The snorkel extends vertically usually 5 to 8 feet, but no more than about half the headwall height, and terminates in an open pipe. Snorkel risers may or may not be slotted along their length to allow for inflow when the main culvert plugs and water rises. The top of the vertical riser on a snorkel pipe is often screened for safety purposes and to prevent plugging by floating debris. However, this screen also increases the likelihood that the riser will be plugged too.



FIGURE 113. *The slotted culvert inlet snorkel on this small stream crossing culvert is designed to provide emergency overflow protection in case the main culvert becomes plugged with debris. Unfortunately, because of the small spacing of bars on the top of the riser, the snorkel could also become plugged with floating debris. To be effective, the top inlet or “glory hole” at the top of the snorkel riser must be lower than the adjacent road and ditch.*

In contrast, drop inlet riser pipes are usually extended vertically from a 90 degree elbow fitted over the culvert inlet. The drop inlet riser should be the same diameter as the stream crossing culvert, but no smaller than 36" diameter to provide the needed flow capacity and to prevent plugging. Very tall risers (over 8 feet) in larger drainages may require anchors to keep them from moving with the expected currents and flow velocities. Risers can also be toppled by high flows or debris flows if they are not well secured. However, **risers should not be higher than about half the fill height to prevent developing hydrostatic head and saturation in the fill.**

Risers take advantage of the basin behind the fill to store both water and sediment. Slotted riser pipes function to encouraging temporary ponding of water while sieving out most debris and transported sediment (Figure 114). A riser pipe is usually slotted over its vertical length to allow water passage during rising water levels. Slotted risers are open at the



top or the top has a debris screen for safety that is also intended to prevent plugging of the riser. Sediment that accumulates in the basin behind the road fill will need to be excavated and hauled away during the dry season so the basin has full capacity to trap sediment the next wet season.

Risers do not increase the flow capacity of the stream crossing culvert. It is critical that the opening at the top (the glory hole) is not plugged with floating debris as this is the only significant opening from which to release flood flows into the culvert. If it plugs, water levels may continue to rise until they overtop the road fill and erode the crossing.

Risers should only be employed in specific circumstances and settings. Risers are sometimes used on small streams that carry excessive sediment loads and pollute downstream areas; where trapping and removing the sediment is desired. Risers are sometimes used to protect transportation infrastructure on roads with large fills where access and road use must be maintained.

FIGURE 114. *This culvert inlet in a recently burned watershed has been fitted with a slotted riser so that flood flows pond in the large inlet basin, the stream drops its coarse sediment load, and flood waters gradually recede. If ponded streamflow reaches the top of the riser pipe it will pour into the top opening. Basins with slotted risers are sometimes used where sediment delivery from upstream areas is expected to be high (e.g., after a wildfire) and sediment needs to be retained to protect downstream areas. All sediment basins need to be intermittently cleaned of accumulated sediment to maintain needed capacity.*

However, by design, risers reduce the hydraulic efficiency of the culvert, so they may increase the vulnerability of some culverted stream crossings to excessive ponding and potential overtopping. Risers cannot be used in areas where fish or other aquatic passage is required.

f. Emergency overflow culverts

In situations where a culvert is placed at the base of a very high fill (over 20 feet) on a stream with significant debris problems, it may be necessary to install an emergency overflow or bypass culvert in case the main culvert becomes plugged with debris. A plugged culvert in a high embankment can impound a tremendous volume of water. The sudden failure of a high fill is possible, and this could result in either catastrophic road failure (via deep gulying of the fill), or a debris flow traveling great distances downstream. The overtopping and failure of large stream crossing fills can overwhelm downstream channels, destroy aquatic habitat in valuable streams and rivers, and potentially endanger

downstream property owners and roadway users. **In deep fills an emergency bypass culvert will limit the level of impounded water behind a stream crossing fill to a safer level, so the fill is less likely to become saturated or overtopped. This is a risk reduction measure that provides significant protection.**

Emergency overflow culverts should be installed on large, deep stream crossing fills where the main culvert at the base of the fill is either 1) too difficult to clean and maintain, or 2) undersized, but funds are not available to properly upgrade it to current design standards. The reach of the excavating equipment may dictate the maximum depth to which the overflow culvert can be installed. In general, the overflow culvert should be installed half way down the fill from the road surface or, where possible, no more than 5 to 10 feet above the crown of the main culvert (Figure 115). Ponding should be minimized to the extent possible. If the fill is very deep, the emergency overflow pipe should be installed by trench excavation about 15 vertical feet below



FIGURE 115. *Where stream crossing culverts may not be adequately sized for the design flood flow, and they are not scheduled for immediate replacement, they can be fitted with more efficient entrances (such as the headwall seen here) as well as emergency overflow pipes installed higher in the fill. The overflow pipe provides relief during the large flow events or when the main culvert becomes plugged with debris. This overflow culvert experienced flood flow during the first winter after it was installed (See Figure 111).*

the elevation of the road surface, so it can be cleaned using a backhoe during a storm event.

Bypass culverts may also be used on stream crossings where it is not feasible or desirable to construct a critical dip at the crossing fill (perhaps the road grade is too steep for a functional dip), thus serving as an alternative to a critical dip. Although emergency overflow culverts may not be as effective at preventing stream diversions as a dipped crossing fill, they still offer increased protection to overtopping and/or stream diversion, at a greatly reduced cost, whenever the main culvert becomes plugged with debris. **Ideally, a stream crossing fill with an emergency overflow (bypass) culvert should also have a dipped road fill, or be fitted with a critical dip, so there are multiple layers of potential protection against catastrophic stream diversion or crossing failure.**

There is no magic formula for calculating the proper size (diameter) of an emergency overflow culvert. A reasonable estimate is that it should be about 50 to 60 percent of the diameter of the main culvert, and not less than 36 inches diameter for streams with large fills. The large ponded reservoir behind the fill will significantly reduce and broaden the timing of peak flood flows in the stream channel, so design-size culverts are not likely to be needed. If possible, the bypass culvert should be placed out of the main flow path so that the risk of it also plugging due to floating debris is minimized. In addition, the overflow culvert must be fitted with an anchored, full round downspout on the outside fill face to carry flow to the base of the fill slope and back into the natural channel without causing fill slope erosion.

4. BRIDGES

Bridges almost always have less environmental impact than culverted stream crossings.

They usually provide much better clearance for extreme floods and floating debris, and bridges are the ideal crossing structure for meeting fish passage requirements. **The cost of portable bridge installation is now highly competitive with the installation of plate arches and large size culverted (filled) stream crossings in many situations.**

Bridges may be temporary or permanent. Temporary bridges can be constructed across a stream channel, and then removed upon the completion of operations. Because little soil is disturbed in or along the stream channel, the crossing site can easily be returned to its original condition. **Surplus railroad flatcars are the most common, low-cost alternative to conventional bridge construction used for forest and ranch roads.** They can also be easily hauled on low-boy trailers from site-to-site and require little preparation prior to installation.

Railroad flatcars can also be left in-place and used as permanent bridges (Figure 116). The bridge abutments may be made more permanent by the use of precast or poured concrete supports. Permanent bridges were once commonly constructed out of log stingers (large diameter logs extended across the stream channel), but this type of bridge is difficult to engineer and large logs are hard to find. Heavy duty portable bridges are now constructed of prefabricated steel I-beams with a steel or concrete driving surface and pre-made abutments that can be lowered in place (Figure 117). Portable, pre-fabricated, truss bridges, more commonly known as Bailey Bridges, are also commonly used and can be used for both temporary and long term installations.

Bridges used for commercial hauling and public vehicle traffic typically require an adequate engineering design and a qualified structural engineer should be consulted. Private roads built or converted for use to access homes or residential developments may also require



FIGURE 116. Low cost railroad flatcar bridges can be used for temporary crossings of incised stream channels, or they can serve as permanent water-course crossings. This 65-foot bridge spans the entire channel and was placed on large log abutments. The side-slopes have been protected with heavy rock riprap, and the natural channel width has been maintained through the crossing.

engineering certification. In wildland areas those bridges must be capable of supporting fire trucks, water trucks, heavy equipment and other emergency vehicles. Most public roads, even low volume roads in state and federal forests, are required to have an engineering design for bridges, no matter how few cars use it or how light the vehicles are. **At a minimum it is wise to have a qualified and experienced structural engineer certify a bridge's weight bearing load limits prior to installation, and to post that load limit at the entrances to the bridge.**

If the bridge is prefabricated it has been constructed and delivered with known specifications. If you are using a refurbished flatcar, it

may have unseen structural weaknesses from an earlier accident and should be inspected.

Not every stream crossing is equally suited to bridge installation. Generally, bridges should be installed at right angles to the channel with enough clearance beneath the structure to pass the design flood flow (including floating organic debris—usually considered to be 3 feet of freeboard). Incised stream channels with relatively flat or low gradient approaching slopes are well suited to bridges. **Wherever possible, the stream channel should be spanned without using center supports that could alter channel capacity or be subject to channel bed scour or floating debris during flood events. Abutments should be placed well out of the flood zone of the stream, and**

FIGURE 117. This 50-foot bridge is constructed from steel I-beams spanning the channel and secured to the slopes on either side of the channel using steel sheet pile abutments. I-beam bridges can be constructed on-site or they can be specified, prefabricated and assembled elsewhere, and then shipped and installed as a complete unit.



they should not constrict the natural channel's flood capacity. Abutment areas exposed to flood waters should be armored to protect them against erosion, but the placed armor should also not constrict the channel cross sectional area and flood flow capacity. Finally, the surface of the bridge should be slightly elevated above the adjacent road approaches to ensure the approaches are hydrologically disconnected.

Because bridges are generally straight and fairly narrow, all the vehicle turning needed to cross the channel must be incorporated into the approaching road segments. Crossing deeply incised stream channels with steep sideslopes may

require extensive excavation (and endhauling) of material from the approaches before a bridge can be installed across the channel. One method of avoiding some excavation is to install dual, side-by-side flatcar bridges, or double wide I-beam bridges so that some vehicle turning can be performed on the deck of the bridge, or to utilize special construction techniques which allow some turning on the structure (**Figures 118a, 118b**).

The simpler, less expensive bridges are usually less than 100 feet long. For example, railroad flat cars generally come in standard lengths of about 55 feet and 90 feet. It is important to be sure the bridge is able to support the design loads that

FIGURE 118A. *This railroad flat-car bridge has been structurally modified to allow for some truck turning on the bridge deck. Deeply incised stream channels with steep sideslopes would require extensive hillslope excavation if a straight approach was utilized.*



FIGURE 118B. *Turning on the bridge can also be accomplished by using a double-wide flat-car bridge (two flat cars welded together), where the bridge width is sufficient to accommodate some turning by trucks with long trailers.*



will be passing over the road. Longer bridges may require added superstructure supports, or a center pier to support the extra length (Figure 119). Where such complications are present, an engineer should be consulted before fabricating and installing a bridge structure.

5. ARMORED FILLS

An armored fill crossing is built to convey stream flow directly across the roadbed and down an armored fill slope to the natural channel below (Figure 120). A vented porous rock fill is a special case of an armored crossing, where most low discharge streamflows pass through a porous fill rather than over the road surface. Armored fill crossings and porous rock fills are not technically ford crossings. Ford crossings are built directly across the natural streambed in low gradient settings and do not contain any road fill material. As stream gradients increase, it is impossible to build a stable roadbed across the stream channel without raising up the road with fill materials for a level or dipped driving surface into and out of the crossing.

Armored fills—Generally, an armored fill crossing is intended for low-volume traffic areas, such as ranches, seasonal logging roads, utility access routes, open space districts, and parklands. Armored fills are a good design for ephemeral and intermittent streams when the majority of traffic will be crossing during low flow or dry conditions. They should not be built in perennial streams or in fish-bearing streams. When designed and properly built, armored fill crossings are a good option for a low maintenance, remote access routes. If rock armor is locally available they will be less expensive to install than culverts and bridges, and they require less frequent inspection and maintenance.

Constructing an armored fill crossing involves a multi-step process (Figures 121a through 121f). In general, armored fill crossings are constructed with a wide dip through the road



FIGURE 119. It is important that all bridges used to transport vehicles and equipment be properly designed or evaluated by a structural engineer before they are put into use. This long, truss-reinforced bridge was fabricated from two 90-foot long railroad flatcars with a center pier support that can be folded up under the bridge during winter flood flows. The center pier must be put down to haul heavy loads across the bridge.



FIGURE 120. This armored fill crossing of a steep, ephemeral stream was constructed to provide a low maintenance crossing. The crossing has been deeply dipped to reduce the volume of road fill and to eliminate the potential for stream diversion. The fill slope has been heavily armored through the axis of the crossing to contain flood flows and prevent down-cutting. Armored fills cannot be used on fish bearing streams.

FIGURE 121A. The following photos depict the typical steps for constructing an armored fill. The original undersized, perched culvert on this intermittent stream was prone to inlet plugging and outlet erosion and it was located on a road that received only intermittent maintenance.



FIGURE 121B. In the first step, the stream crossing culvert is removed and the fill is broadly dipped out in a U-shape using a dozer. The dip must have enough capacity to pass the 100-year design flow without diverting. Spoil material is either endhauled to a stable disposal site, or it is bladed down the road approach(s) where it will not erode and enter the stream. Some fill is left in the crossing so vehicles will have a level roadbed to cross the channel.



FIGURE 121C. An excavator or backhoe is used to dig a broad keyway across the base of the fill, where the fill intersects the natural channel, and another broad keyway at the top of the fill, where the top edge of the road surface is planned. The largest rock goes in the lower keyway, and coarse armor is also placed in the upper keyway across the full width of the design spillway where streamflow will flow over the fill and down the armored fill slope. Filter fabric, or a filter layer of small rock, is placed on the underlying soil to prevent erosion or winnowing of soil beneath the armor.





FIGURE 121D. Well graded rock armor is then backfilled into the structure and spread across the breadth of the U-shaped stream crossing, and about one-third the way up the roadbed, so that streamflow will only flow over or come in contact with resistant armor material. The armor must be spread and compacted across the design width of the expected flood flow channel width so peak flows will not flank the armored structure.



FIGURE 121E. Two weeks after this armored fill was constructed, a storm flow event occurred and the structure maintained its function and integrity. The road approaches had not yet been compacted or surfaced with road rock.



FIGURE 121F. The same armored fill as it appeared after the first winter flood flows. No maintenance was required to reopen the road. It is also clear that no stream diversion is possible at this stream crossing site, and the volume of fill within the crossing has been reduced to the minimum amount needed to maintain a relatively smooth driving surface on this low volume road.

and a riprap armored spillway. The first step involves removing any existing drainage structures (e.g., culverts or buried logs). A large “U” shaped dip is then constructed through the crossing that is wide and deep enough to accommodate the expected 100-year peak storm flow and to prevent stream diversion.

A general rule of thumb is that the width of the armored channel at the outboard edge of the dipped road should be at least 5 times the estimated design peak flow wetted perimeter in the upstream natural channel, and the depth should be at least 1.5 times deeper than the average flood flow depth in the natural channel. Thus, a natural stream channel with an estimated peak flow width of 6 feet and depth of 1.5 feet should have an armored fill that is at least 30 feet wide and 2.5 feet deep at the outboard edge of the road crossing. This is intended to keep flood flows confined within the armored portion of the dipped crossing. When constructing an armored fill, these estimates should be tailored to your particular setting.

Next, a trenched keyway prism is excavated into the outer third of the roadbed and down to the base of the fill. It needs to be wide enough to contain the design 100-year flood flow. A keyway slot is then dug across the channel at the base of the fill to hold anchor rocks. Another keyway slot is dug across the outer edge of the roadbed, where large rock will be placed to prevent headcutting into the road prism. The keyway slots are first packed with rock armor that will help hold upstream armor in place. The largest armor pieces will be placed in the keyway at the base of the fill and slightly smaller pieces in the keyway slot at the outboard top edge of the road’s fill slope. Well graded rock armor is then back-filled into the excavated prism areas on the outer third of the roadbed and on the fill face.

Riprap sizing for armored fill crossings requires considerable professional judgment, as well as

the utilization of published empirical methods that incorporate existing stream channel conditions, such as stream channel slope and estimated discharge at high flows. Because armored fills are similar to rock chutes, in that they are typically constructed on steeper streams with more turbulent, impinging flows; the ARS rock chute design technique is a good method for rock size determination. This method is outlined in the National Engineering Handbook: Technical Supplement 14C: Stone Sizing Criteria (USDA-NRCS, 2007). Most riprap sizing techniques only design rock armor for slopes less than 40% and therefore when designing on steeper slopes it is important to apply a factor of safety of 1.1 to 1.5 to rock size, depending on site conditions.

If soils are fine grained it will be necessary to install geotextile fabric in the keyways prior to backfilling with armor. The final road shape through the armored fill crossing should be a broad “U” shaped dip with a flat gradient from the inboard to outboard edge of fill. The flat road gradient is important to prevent the initiation and headward migration of rills or a small gully through the road fill.

Other structures, including gabion baskets, jersey barriers, concrete walls, and logs have been used for the construction of “armored fill” crossings. These structures are typically placed vertically at the outboard edge of the road and create a cascading waterfall to the channel below. Any such grade control structures must span the width of the design flow and have a stream-centering spillway sufficiently sized for the design discharge. It is important that the structures are properly placed and embedded in the channel to prevent undercutting and failure of the crossing, and incorporate rock armor energy dissipation at the base in order to prevent scour and undercutting. Although these structures may seem like a “quick, cheap fix” they are not recommended as a stable support for armored fill crossings and typically require regular maintenance and monitoring. These structures

should only be used in low-gradient settings with low stream velocities, and minimal fill.

Vented fills—A porous rock fill crossing (a vented fill) is a specialized type of armored fill crossing that is useful in crossing steep stream channels that are prone to debris flows or torrents. They are constructed of coarse rock and transmit low water streamflows through embedded culverts and through their porous, coarse rock fills. Higher streamflows that exceed culvert and porous rock capacity are carried over the hardened top and downstream fill face of the armored fill.

The same basic steps are used to construct a vented fill, except that a porous rock fill crossing is usually excavated deeper into the road (e.g., ½ the road is excavated) and backfilled with the largest (D_{95}) angular, well graded rock available. This type of armored fill crossing is intended to be porous and pass water through the fill. Over time, the voids in the large rock armor will be silted-in so that it becomes impermeable and most flows are directed over the top of the structure. The road surface may be capped with concrete or other non-erodible material, and armor on the fill face grouted in place, so

that overtopping will not seriously erode the road fill or the fill face during overtopping.

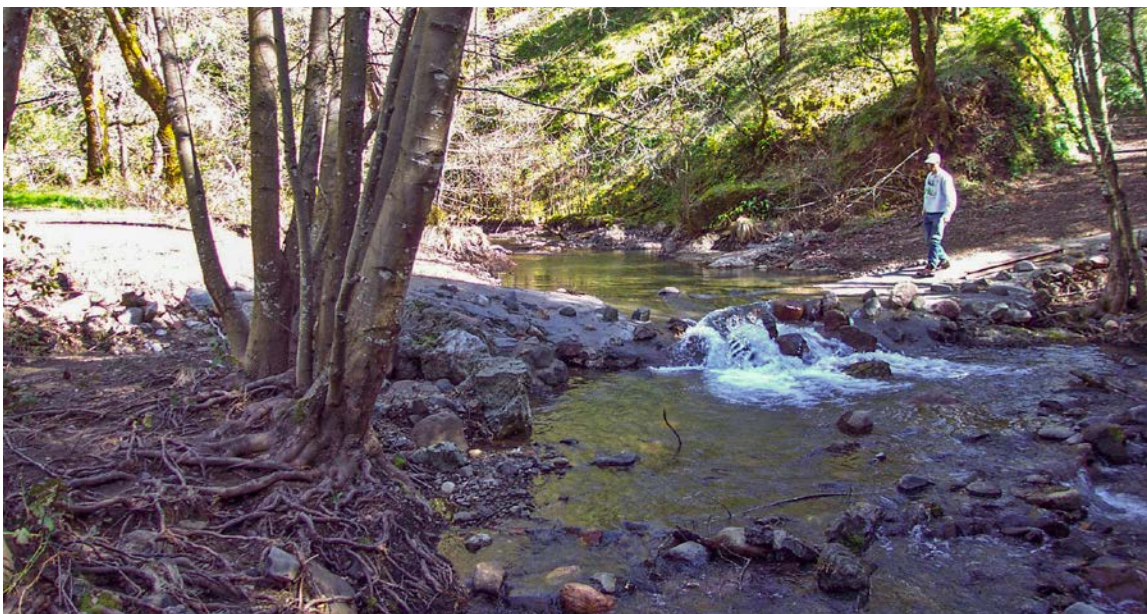
Even if the crossing washes out, the amount of fine sediment delivery would be minimal and have minimal impact on downstream fish habitat. It is important that porous rock fill crossings (vented fills) are installed in upslope or headwater locations where stream flows are lower and crossings are likely to remain intact and unlikely to wash out.

6. FORDS

Fords are stream crossings where vehicles drive on the bed of the stream channel (i.e., no man-placed fill in or on the streambed). Fords work well on small to medium sized streams where there is a stable stream bottom and traffic is light. However, “construction” of fords and other unimproved stream crossings on well-traveled roads should be avoided where water regularly flows because of their potential to impact water quality. In certain situations, where flash floods, high seasonal flood peaks or floating debris are problems, fords may be a practical answer for low volume roads.

FIGURE 122. *Wet ford on a Class II (non-fish) perennial stream.*

Coarse rock armor that has been grouted in place provides energy dissipation and protects the outer edge of the hardened roadbed. Fords should not be used if high wet season flows would cut off access to inspect and maintain drainage structures further out the road. Unvented, hardened fords may also obstruct fish passage.



Fords of live streams, called “wet fords,” are typically composed of streambed gravels or concrete structures built in contact with the streambed so that vehicles can cross the channel (Figure 122). If possible, a stable, rocky (or bedrock) portion of the channel should be selected for the ford location. **The simplest of fords are those on low volume roads where occasional traffic drives over a naturally hardened streambed composed of bedrock or cobbles.**

Where the streambed at the crossing site is not sufficiently hard, fords can also be fortified or constructed of permeable trench drains of coarse, imported cobbles and boulders. Low summer flows seep through the fill, and higher water discharges flow over the top without scouring or removing the armor layer. Some post-winter or post-wet season maintenance may be needed. During extreme events, however, the ford may be completely washed-out and need reconstruction. Permeable or concrete fords are likely to be a barrier to migrating juvenile or resident adult fish and should not be used in fish-bearing channels.

Paved (hardened) fords across live streams may be necessary to maintain water quality if there is to be regular traffic. These are sometimes called “Arizona Crossings” for their prevalent use as ford crossings of dry streambeds in the USA’s desert southwest. Paving, if used, usually consists of a concrete, slightly dish-shaped slab built across the stream channel that extends sufficiently up each streambank to contain design flood flows (i.e., the wetted perimeter for the design (100-yr) flood flow).¹³ These may sometimes contain enough fill material beneath the concrete to maintain a level driving surface. A discharge apron or

energy dissipater is constructed on the downstream side of the ford to prevent scour and undermining during high flows and this must also extend the entire width of the 100-yr flood flow wetted perimeter (Figure 123).

Fords are designed to pass both sediment and debris during high flows. Unfortunately, concrete fords are often plagued by scour around their edges because of a lack of capacity (depth and width) or because armor was not placed to the full width of the flood flow channel, sometimes leaving the ford elevated and impassable. Hardened ford structures are sometimes even moved downstream by large flood flows after the outfall has been eroded and the structure undermined.

Vented fords can also be constructed with a culvert embedded in the concrete or hardened structure to handle low seasonal flows. Fords, particularly vented fords, can be constructed to pass large flows and large amounts of debris while still accommodating fish passage. On streams that contain fish during some part of the year, fish passage is frequently obstructed at low flows unless venting culverts have been embedded into the basal concrete. Unless the vent/area ratio is large (Figure 75), vented fords typically require regular maintenance to clear debris from the culvert inlets. The larger the venting culvert, as compared to the stream width, the less likely they will become plugged with debris.

Unless it has a bedrock foundation and hardened approaches, most ford crossings are vulnerable to erosion and can create pollution from several sources. High traffic levels and/or high water flows can cause erosion of both natural and artificial streambed materials (Figure 124). Material placed in the stream or moved about by vehicle traffic can create a barrier to fish migration. Vehicle passage through fords with fine sediment channel bottoms creates plumes of turbidity with every passage. Deep water ford

¹³ It is rare to observe a hardened ford that has been constructed to contain the 100-year flood flow, or even the 20-year flood flow. Most hardened fords are overtopped and flanked by large runoff events due to the lack of depth in the axis of the stream, and the limited width of the hardened, dipped crossing. Many such fords are found in valley bottoms and floodplain settings where channels are not deeply incised and floods may be valley-wide.



FIGURE 123. Flow in this hardened ford is from right to left. Low flow energy dissipation has been built into the center of the structure, but high flood flows have scoured to the base of the concrete ford in the foreground. Both the hardened ford and the downstream energy dissipation must be broad enough to encompass and contain the expected 100-year design flood flow.



FIGURE 124. This unimproved ford crossing of an intermittent stream was poorly located in a channel reach that had a fine, erodible bed. Efforts to stabilize the channel bottom with rock and concrete chunks have been unsuccessful. A plume of turbidity is released in this fish bearing channel with each crossing.

FIGURE 125. *In addition to the actual ford crossing, the road approaches also contribute to sediment pollution unless they are paved or heavily rock surfaced. Fords are always low points in the road, so runoff from the connected approaches is delivered directly to the stream channel.*



crossings can cause oil products to be released from vehicles as they pass through a wet ford.

Fords are always the low point in a road alignment, where each road approach drops into the channel and then climbs back out. Unless the approaches are heavily rocked or paved, and hydrologically disconnected, rainfall and runoff will erode the roadbed and deliver fine sediment directly to the stream at the crossing site (Figure 125). Incised stream channels with high streambanks require the excavation of substantial ramps to get vehicles down to the streambed. Unless they are similarly protected, these through cut ramps are often sites of substantial surface and rill erosion that causes eroded sediment and turbid runoff to enter the stream during periods of heavy rainfall.

On small, poorly incised, ephemeral or intermittent streams a ford may be needed if there is insufficient channel depth to install a culvert. In fact, a rock lined rolling dip with a rock apron face may be preferable to a permanent culvert on some swales and small watercourses. **Fords and armored fills have the advantage,**

over culverted fills, of never plugging.

Fords on small streams should be rock armored to prevent erosion of the road surface during runoff events. **What are sometimes referred to as “unimproved” fords, where a stream channel has been filled with a substantial quantity of soil and left unprotected by armor or rock surfacing, is a high maintenance crossing that is a hazard to water quality and should not be constructed.**

7. TEMPORARY STREAM CROSSINGS

Temporary stream crossings are used to provide short term access to an area. Temporary crossings should be installed wherever a proposed temporary road crosses a stream channel, regardless of its size. **Any stream channel or water source that would be fitted with a drainage structure on a permanent road should receive a temporary drainage structure on a temporary road.** The structure should be capable of passing the expected discharge of the channel during the season(s) that it is to remain in place. **If a stream crossing**

is to remain in-place during the winter or wet season (beginning October 15 in Northern California), it must be designed and constructed to pass flood flows from the 100-year design runoff event, as well as debris and sediment loads, just as though it was a permanent stream crossing structure.

Specific techniques for constructing temporary stream crossings are discussed in Chapter 5.

For temporary roads, only temporary crossings are acceptable. Dry fords that are removed following land use operations and before beginning of the wet season are appropriate for dry channels. For live streams, a more substantial crossing is needed. They can be constructed of a variety of materials including culverted fills, log crossings, combinations of logs and pipes, straw bales over pipes and logs,

and temporary log or railroad flatcar bridges (Figure 126). Where channels are wet or incised, temporary culverts, temporary log fills or temporary bridges should be used. Log fills (with or without culverts) and portable bridges can often be installed, used and removed with little damage to the streambanks or channel bed.

It is important that the original base level of the stream channel be maintained when a temporary crossing is removed following operations. For this, a “marker” consisting of several inches of straw, or another distinctive marker placed in the bed of the channel, is often used to identify the natural channel bed before any logs or fill for a temporary crossing is placed in the channel. Re-excavation of the crossing down to this horizon is then relatively simple.



FIGURE 126. This small, temporary log crossing is constructed with a culvert at its base, with logs, straw bales and finally road surfacing material on top. A geotextile fabric can be used instead of straw to provide separation between the stream and the overlying road materials. Ideally, the road surfacing materials should be clean road rock or gravel (not dirt) that will not adversely affect water quality if some makes its way into the stream. Temporary crossings should be removed before each wet weather season.

A special category of temporary stream crossing is the low water crossing that is often installed to provide summer vehicle traffic across larger perennial streams and small rivers during summer low flow conditions (e.g., **Figures 127a, 127b**). These crossings are typically composed of streambed gravels that have been ramped up on both approaches to the low flow channel with one or more culverts or a temporary bridge used to carry streamflow. Only clean gravels are used in its construction and no new soil or fine sediment is introduced into

the channel or floodplain. The low flow crossing and culverts (or bridge) are then removed prior to the first fall rains which would raise flows in the river. Fish passage should be considered and designed into the low flow crossing of fish-bearing streams so that juveniles and adults can pass through the structure. A temporary flatcar bridge is frequently used to span all or part of the low flow channel instead of culverts where fish are present. Like culverts, the temporary bridge is then removed prior to the rainy season.



FIGURE 127A. Summer low-water crossing of a Class I (fish-bearing) perennial river. Coarse, clean streambed material has been used to ramp up and over the flowing water. Two embedded culverts have been installed at water level to allow for uninterrupted flow and the migration of young fish.



FIGURE 127B. A temporary bridge crossing should be used where migrating adult or juvenile fish need to pass beneath the crossing. This temporary bridge crossing spans the active summer channel and the abutment in the channel is composed entirely of clean stream gravels. All temporary low water crossings should be removed before the first seasonal rains.



5 CONSTRUCTION

A. INTRODUCTION TO CONSTRUCTION

The construction phase of a road project is when planning and design decisions are carried out on the ground. To achieve the intended road standard, and to cause minimal impact to the environment, each phase of road construction should be conducted according to the formulated plans. **Improper execution of plans, no matter how well designed, can result in a poorly constructed road that causes serious impact to the watershed and environment.**

Such substandard results are most often caused by untrained supervisors or unskilled, inexperienced operators rather than inadequate design. Thus, the skill and experience of supervisors and equipment operators selected to complete the road project will play a large part in determining its success.

Construction should always include some degree of inspection and quality control. Plans and designs may need to be modified during construction as changing conditions are encountered in the field. Minor changes in the proposed work can be accomplished in the field by experienced supervisors and equipment operators. However, substantial changes in road alignment or in road and drainage design should only be made by qualified personnel, and may require additional permitting from the regulatory agencies.

B. SELECTING CONTRACTORS

Contractors or in-house construction crews can make or break a road construction project no matter how good the original design and layout. The job can be as simple as a low standard rural access road to one or more properties, or as complex as a forest or ranch road built across steep topography for land and resource management purposes. **To ensure a quality construction project you should have qualified and experienced supervisors and construction crews, as well as the proper heavy equipment for the job.**

Reliable, high quality, cost-effective construction crews can be secured by contract in the local market, or they may be part of an in-house equipment crew the landowner or land manager employs to manage their properties. A high quality contractor or equipment crew will have a number of attributes to look for:

- The contractor is financially solvent and able to perform the work and be paid incrementally for work completed.
- They are able to secure a performance bond for the work (if needed), and they maintain or can obtain all other licenses and insurances that may be required or desired.
- The contractor and their operators have an excellent reputation within the local contractor market, or internally within the organization where they work; they are considered the “go-to” contractors and operators for this type of job.
- The contractor and their employees are team-players that work well together, are willing and able to take instruction, and can follow plans and specifications prepared by others.
- The contractor is generally known to be hard working and to complete their project work on-time and within budget; their rates are competitive within the local market.
- They have experienced supervisors and equipment operators that have been assigned to this particular job for its duration.
- The operators are trained and experienced using the same type of equipment as is needed for this job, and each operator is experienced using more than one type of heavy equipment (especially for the key equipment types (e.g., excavators and dozers).

- The contractor has the required types of equipment needed and specified for this particular job, including the size of the equipment, its features and specific capabilities, or can easily rent it.
- Their equipment is modern and well maintained; it does not leak petroleum fluids.
- They have experience building or reconstructing similar roads through similar terrain.
- They have experience successfully completing the specific design work that is called for or expected on the proposed project.

In applying for the job, contractors should be required to provide professional references for similar work they have performed for other clients. Frequently, word-of-mouth can provide some useful information about local contractors. Regardless, you should seek both a qualifications statement and cost bids for the work you are requesting. In the qualifications statement you should request a list of names, qualifications and experience of their key supervisory and operator personnel including a list of recent, comparable projects they have completed. Check the contractor licensing board to see if there is a history of violations.

In addition, you may choose to list what you believe to be the desired or minimum heavy equipment specifications required for this project, and ask the contractor to list the equipment they propose to use. The equipment list should identify the make, model and year of each piece of heavy equipment they propose to use, its specifications and attachments, and any other performance information deemed relevant (e.g., a dozer with 6-way blade and rear-mounted hydraulic rippers). Make sure they also have all the secondary personnel and equipment that will be necessary such as laborers, straw blowers, portable vibratory compactors, water pumps, emergency spill response

kits (for accidental fuel spills), fire control equipment and accident prevention plans.

It's important to have a positive working relationship with the contractor and the operators who will be working on the project. Open and clear communication is very important, and a chain-of-command at the work site helps keep everything running smoothly.

C. TIMING

Project timing is dependent on several factors including: your readiness to conduct the work; successfully obtaining the required permits from regulatory agencies; seasonal regulatory restrictions that may exist for certain operations; and the most favorable environmental conditions or period to perform the work. While planning, design and field reconnaissance work can be conducted at any time of year, the proper timing of each phase of road construction is critical to a successful project.

Regulations in many areas restrict certain operations (such as stream crossing construction or reconstruction) to a particular time of the year, regardless of how favorable conditions may be during other time periods. Check with the appropriate regulatory agencies in your area to see if the proposed road building or reconstruction operations in your area have mandatory seasonal restrictions.

Once the possible operating season has been determined ([Table 4](#)), make sure you have obtained the necessary permits for the work. These may include forestry permits for timber harvesting, grading permits for land clearing and earth moving, permits for constructing stream crossings, as well as permits for disturbing wetlands, operating near or within habitat for endangered plant and animal species, and avoidance of historic and archaeological resources. These and other permits, and the studies or field reviews needed to support and

obtain them, could take a year or more to acquire in some locations. Do your homework well before you actually want to begin a project, to make sure it is actually feasible and can be constructed when it is needed.

Environmental conditions also control project timing. The time varies when each of the construction activities (clearing, grubbing, burning, excavation and grading, compaction, stream crossing installation and surfacing) can best be conducted. For example, scheduling road building activities in steep areas for the drier months can be an effective landslide control measure. Similarly, if the project has numerous stream crossings it may be best to wait until the streams have dried up or at least reached their lowest seasonal base flow before disturbing the channel. **Roads should be constructed during the time of year when the best results can be achieved with the least environmental damage** ([Table 4](#)).

Clearing (cutting and removal of trees and brush from the right-of-way) can be performed anytime weather permits ground crews to cut the vegetation and equipment to pile or yard it to a storage site. In forested areas, felling crews may cut vegetation along the alignment up to a month before equipment is on-hand to remove the material. Removal of trees and vegetation results in soil disturbance and should be limited to reasonably dry soil conditions when rain storms are unlikely. Likewise, grubbing (the removal of organic material from the soil surface, including stump removal) should only be performed when the threat of erosion from the disturbed areas is minimal, yet early enough for you to take advantage of moist soils that are comparatively easy to work.

Grading (the excavation and creation of the road bench) creates large expanses of bare soil, and should therefore be performed only during dry spring, summer or early fall conditions. To achieve proper compaction of fill materials

used in stream crossings, landings, and along cut-and-fill road benches, most soils will require adequate moisture. Rocky, coarse-textured soils may be placed during relatively dry conditions. Watering using a water truck may be required to achieve proper compaction of fill materials as they are laid down and compacted. Overly dry or very wet, fine textured soils often cannot be compacted enough to produce the soil strength needed to support loaded trucks or to remain stable on steep slopes. If the soils are too wet, they should be allowed to dry, and if they are too dry they should be watered to achieve proper moisture levels for adequate compaction. Local problem areas are likely to be encountered that will need to be treated by drying or watering. A qualified engineer or geologist can recognize improper soil moisture conditions by using simple field tests.

Stream crossing installation, and the reconstruction (upgrading) of existing stream crossings, is one of the most sensitive road construction operations. **The timing of stream crossing installation is critical to maintaining and protecting water quality.** It requires proper timing to achieve good results and can adversely affect both water quality and aquatic systems in downstream areas if done incorrectly. Timing is also important to fisheries in many watersheds. **Work should be performed as quickly as possible during the dry period of summer, when streamflows are at a minimum (or the channel has dried up) and there will be minimal soil disturbance and risk of sedimentation.** If streams are flowing, proper isolation methods will be needed to ensure water quality is not degraded during stream crossing work.

All road construction activities, including the installation of stream crossings and erosion control work, should be completed before the onset of the seasonal rainy period (October 15th for forestry operations in California). Final grading and proper installation of road drainage

structures are critical to keeping erosion from the new road to a minimum during the first winter. Likewise, all temporary stream crossings should be removed and all erosion control measures installed before the wet season begins. In many areas there are additional regulatory requirements in effect for forestry operations or construction work conducted anytime during the winter or wet weather period. These include developing a “winter period operating plan” that includes the details of any proposed land use and erosion prevention activities that will be undertaken. For example, during the dry season you can often work well ahead of your erosion control work because the chance of rain and subsequent erosion is minimal. However, if you are allowed to work during the wet weather season, or near its margins, regulations and your work plan may require all bare soil areas be adequately drained and protected with suitable erosion control measures concurrent with the conduct of construction operations.

D. EQUIPMENT NEEDS FOR CONSTRUCTION AND RECONSTRUCTION

Construction is the application or implementation of road design on the ground. How well the design is followed during construction depends both on the skill, experience and understanding of the equipment operators and the type, size and capabilities of heavy equipment used for each task. For example, constructing a full bench road with endhailed spoil material requires suitable excavating equipment. A tractor will not work, especially on moderate or steep slopes. Similarly, without a skilled equipment operator, there is a much higher chance of making expensive mistakes or causing environmental damage.

In steep or mountainous areas, it is often a serious mistake to design the road around the types of equipment you own or have to work with. **Roads should be designed for stability as a primary concern, and then**

constructed using the types of equipment called for by the road design and the environmental setting.

The upgrading of open, maintained roads is perhaps the single largest task that must be conducted in most watershed areas.

This typically employs excavators, dozers and dump trucks, with support by road graders, vibratory compactors, water trucks and smaller pieces of heavy equipment for specialized tasks. **The most common road upgrading tasks include stream crossing upgrading, excavation or stabilization of unstable fill slopes, and dispersion (hydrologic disconnection) of road surface drainage.**

Road reconstruction on abandoned, unmaintained, overgrown roads typically begins with vegetation removal and grading performed by tractors and or excavators. As with road construction, however, it is very important to use the proper types of heavy equipment when the more complicated situations are encountered (Table 30). Thus, excavating equipment is often specified for the reconstruction of formerly abandoned roads, especially where the old road has been built next to a stream or within a watercourse protection zone (Figure 128).

Where stream crossings have partially or completely washed-out, hydraulic excavators may be needed to reinstall upgraded culverts and to place and compact fill. Loaders and dump trucks may be needed for spoil removal where the road is blocked by cutbank failures.

E. CLEARING AND GRUBBING

The road centerline, or the cut-and-fill staking, should be marked on the ground prior to clearing. The upslope and downslope boundaries of the right-of-way should also be flagged or staked to mark the limits of vegetation removal for work crews and equipment operators who will be performing the clearing. This will help prevent over-clearing. Trees and other large vegetation should be felled and cut into manageable lengths. In addition to right-of-way clearing, hazardous snags and unsafe trees should also be felled at this time. **Trees and shrubs should be left growing at the base of the proposed fill slopes, and the right-of-way should be kept to the minimum width necessary for the planned use of the road.**

During grubbing of the surface, stumps should be removed from within the road prism and anywhere fill or sidecast material will be

TABLE 30. Settings and equipment combinations suitable for various types of road construction and upgrading methods

Generic road type	Hillslope characteristics	Typical equipment types
Sidecast (cut-and-sidecast)	Gentle (<35%); stable, far from streams	Tractor; grader; water truck
	Moderate (<55%); stable, far from streams	Excavator and tractor, or tractor; grader; water truck
Cut-and-fill (with compaction)	Gentle (<35%)	Excavator and tractor; grader; water truck
	Moderate to steep, close to streams (35-55%)	Excavator, or excavator and tractor; grader; water truck
Full bench (cut)	All slopes	Excavator; dump trucks; tractor; grader; water truck
Temporary fill (cribbed)	Moderate to steep	Excavator and tractor
Reconstruction	All slopes	Excavator; tractor; loader; dump trucks; grader

FIGURE 128.

Perhaps the most versatile of road building equipment today is the hydraulic excavator. Low impact roads can be built quickly and efficiently using this now-common type of earth moving equipment. Roads constructed exclusively using bulldozers to cut-and-sidecast soil material are best confined to hill-slope gradients less than about 35 percent and to areas where stream channels are not close by. Excavators come in many sizes and the largest one suitable for the physical work environment is usually preferred.



deposited (Figure 129). **Mixing stumps and other vegetative debris into the road fill should always be avoided** because the voids which form when the wood decomposes reduce the stability of the fill. Fine slash and small limbs are usually not a problem, but all chunks, logs and slash over approximately 3 inches in diameter and 3 feet in length should be removed and safely disposed. **For slopes over 35 percent in gradient, the organic layer on the soil surface should be substantially disturbed or removed prior to fill placement or sidecasting.** This will help ensure a good frictional bond between the native soil surface and the fill which is placed and compacted on top of it.

Cull logs and coarse slash can be piled in a row (called a “windrow”) parallel to the road at the base of the proposed fill. When performed ahead of road construction, this practice can effectively control sediment movement from sidecasting and provide an economical, environmentally sound way of roadway slash disposal. This is especially useful when the road is being built near a stream channel. The slash should

be packed onto the ground surface to maximize contact, and the height, width and length of the windrow piles should be limited to allow for wildlife migration through the road corridor.

If an excavator is used to perform clearing and grubbing work, merchantable logs can be placed on top of windrowed slash piles for collection and loading when the road is passable to yarding equipment and log trucks. This practice reduces yarding costs and makes the clearing process more efficient. If some of the accumulated slash is to be burned, state fire regulations must be followed and permits obtained from the Department of Forestry and Fire Protection and/or from your local fire department.

F. GRADING AND COMPACTION

Most forest, ranch and rural roads are built by excavating a roadbed out of naturally sloping ground. Thus, grading is when the bulk of soil excavation and disturbance occurs. For a given road width, the steeper the ground the greater will be the volume of soil that must be



FIGURE 129. Hydraulic excavators have become the preferred piece of heavy earthmoving equipment for wildland road construction. Here an excavator is clearing and grubbing the alignment for a new forest road. All organic material must be removed from the alignment and woody debris should not be incorporated in fill materials.

excavated or displaced during road construction (Table 15). Road design and layout (flagging and stakes on the ground, together with plans and maps to look at) show equipment operators the correct alignment and the proper cut slopes and cut slope steepness to be developed along the new road. Operators may be asked to either construct roads using sidecasting methods on gentle terrain, to use cut-and-fill (with true compaction) on moderate slopes, and to employ full bench construction techniques on steep slopes or where road construction is to occur near stream channels, lakes or wetlands.

1. SIDECAST CONSTRUCTION

In sidecast construction, the bulldozer starts at the top of the proposed cut slope, excavating and sidecasting material until the desired road grade and width is obtained. Material is pushed or “drifted” in front of the blade to areas where fill is needed (Figure 130). Road fill is used to cover culverts, and build up flat or low areas along the alignment. Since the sidecast fill must support traffic, it needs to be spread and compacted as



FIGURE 130. Road constructed by cutting and sidecasting (cut-and-fill road) in an upper hillslope location. A row of slash and organic debris along the base of the sidecast slope can help catch and filter soil eroded from the loose fill slope. Soil should only be sidecast onto gentle or moderate slopes that have been cleared and grubbed of vegetation, and where material cannot be eroded and delivered to a stream.

much as is possible to develop sufficient strength. Unfortunately, this common method of sidecast or “top-down” road construction does not lend itself to standard, engineered compaction methods where fill is placed and compacted in thin layers.

In sidecast construction, much of the spoil material moves down the slope below the final roadbed and cannot be adequately compacted or contained. For this reason, **sidecasting construction methods are not suitable on steep or moderate slopes (especially near stream channels) where loose material could saturate during wet weather and erode or slide further downslope. During sidecast construction it is critical to keep sidecast or waste material away from streams, or placing it where it could erode and be delivered to a watercourse.**

Road construction can increase landslide risk by:

- **Oversteepening** the slope with sidecast material.
- **Overloading** slopes by adding sidecast and fill material.
- **Altering hillslope drainage** by blocking or redirecting surface or subsurface water movement onto fill slopes or unstable soils.
- **Removing material or undercutting** the toe of a steep or potentially unstable slope.

A general rule-of-thumb for moderately and steeply sloping lands is to keep sidecast everywhere less than about three feet deep, measured perpendicular to the original ground surface. Within about 400 feet of a watercourse, the sidecast should feather out within 30 feet of the road edge. This will minimize the risk of shallow landsliding, and of slope failures delivering sediment to stream channels. Roads built within a stream protection zone, or roads constructed across moderate or steep slopes

that extend, without significantly flattening, all the way downslope to a stream channel or other water body, should not have sidecast more than about 1 foot thick and it should feather out within about 10 feet of the road.

Overloading and oversteepening already steep or wet slopes with sidecast material during road construction is perhaps the single most common cause of road-related landslides. Sidecast failures are usually associated with ground slopes of 65% or steeper, although springs and seeps can cause failures at much gentler slope angles. In addition, steep, bare sidecast fill slopes are often difficult to revegetate and stabilize against surface erosion (raveling and rilling). A good rule-of-thumb is to not sidecast on ground slopes of over 35%, but sidecasting can occur on slightly steeper slopes if the soils are not wet or unstable, and streams, lakes or wetlands are not nearby. Road-related failures on lesser slopes occur mainly where there is emergent groundwater beneath the sidecast fill or where road drainage has directed surface runoff onto fill slopes.

A more protective method of “sidecast construction” utilizes a hydraulic excavator, instead of a bulldozer, to pioneer the road bench. The excavator is able to cleanly remove slash, stumps and logs and place them at the base of the fill slope so they are not incorporated in the fill (Figure 131). It then grubs or cleans off the organic layer, excavates mineral soil and places it, bucket by bucket, beginning at the base of the slope (Figure 132). If necessary, the excavator can excavate an insloped bench at the base of the fill and then backfill from the bottom of the slope up to the road bench. The hydraulic system of large excavators permits them to partially compact the fill as it is placed. Any excess fill or spoil material is placed behind the excavator on the already constructed road bench, where the dozer can then drift and compact the material in thin lifts while achieving the final out-sloped road shape (Figures 133, 134 and 135).



FIGURE 131. Excavators can perform a simple three step process of clearing and grubbing, excavating and subgrade development during construction of a balanced bench road. Using an excavator minimizes the volume of sidecast material. In the first pass an excavator operating from a pioneered bench removes logs and stumps, grubs the slope and installs a filter windrow of slash material at the base of the proposed fill slope. The second task is for the excavator to remove the overburden and place and compact the fill on the bench it has created (see piles of clean soil) and downslope above the windrowed slash. Thirdly, the uncovered, unweathered material is used to construct the bearing surface of the road.



FIGURE 132. Each step of the way, the excavator clears vegetation and grubs the slope surface in front of it before it excavates and extends the road bench. Excavated soil from the new segment of road bench is placed and compacted on the new road bench and on the grubbed slope below the new segment. Cleared vegetation placed along the base of the future fill slope helps contain erosion from the exposed fill materials until they stabilize and revegetate (Modified from: BCMF, 1991).

FIGURE 133. Behind the excavator, a bulldozer is used to prepare the final subgrade, shape the surface, create needed road width, and provide field compaction to the new fill.



FIGURE 134. New road constructed by excavator and bulldozer. Logs harvested from the right-of-way have been placed on top of the filter windrows and will be hauled away later. Final road surface shaping (outsloping), berm removal and surfacing (if any) will be done using a dozer or grader, and water truck.



FIGURE 135. Rock surfaced, outsloped forest road constructed by hydraulic excavator. Note the absence of an outside road berm which would otherwise collect and concentrate surface runoff on the road prism.



Spoil carefully placed using this excavator method is more stable and less susceptible to failure than sidecast road fills placed solely by bulldozers. It also precludes the need for extensive truck endhauling of spoil materials as would normally be required for full bench construction where all the spoil material must be hauled off-site. A fill face of about 55% to 65% (depending on the materials) is generally the steepest angle material can be placed, unless the fill is “engineered” using standard compaction methods, as described below.

Filter windrows of slash material are easily formed and placed at the base of the fill by the excavator to contain surface erosion following construction. The excavator or a bulldozer then follows up on the pioneered road bench (Figure 133) to develop the final road width and surface shape, using the uncovered, unweathered material to construct the compacted bearing surface of the road (Figure 134). The roadbed can then be rock surfaced for all-weather use (Figure 135).

2. COMPACTED CUT-AND-FILL AND BENCHING CONSTRUCTION

A variety of road benching techniques may be employed on moderate and steep slopes to improve the road’s stability. These include balanced benching (using the excavator), sliver fills, backcasting, multi-benching, and full benching with endhauling. These techniques each utilize construction methods that can lend added stability to the road prism, compared to sidecasting. Each is also suitable for a specific soil and slope type, and should not be used in other situations.

Backcasting and **multi-benching** construction employs a technique called “bottom-up compaction” which adds stability to fill material placed along the outside of the road prism. **Multi-benching is not often used, but it is a good way to develop a stable footing with a minimum of**

sidecasting. First, a bench is cut at the proposed base of the fill, about 30 feet slope distance below the proposed road grade (its exact location depends on the slope of the hillside and the width of the final road). It may be necessary to excavate and endhaul material from this first cut so that it is not sidecast downslope. Next, the operator moves slightly upslope to create another bench, casting the spoil material onto the first bench downslope where it is then compacted. After the second bench is completed, the process is repeated upslope to the final road elevation. The result is a fill that is “keyed” into the hillslope on multiple, small benches, with minimal sidecast (Figure 136).

Single benching is a more popular technique employing the same basic methods as multi-benching. After the first (lowest) bench is cut, a bulldozer or an excavator may be used to cut into the hillslope above the bench to widen and raise the roadbed. As cutting progresses in the upslope direction, the roadbed is widened and layers of spoil material are added to the bench in thin “lifts” that are compacted as they are laid down. Cutting, filling and compaction of the roadbed continues until the road reaches the final design grade and width (Figure 137).

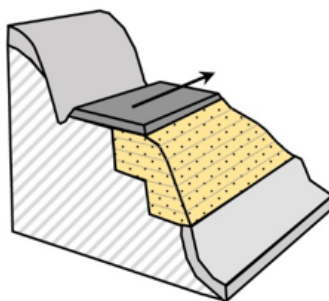


FIGURE 136. Multi-bench road construction. Note the two benches cut into native soil or rock materials and the layered compaction of fill materials on the benches. Multi-benching provides added structural stability to the fill and is used when constructing roads on steep slopes.

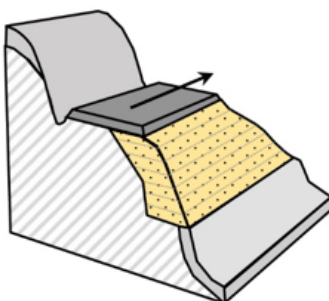


FIGURE 137. Single or “balanced bench” road construction, where the volume of cut material is balanced (equals) the volume of fill material that is placed on the outside of the road bench. In most instances, a bench is excavated at the base of the proposed fill and layers of fill are placed in lifts and compacted until the desired road level has been attained.

Remember, bulldozers and loaders are not efficient compactors. All else equal, wheeled equipment (e.g., rubber tired loaders, dump trucks, etc.) provides better compaction than tracked equipment (bulldozers). In all cases, care must be taken to cover the entire soil surface with the compaction effort. **Generally, tracked equipment are considered minimally efficient soil compactors, but for properly placed fills at near optimum moisture levels a bulldozer can achieve satisfactory results if the soil lifts are thin and the soil is moist.** In critical situations where fill compaction is necessary to ensure that the material will not fail, true compactors should be used. Check with a road engineer to select the correct equipment for your job. Compactors include grid, sheep's foot, pneumatic, vibratory, and tamping foot machines. Grid and vibratory compactors are appropriate for materials coarser than coarse silts and sands, while the others are preferred for sand and finer sized soil particles. **Regardless of the equipment used, the key to any compaction effort is proper moisture conditioning of the fill materials.** Ask a road engineer or experienced equipment contractor for advice on selecting compaction equipment.

Backcasting is a method of producing a full bench road with no endhauling. The soil must be medium to coarse grained and well drained, and the slopes cannot exceed 80%. It may not be a suitable technique on approaches to incised stream channels where emerging groundwater is commonly found. The surface immediately in front of the excavator is cleared and grubbed, and organic debris is either sidecast or windrowed at the base of the proposed fill slope. Then, a deep full bench is cut in front of the excavator about 25 to 30 feet wide and 8 to 10 feet deep at the road center line (again, depending on the slope of the land and the width of the road). The earth materials excavated from this cut are "backcast" and piled on the subgrade behind the excavator. Once the bench has been constructed, the piled subgrade material is leveled and graded

by a bulldozer or the excavator, with little or no sidecasting (Figure 138). Because the roadbed materials are all excavated and placed, with little compaction, they should be allowed to settle and drain before the surface is out-sloped or final ditches and ditch relief culverts are installed. On steep slopes, the fill will have to be reinforced or retained, and subdrains will be needed for springs and wet areas.

Sliverfill construction is a potentially hazardous method that can result in slope failures and water quality problems if material and site conditions are not correct. Sliverfills are thin fills lying parallel to the underlying hillslope, rather than as wedges used in normal cut and fill construction. Sliverfills cannot be compacted on slopes exceeding about 35%. On gentler slopes, sliverfills are small and relatively stable. As slopes increase, the fills become thicker and more susceptible to failure.

Sliverfill construction should be used only in special situations where $\frac{3}{4}$ -bench to full bench roads are constructed through rock or coarse alluvium and there is nowhere to dispose of the excess material. The rationale is to avoid producing an oversteepened slope by placing or spreading a thin veneer of coarse material on the ground surface at a slope less than its angle of repose (Figure 139). An excavator with a normal 35-foot reach can usually control and drape a sliver fill up to 40 feet downslope from the road bench.

Sliverfill construction should be a method of last resort, because the potential for failure is relatively high, and a large amount of forest slope is taken out of production. Raveling from the fill can also create a dangerous condition if there are roads or buildings downslope from the sliverfill. **Sands, silts and clays are completely unsuited for sliverfill construction. Sliverfills are placed and not constructed by sidecasting, because uncontrolled sidecasting on steep slopes**

produces highly unstable deposits that ravel and/or fail by debris sliding.

3. FULL BENCH CONSTRUCTION

Full bench construction, the final method described here, typically involves excavation of the roadbed using a hydraulic excavator. A bench is cut into the rock or soil equal to the width of the road. No material is sidecast and spoil is used to fill low areas or stream crossings along the road alignment. Excess material can be hauled off-site to a stable storage location, while only a very minor amount can be safely drifted or feathered over and compacted on the road bench (**Figure 140**).

Full bench road construction is typically reserved for moderate or steep slopes, or where a road approaches or parallels a stream channel that could be impacted by sidecasting. Endhauling can be expensive, and full bench construction can cost four to seven times more than cut and fill methods. However, full benching without endhauling on steep slopes is a sure recipe for sidecast failure on many sites, as well as resultant impacts to downslope stream channels.

Full bench roads often result in tall cuts. Several rock and soil types may not support these tall cut slopes. Unstable rock, including soft or highly fractured sedimentary rocks, or rocks with layering dipping steeply into the road cut, may not be suitable for full-bench cuts. These deep cuts can remove critical toe support and initiate upslope failure. Deep, soft clays, lake deposits and other earth materials with similar physical properties may also be unsuitable for tall cuts because of their susceptibility to rotational failure. Although balanced benching or back-casting may be better construction techniques for such soft and unstable soil and rock materials, it still may not be possible to build the road where slopes are steep and the rock is weak.

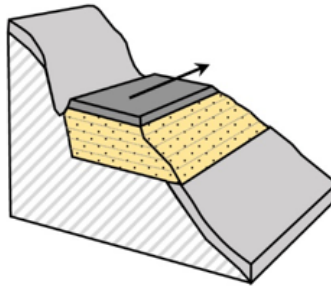


FIGURE 138. Backcasted bench road construction provides a full fill road bench in which the entire roadbed is built up by compacting layers of fill on a single, wide bench with no sidecasting. Internal reinforcement may be needed for steep fill slopes, and emergent groundwater will need subsurface drainage.

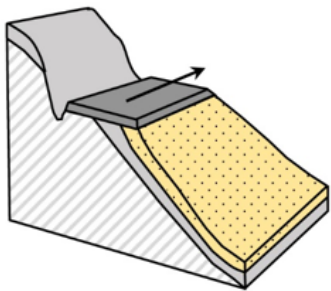


FIGURE 139. Sliver fill road construction is where a thin veneer of fill is “placed” (not sidecast) over the slope below the road. Sliver fills should only be used in specific situations, usually with free draining broken rock materials where slope gradients are below the material’s angle of repose, and there is no other place to put the excavated material. This method of construction is rarely used and should be completely avoided near streams, on steep slopes or where silts, clays, and other fine grained soils are common.

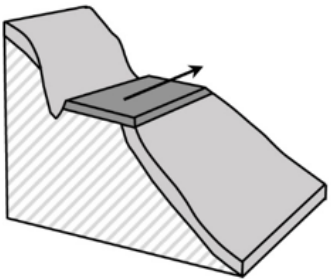


FIGURE 140. Full bench road construction, in which all excavated material has been truck-endhauled from the site and deposited in a stable storage site.

Excess spoil should be endhauled and stored at a stable location where it will not erode or fail and enter a watercourse. In addition, spoil should not be placed on unstable slopes, where the added weight could trigger land movement. Excessive loading of clay or silt soils at an endhaul dump site could also cause a bearing capacity failure in the subsoil. **Rock pits; wide, stable sections of road; ridges; benches; and the inside edges of landings are typical locations where fill can be safely stored. Storing spoil materials**

along the outside edge of roads, turnouts and landings built on steep slopes should be avoided as the added weight could trigger failure of the fill slope. All proposed fill sites should be field examined before construction. Large spoil disposal sites that are proposed for use should be reviewed by a qualified geologist or engineering geologist prior to developing the site to make sure it is stable. Those sites exhibiting emerging groundwater or thick organic layers could experience slope failure after loading and should not be used.

For most situations, spoil material is directly loaded into dump trucks by the excavator and hauled to the storage site where it is spread in layers that can be reworked and “field compacted” in layers by a bulldozer. In some cases, bulldozers can economically carry (push) spoil material to stable storage sites for distances up to 500 feet. The finished spoil pile at the

storage site should generally conform to the local topography to provide for free draining, dispersed drainage. Prior to the wet season the spoil materials should be mulched and planted to control erosion (**Figure 141**).

G. CONSTRUCTING ON WET SOILS

If small springs and seeps cannot be avoided when laying out the road alignment, special construction materials and techniques can be used to minimize wet soil problems. Established techniques for constructing clean gravel drains and surface rocking have been dramatically improved by the use of synthetic geotextile materials (see Chapter 4, Section B, 5(b)). These fabrics and engineering materials often come with detailed manufacturer’s instructions that should be followed to achieve best



FIGURE 141. Typical spoil disposal site for endhauled spoil materials from a full bench road construction site. Spoil disposal site is located on a broad, gently sloping, dry ridge. Material is dumped, and will later be spread, compacted (by bulldozer) and seeded, mulched, and planted. Spoil material should be placed where eroded soil will not contaminate the road or ditch, or be delivered to a stream.

results. Many companies provide free consultations to help in specific user applications.

Water emerging from road cutbanks can be controlled using a French drain or vertical drainage trench (an “underdrain”) (Figure 142). The trench is excavated, lined on both sides and the bottom with a geotextile fabric, backfilled with open graded, clean gravel and topped with fabric and soil. In some cases, a perforated drain pipe will be installed near the bottom of the trench, surrounded with gravel, to provide for rapid removal and discharge of intercepted subsurface flow. The fabric keeps fine soil materials from entering the trench and plugging the drain. The trench is then drained across the road prism in an outflow trench or subsurface drainage pipe situated down the ditch line.

Water emerging beneath the roadbed can be controlled by installing a drainage blanket beneath the fill. This provides an easy path for the emerging water to flow out from under the road without saturating the roadbed and overlying fill materials, thereby preventing rutting, rilling, muddy surface conditions or fill failures. In the field, a permeable geotextile blanket is laid down over a series of cut benches in the wet zone prior to road construction, and a gravel layer is backfilled over the top. This gravel blanket should slope to the outside edge of the road and “daylight” near the base of the fill to ensure proper drainage. The benches maintain slope stability with the road base and surfacing materials overlying the sandwiched gravel blanket. Another geotextile layer is then laid on top and native soils are spread and compacted over the top until the desired roadbed level is attained.

The above examples provide a brief introduction to the highly successful engineering methods available to solve problems of subsurface drainage. Additional reading and research is highly recommended before using geotextiles for sub-drainage (see Chapter 4 for additional

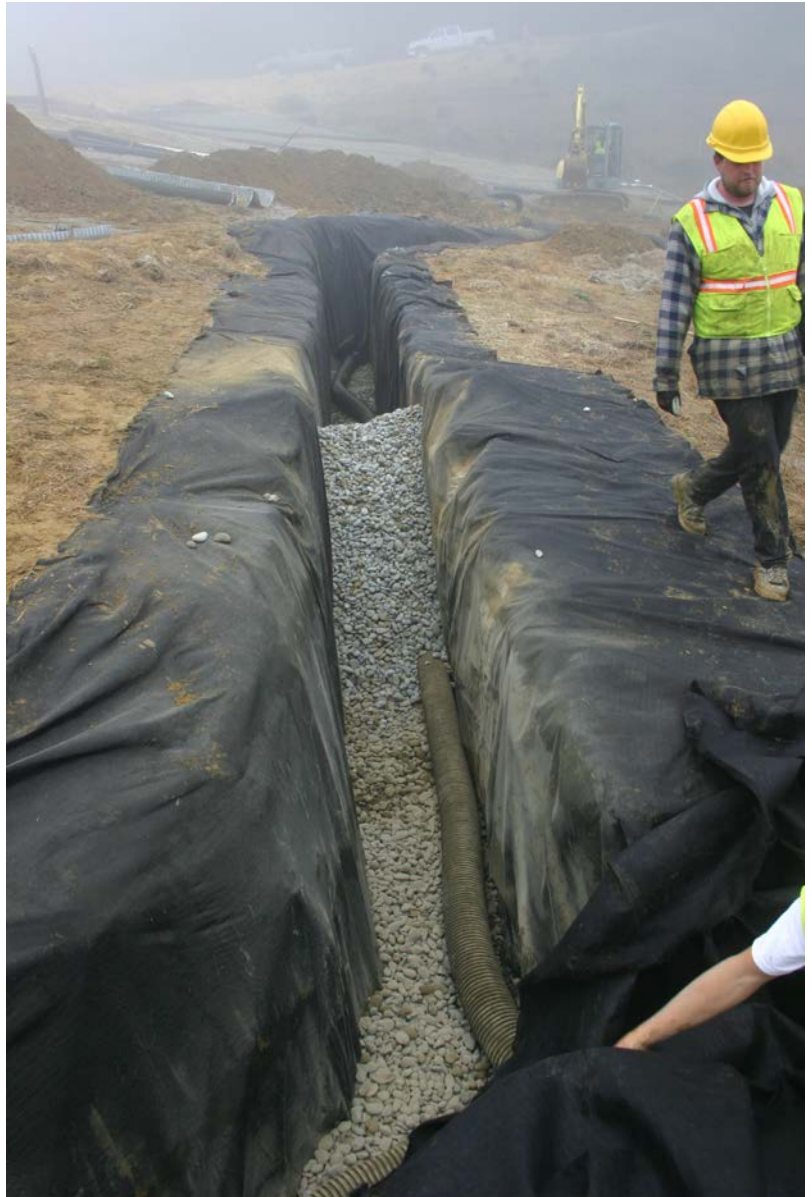


FIGURE 142. Pipe underdrain used to capture subsurface groundwater before it can saturate an adjacent fill slope. This trench was 10 feet deep and 2 feet wide, lined with non-woven geotextile and filled with gravel. A perforated flex pipe was placed on a thin layer of gravel at the bottom of the trench and the drain sloped gradually downhill and discharged captured subsurface flow onto a nearby stable slope.

detail on the selection and use of geotextiles). Assistance may be obtained from an experienced road engineer or qualified geologist or engineering geologist who has had success using these products, or from the field representative of a company that manufactures or distributes geotextiles designed for these applications.

H. CONSTRUCTING ON UNSTABLE SLOPES

The first rule of road construction is to stay away from unstable areas and landslides. However, there may be times when all other options have been exhausted and road construction in unstable zones is the least damaging alternative. **If road construction must occur on unstable slopes, it is highly recommended that a qualified engineering geologist or geotechnical engineer be consulted to develop plans and construction methods for the specific road segment.** In situations where water quality would be seriously threatened by operations on unstable slopes, road construction or reconstruction projects may have to be deferred or entirely avoided. **Unstable slopes that threaten water quality must be recognized**

and should be considered unsuitable for road building. Refer to “Chapter 4: Road and Stream Crossing Design, Section B, 4(c) for guidelines and special considerations for road construction on unstable terrain.

Some preventative measures can be applied to compensate for expected decreases in slope stability that often accompany road building. These recommendations include 1) don't oversteepen or load the upper part of an unstable slope with sidecast material, 2) don't alter the hillslope drainage by blocking or redirecting surface or subsurface flow onto an unstable area or slide mass or by ponding water, and 3) don't remove material from the toe of an unstable slope or slide. These preventative measures should be applied when operating on slopes steeper than 50% to 55%, and may be necessary on some soil types at lesser gradients.

Most road-related failures (especially fill failures) are the direct result of excessive fill and sidecast on steep slopes, fill materials sidecast on zones of emergent groundwater, or concentration and discharge of surface runoff onto road fill slopes (Figure 143). Narrow roads can

FIGURE 143. Sidecast road construction on steep inner gorge slopes above a fish-bearing stream. Fine grained sidecast materials are perched on 70% slopes and show signs of instability and pending failure. The remaining, stable part of the roadbed is on the road cut.



significantly reduce the amount of material that must be excavated during road construction in these areas (Table 15). Thus, on steep slopes (over about 60%), sidecasting should be entirely avoided. In addition, unstable soil types or the presence of springs and seeps may limit the use of any sidecasting on slopes as low as 45% in order to minimize the potential for sidecast instability or fill failures.

It is especially important to avoid sidecasting on steep slopes in headwater swales, where hillslopes converge into a narrow, steep channel. These locations are prime sites for generating debris slides and resultant debris flows which can travel thousands of feet downslope, scouring steep channels and depositing large amounts of sediment and debris that severely impact fish-bearing streams and domestic water supplies (Figure 144). Professional judgment and recommendations are critical for the identification of debris flow hazard and can best be made by an experienced and qualified geologist or engineering geologist.

Debris avalanches on steep slopes can also be triggered by ground motion from heavy blasting during road construction or quarry excavation, especially during wet conditions. This suggests that the potential for initiating a landslide in the vicinity of blasting can be reduced by conducting blasting in the dry summer period. On steep slopes, excess blast material should be endhauled and not sidecast or allowed to accumulate on the hillslope below the road.

Knowing the boundaries of an unstable area (slide mass) is essential in selecting the type and location of cut and fill construction to be used. Cuts and fills can be located across some landslides with little effect on their stability, or even a net increase in slope stability. For example, the toe of some existing or potential rotational slides can be loaded with weight, or the head can be unloaded, without decreasing slope stability (Figure 145). Thus, a full fill road (using

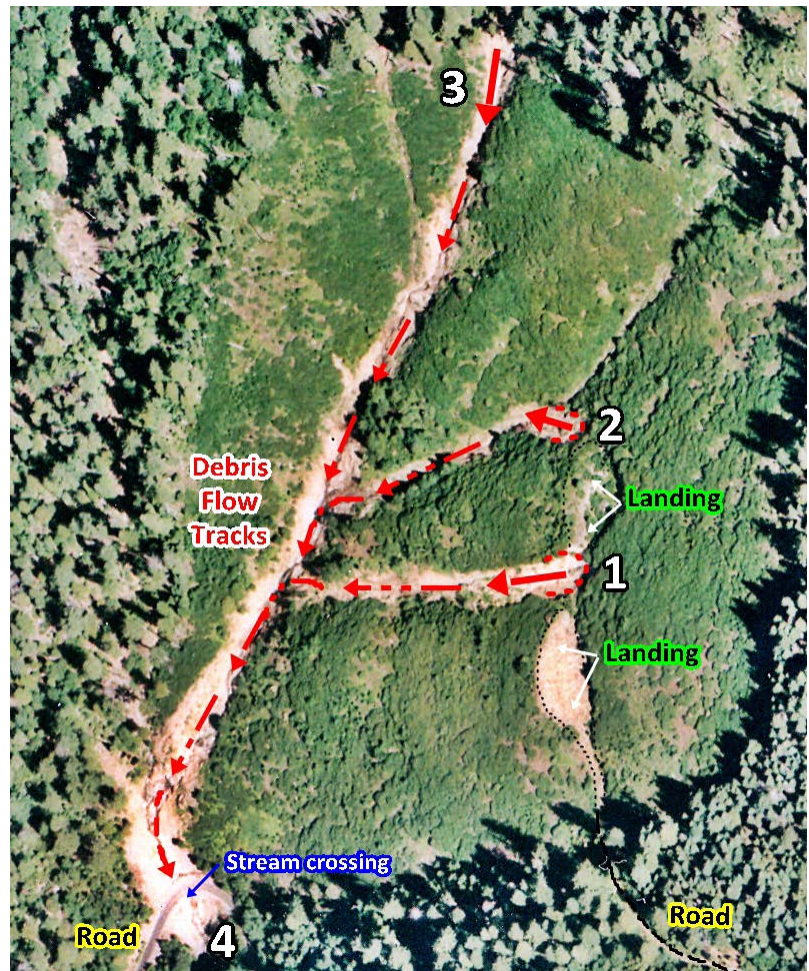
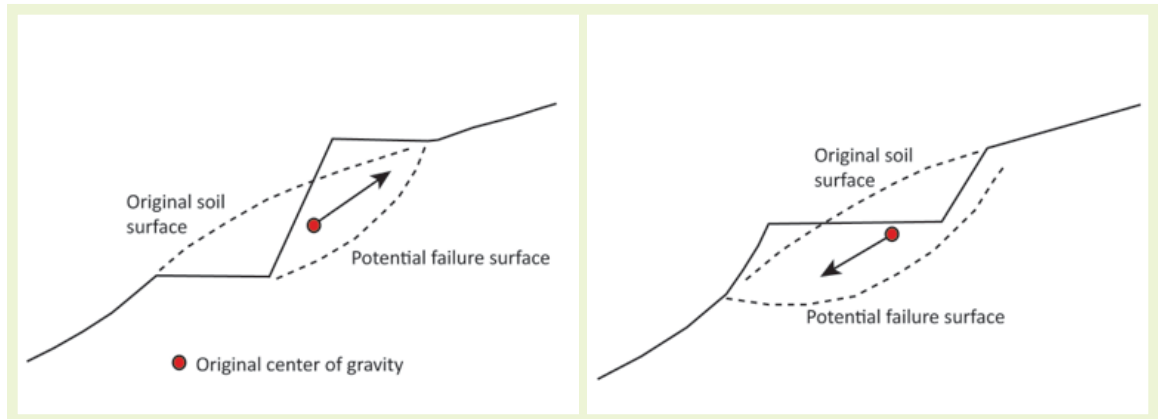


FIGURE 144. Aerial photo showing debris slides and flows triggered by a large storm event. Slide #1 occurred where a forest road was constructed over a steep topographic swale. Slide #2 originated where the landing sidecast failed on a steep, inner gorge hillslope. Slide #3 started about 2000 feet upstream where a road had been constructed through a steep, wet swale. Each debris slide traveled as a fluid mudflow, scouring the channel of sediment and woody debris. The merged torrents washed out and incorporated eroded fill from stream crossing at #4 and traveled another 0.5 miles downstream.

FIGURE 145.

In general, the toe of a rotational slide should be loaded, whereas the head should be unloaded. Loading the head and/or unloading the toe (left diagram) acts to raise the center of gravity and actually causes greater instability. Loading the toe and/or unloading the head shifts the center of gravity downward and can increase slope stability. This strategy does not work for other landslide types, where road building should be avoided.



endhailed material and little or no cutting) at the toe or a full bench road (with endhaul) at the head of this type of slide will not reduce stability and may even improve conditions (Figure 146). However, in spite of employing state-of-the-art road building techniques, slide movement may still continue. As a general rule, landslides and unstable areas should not be crossed with roads.

Finally, the overall risk of slope failure can also be reduced by reducing total road length, as well as road width, especially for roads built across steep slopes.

For example, using long-line or helicopter yarding systems for forest operations can reduce road construction on unstable hill-slopes by up to 50%, or more. Narrow roads

are also less disruptive than wide roads, and are less likely to impact unstable areas.

Steep road gradients and pitches can be used to reduce road mileage, and to avoid unstable areas, and may be more cost-effective than full bench, end-haul construction across unstable areas or steep slopes. Employing locally steep road grades and pitches can be used to get your road onto low-maintenance, stable ridge-top areas and benches within the watershed. However, steep sections of road will often require outsloping, better ditching, more surfacing, and improved surface drainage compared to low gradient roads.

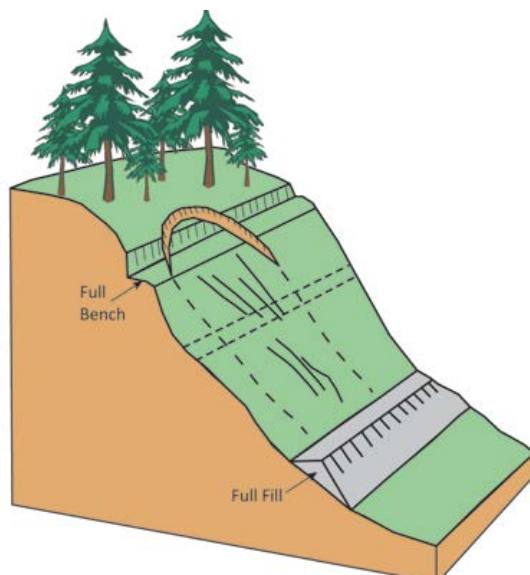
I. CONSTRUCTING STREAM CROSSINGS

Common types of permanent stream crossings include bridges, culverted fills, armored fills and fords as well as a variety of temporary stream crossings that are removed prior to the winter or wet weather period (see Chapter 4). The use of log crossings and unculverted fills are not suitable for permanent stream crossings, even though they may have been commonly used in the past.

Constructing a stream crossing is a two part process consisting of: 1) constructing the road bench approaching and leaving the crossing site, and 2) constructing and installing the drainage structure(s) and fill at the crossing.

FIGURE 146.

On certain rotational landslides, building a full fill across the toe (loading the toe) or cutting a full bench, endhailed road across the head (unloading the head) can be performed without decreasing slope stability. However, in most instances it is best to avoid unstable slopes altogether.



1. STREAM CROSSING APPROACHES

Excavation of the approaching road is a critical part of constructing a stream crossing. If the channel sideslopes are steep, any sidecasting on the approaches could easily deliver loose soil directly to the watercourse (Figure 147).

Where roads are to cross stream canyons or incised channels with steep sideslopes, the approaches to the channel should be built with full bench construction methods.

Spoil material may be endhailed with trucks or placed on the excavated road prism behind the excavator and pushed farther back from the crossing using bulldozers. **Sidcasting should not be used!** Excavators are ideal machines to perform full bench construction on difficult stream crossing approaches.

Roads which cross steep slopes in stream canyons also often pass through wet and/or unstable soil materials. Potentially unstable soils and slopes near a crossing site should be identified before the equipment cuts into the slope, so the approaches can be designed to avoid, or drain and stabilize, the unstable area. In wet areas, the road may need to be ditched (whether it is insloped or out-sloped) and surfaced with rock to add stability and reduce erosion of the roadbed.

Where roads are to cross channels with more moderate or gentle channel side slopes, full bench or cut-and-fill construction techniques can generally be used without damaging the stream. Roads can be pioneered using excavators to remove and place fill below and on the roadbed behind them without sediment reaching the stream channel. The excavated material can be stored temporarily for later



FIGURE 147. *Uncontrolled sidecasting on the approach to this poorly constructed stream crossing delivers sediment directly to the stream channel. Roads built next to streams should be full bench endhailed, fill slopes should be at a stable angle (about 2:1), armor should be placed around the culvert, culverts should be extended approximately 6 feet beyond the base of the fill, and the slopes should be mulched and vegetated.*

use in the stream crossing fill, or a bulldozer can spread the material on the roadbed away from the approach. Fill can also be placed in compacted layers at the base of the newly build road prism and used to construct a stable fill. **Sidcasting on stream crossing approaches should be avoided.**

Regardless of the type of stream crossing, the road approaches should be hydrologically disconnected to the extent feasible.

That is, the approaching road reaches and ditches should be drained away from the stream and onto adjacent, vegetated hillslopes. The outlets of road drainage structures (i.e., rolling dips and ditch relief culverts) on the road approaches to stream crossings should be flagged along the proposed alignment and constructed far enough away from the watercourse that they do not directly or indirectly discharge to the stream. Those remaining **road segments that will still drain to the stream should be rock surfaced, paved or otherwise treated to minimize surface erosion and sediment discharge to the stream.**

2. BRIDGE INSTALLATION

Bridges are usually the best, least damaging choice for stream crossing installations and should be considered for all larger, deeply incised or Class I (fish-bearing) watercourses. Compared to culverted fill crossings, there is less soil disturbance during installation of bridges, less chance they will fail during floods, and any failures do not usually result in catastrophic discharges of sediment.

The main components of most bridges used for low volume roads include bank abutments, stringers or steel cross-channel members, decking, running-planks and wheel guards. Depending on the installation, armor is sometimes used to protect the abutments from channel scour during flood flows. Most of the bridge parts can be pre-assembled off-site

and quickly installed at the crossing location, or the bridge can be constructed entirely on-location. Vendors of prefabricated I-beam bridges often have one-stop shopping for bridges and bridge abutments that includes your choice of custom or generic specifications, transportation from the factory to the work site, and installation by their skilled crews.

As with culverted stream crossings, the greatest potential impact to stream channels occurs during bridge installation. Above all, installation should minimize or eliminate the use of equipment in the stream. A low impact equipment crossing (ford) may be needed in the immediate vicinity of the crossing to prepare both abutments and approaches for placement of the bridge. If approved by regulatory agencies (e.g., California Department of Fish and Wildlife), this ford may later be used by tracked equipment crossing the stream during low water periods to avoid damaging the bridge decking (Figure 148) or where the bridge's engineered weight limit would be exceeded.

The environmental impacts of infrequent, low water crossings by tracked heavy equipment can be minimized by laying down timbers, clean gravel or gravel-filled fabric bags, or straw bales in the channel bed. If the stream is too large or deeply incised to be crossed with heavy equipment, access will need to be developed from the other side, or a mobile crane will need to provide lifting services from the near bank. In either case, construction activities should result in only minimal disturbance to, and no sidcasting into, the watercourse channel.

Successfully installing a permanent or temporary bridge across a watercourse requires forethought and planning, and an experienced equipment operator and engineer may be required. First, the bridge abutments should be prepared and placed (or constructed) on each bank to accept the bridge. "Permanent" bridges may be secured to the banks by using

**FIGURE 148.**

Many bridges built on small forest and ranch roads cannot support or would be damaged by heavy tracked equipment passing over them. For this reason, an adjacent equipment ford is sometimes constructed. These steep fords can erode and deliver sediment to the stream channel if they are not rock surfaced, or waterbarred, mulched, and seeded between uses and prior to the rainy season.

piles driven into the natural ground, or by using constructed, poured or precast concrete abutments that are anchored to bedrock or cabled to “dead-man” anchors buried behind the abutment. The specific abutment design will depend on the bridge, the expected loads and local site conditions; it will need to be prepared by a qualified and experienced professional (e.g., a licensed engineer or engineering geologist). To minimize the chance for movement when

being used, temporary bridges may also need to be set on or secured to abutments such as logs or precast concrete slabs (Figure 149).

Each abutment should be leveled and secured far enough into the bank so that slumping or bank failure will not occur due to bridge and vehicle weight during use. Abutments and piers should be parallel to the stream channel and set back from the channel to

FIGURE 149.

Bridge abutments can be built of logs, piers, concrete pads, and other supports. This abutment is a precast concrete support that was fabricated off-site and installed when road construction reached the crossing location. A level pad for each abutment is excavated, base material spread and compacted, and the prefabricated concrete abutments placed and measured for the specific bridge.



FIGURE 150.

I-Beam bridge construction on a forest road. If rock armor is needed along the stream-banks, it needs to be placed before the bridge is installed.



prevent any narrowing of the streambed and banks (Figure 150). The bridge crossing should be at right angles to the channel, and, if possible, with at least 50 feet of straight approach before the bridge (Figure 151).

FIGURE 151.

Railroad flat car bridge correctly crosses stream channel at about a 90° angle, but it is too short (perched on the top edge of the channel bank) and the bare, unprotected soil abutments are subject to erosion during high flows. Bridge length must account for channel flood width and flow capacity as well as the top width of the channel bank. Banks must be sloped to a stable angle and extra width added for armor if it is needed.



road surfaces directly into the stream, bridges should not be located at the bottom of an abrupt dip in the road grade, if at all possible (Figure 152). Preferably, the bridge should be elevated slightly above the approaching road grades to insure that the crossing does not receive road surface runoff from one or both approaches (Figure 153). If the bridge crossing is the low point in the road, the approaches should be rock surfaced or paved back to at least

**FIGURE 152.**

The segments of road which approach a bridge should not drain onto the bridge surface. Otherwise, soil eroded from the adjacent road surface can be carried onto the bridge and into the stream. If the bridge is at a low point in the road grade, make sure the uphill road surface is well drained before the bridge and consider surfacing the connected approaches with rock or paving.

the nearest road surface water break (rolling dip). If the road climbs away from the crossing in one or both directions, the approaches should be flattened for at least 50 feet, with road surface runoff directed into a ditch relief culvert or rolling dip which drains into a vegetated buffer strip before reaching the bridge site.

Steel I-beam structural supports to be used for the bridge should not be dragged through

the streambed. A crane, an excavator, or an excavator and a winch-tractor can be used to move a portable bridge into place, with one piece of equipment on each side. If decking is installed on the bridge surface, it should be laid and bolted solidly across the top to provide a good bearing surface and to spread the load of vehicles to all the spanning supports or structural steel members. On wood bridges, running planks can be attached to the decking.

**FIGURE 153.**

Preferably, the bridge approaches should be slightly lower than the bridge running surface so water drains away from the bridge. Note how the approaching road slopes up to the bridge so that road runoff does not flow onto the bridge deck.

Bolts should be used to attach the decking because spikes tend to loosen and come out as the bridge flexes under heavy loads. Finally, for safety reasons, poles, sawn timbers or metal wheel guards should be installed along the outside edges of the bridge to alert drivers who wander off the running surface and too near the edge of the deck (Figure 154).

3. CULVERT INSTALLATION

During road building, the construction of culverted stream crossings has the greatest potential of all activities to cause immediate sediment pollution (see Chapter 5, Section M (6)—Protecting water quality during construction). If the stream is flowing at the culvert installation site, the crossing can be dewatered by constructing a small diversion dam (i.e., cofferdam) just upstream and pumping or diverting flow around the project area. The dewatered stream channel is then cleared and prepared for the culvert. Large rocks and woody debris should be removed. Both the culvert foundation and trench walls must be free of logs,

stumps, limbs or rocks that could damage the pipe, or subsequently cause seepage of flow around the outside of the culvert.

The culvert should be aligned both vertically and horizontally with the natural stream channel, and properly bedded, back-filled and covered, or they will be subject to eventual failure. Correct alignment is critical for the culvert to function properly. Misalignment of the outlet can result in bank erosion and misalignment of the inlet can increase debris plugging problems. Wherever possible, stream crossing culverts should be installed on straight channel reaches. **The culvert inlet is where most culvert failures originate during peak flows. Thus, if the channel naturally bends at the installation site, it is most important that the inlet be aligned with the natural channel upstream.** If the inlet is at an angle to the natural stream, floating debris is much more likely to lodge against the culvert inlet and plug the pipe during flood flows. In contrast, the outlet can be protected against erosion by using rock armor on the channel bank, or a pipe

FIGURE 154. *Wheel guards on a railroad flatcar bridge (see Figure 153) signal the driver that he is too close to the edge of the bridge. On this flatcar bridge, the road in the foreground slopes down to the bridge but the continuous steel wheel guard also seals the bridge surface so that all road runoff and sediment flows across the bridge and farther down the road before being dispersed onto the vegetated hillslope.*



angle can be added to turn the flow into the natural channel downstream from the outlet.

Stream crossing culverts should be placed at the base of the fill, and at the grade of the original streambed.

In non-fish streams the culvert should be inset slightly into the natural streambed so that water drops several inches as it enters the pipe. Culvert inlets set too low can plug with debris and cause a headcut to migrate upstream, and those set too high can

allow water to undercut the culvert at the inlet (Figure 155). Culverts that are installed at a gradient lower than the natural stream channel experience erosion at the downstream fill face unless an anchored full round downspout is installed. Similarly, culverts installed with a lower gradient than the natural stream channel typically experience increased sediment deposition and ponding at the inlet which increases the risk of inlet plugging and stream crossing

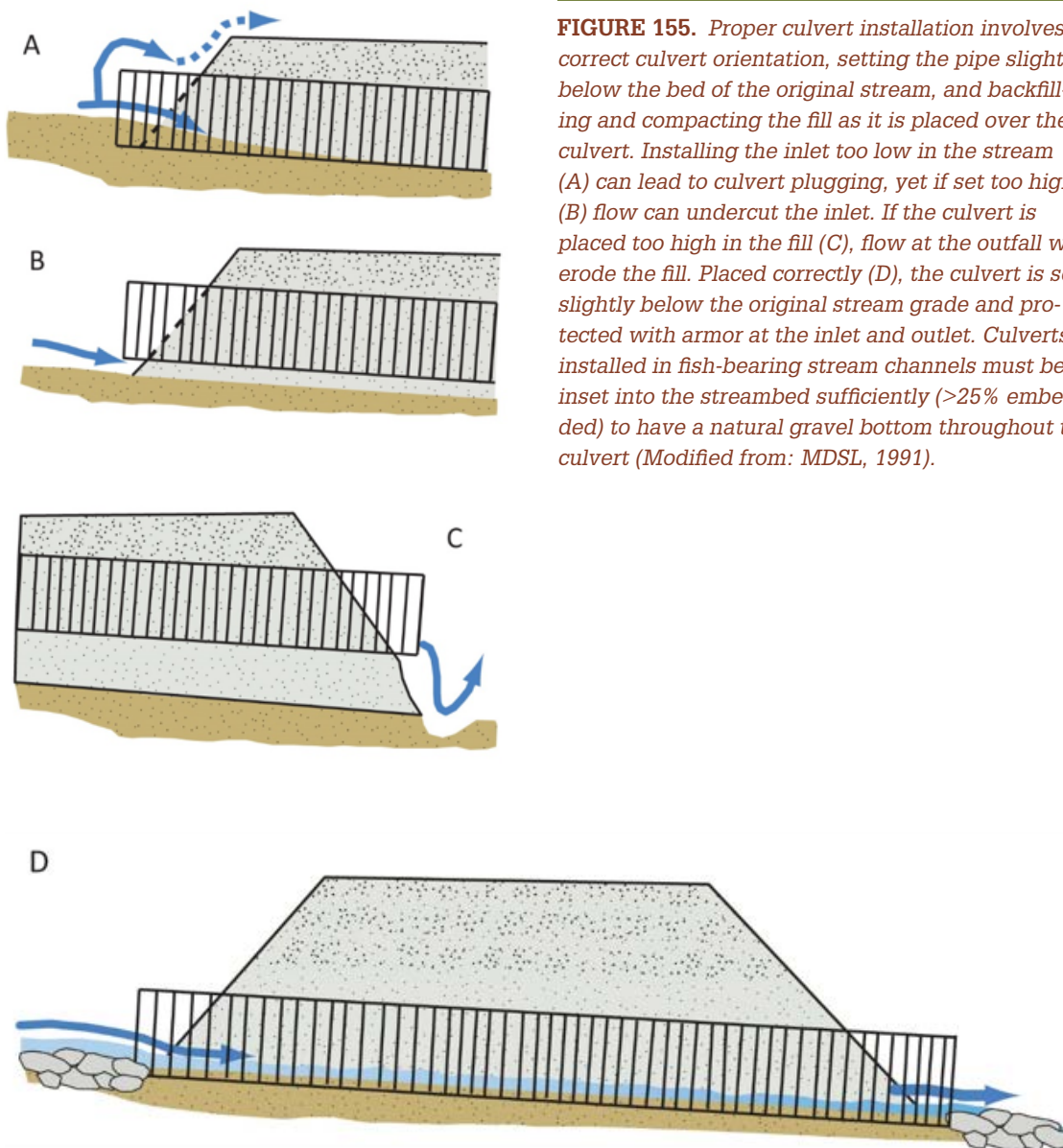


FIGURE 155. Proper culvert installation involves correct culvert orientation, setting the pipe slightly below the bed of the original stream, and backfilling and compacting the fill as it is placed over the culvert. Installing the inlet too low in the stream (A) can lead to culvert plugging, yet if set too high (B) flow can undercut the inlet. If the culvert is placed too high in the fill (C), flow at the outfall will erode the fill. Placed correctly (D), the culvert is set slightly below the original stream grade and protected with armor at the inlet and outlet. Culverts installed in fish-bearing stream channels must be inset into the streambed sufficiently (>25% embedded) to have a natural gravel bottom throughout the culvert (Modified from: MDSL, 1991).

failure. Culverts set at channel grade have a greater ability to pass sediment and wood.

The culvert bed may be composed of either compacted rock-free soil, or gravel (Figure 156). If gravel is used for the bed, filter fabric will be needed to separate the gravel from the soil to minimize the potential for soil piping. Bedding beneath the culvert should provide for even distribution of the load over the length of the pipe. **Nearly every culvert will sag due to soil compaction after it is buried. To allow for this, all culverts should be installed with an “up camber” or slight hump in the bed centered under the middle of the pipe.** The amount of camber should be between 1.5 to 3 inches per 10 feet of culvert pipe length. Natural settling and compaction which occurs after backfilling will then allow the pipe to settle into a straight profile.

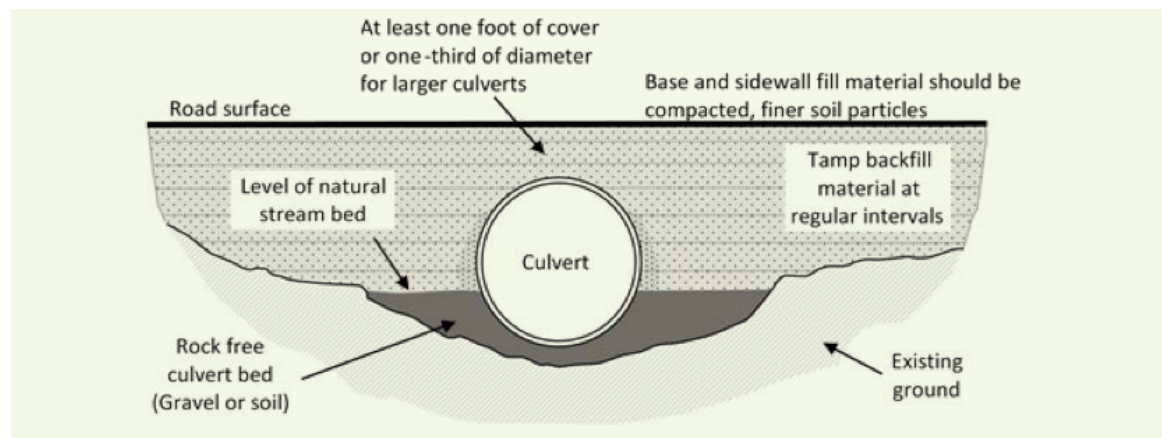
Backfilling can begin once the culvert is in-place in its bed. Backfill material should be free of rocks, limbs or other debris that could dent the pipe or allow water to seep around the pipe. One end of the culvert should be covered, and then the other end. Once the ends are secured, the center is covered. Careful pouring or sifting of backfill material over the top of the pipe using a backhoe or excavator bucket will allow finer particles to flow around and under the culvert sides. Larger particles will roll to the outside. The fine soil particles will

compact more easily and provide a good seal against leaks along the length of the pipe.

The backfill material should be tamped and compacted throughout the entire installation process. The base and sidewall material should be compacted before the pipe is placed in its bed. A minimum amount of fill material should be used for the bed of the culvert to reduce seepage into and along the fill. Backfill material should then be compacted in approximately 0.5–1 foot lifts until at least 1/3 of the diameter of the culvert has been covered (Figure 156). Leaking will be prevented if compaction is done under optimum soil moisture conditions. A vibrating, gas-powered hand-compactor (rammer) can be used to provide compaction alongside the culvert as backfilling is occurring. Once sufficient depth has been reached, rolling compactors and heavy equipment can be used to bring the fill to grade.

Once backfilling has been completed over the top of the pipe, the inlet and outlet of the culvert should be armored. A metal, concrete, sandbag or rock head-wall can be constructed to prevent inlet erosion. Where it is available, rock armor is routinely used to armor the inlet and outlet areas of newly installed culverts (Figure 157). On the inlet side, it protects against erosion during flood events and high water. On the outlet side of the fill rock armor is placed around and slightly above

FIGURE 156. Rock-free fill is backfilled over the culvert in layers and compacted under the pipe and around the sidewall. Soil compaction along the haunches (lower corners) of the culvert provide confining strength to the pipe and reduce deformation, especially for non-round culvert shapes (Modified from: FEMA, 2009).



the projecting culvert pipe to protect the new fill from splash erosion at the culvert outlet and to trap any sediment that is eroded from the new, downstream fill slope until it can be stabilized by vegetation. If the stream is live, flow through the culvert should be observed to determine if and where additional rock armor is needed. As a precaution against sedimentation in the stream, a slash windrow can be constructed at the base of the road fill around and adjacent to the culvert outlet so that soil is not sidcast into the stream channel or onto the inlet during final filling and grading of

the roadbed. Rock armor placed around the culvert outlet can also serve this purpose.

Final filling of the stream crossing can now be performed. Layers of fill are pushed over the crossing until the final, design road grade is achieved. Fill should be placed over the top of the culvert to a depth of at least 1 foot, for 18" to 36" culverts, or a minimum of 1/3 to 1/2 the culvert diameter for larger pipes. **If adequate cover cannot be achieved over a round culvert, then an arch culvert, an oval culvert, or a pipe-arch should be installed** (Figure 158). The



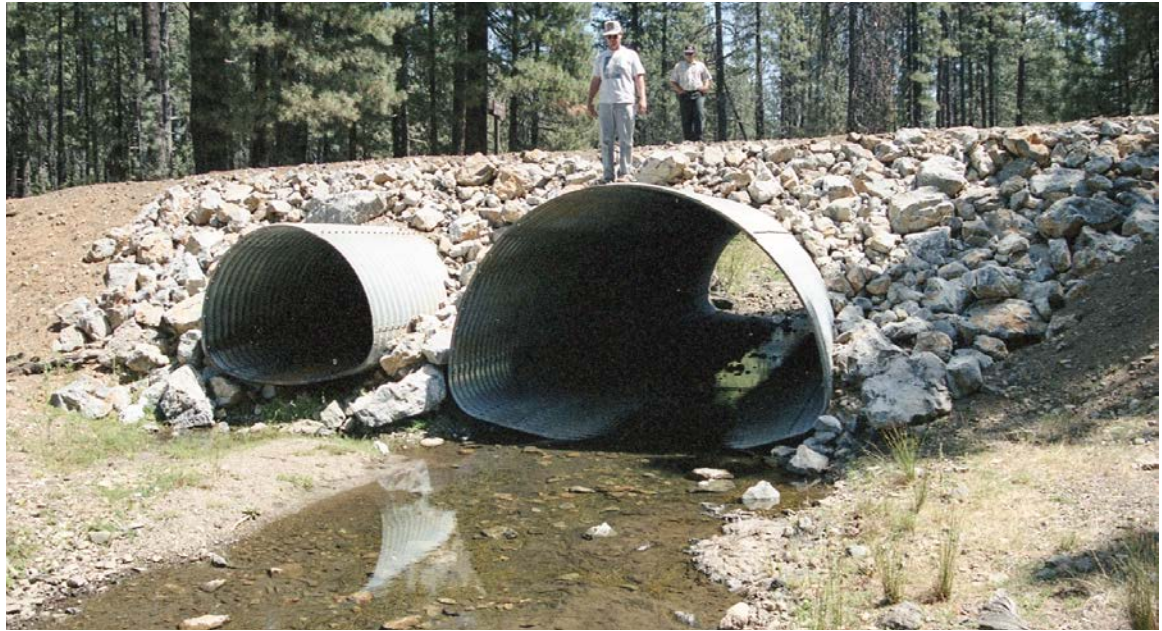
FIGURE 157A. *Culvert installation in a shallow fill on a steep, boulder bedded Class II (non-fish bearing) stream replaced a severely undersized pipe (Figure 157a). The new six foot diameter culvert is set slightly into the original streambed and the inlet is armored to prevent erosion. The aggraded channel above the inlet (foreground) has been excavated and disturbed bare soil areas have been mulched and seeded. The roadbed dips into and out of the stream crossing with a critical dip placed just down-road of the left hinge line.*



FIGURE 157B. *After the first wet season (Figure 157b) the channel bed has self-armed and established a stable cross section leading to the inlet. Bare soil areas are covered with grass.*

FIGURE 158.

Dual pipe arch installation on a fish-bearing stream. Because of the shallow fill, a second pipe arch was installed to upgrade the crossing to pass the design flood flow, and the entire fill face was armored with rock. Low flow passage would have been better served if the smaller pipe had been embedded into the channel bottom, slightly lower than the main culvert. Instead, neither culvert is embedded and the crossing is a barrier to fish migration during low flow periods.



least preferred option would be to install dual round culverts, as their plugging potential would be much higher than a single pipe.

A dip should be placed in the road at the down-road edge of the new fill to provide for a “diversion-safe” drainage design (see Chapter 4). Preferably, the entire road fill should be dipped at the down-road hinge line of the stream crossing. This dip prevents stream diversions while also reducing the erodible fill volume (the potential failure volume) and the length of the new, erodible fill slope. In either case, if the culvert plugs the stream will flow over the road bench and back into its natural channel; not down the adjacent roadbed.

It is also increasingly common practice to inslope the road bench at stream crossings, especially right after construction or reconstruction, so that road surface runoff flows inward to the culvert inlet, rather than over the long, newly constructed and unprotected outside fill face. To minimize road runoff directly entering the crossing, the approaching road can be outsloped and a rolling dip should be placed just up-road from the crossing to drain the road surface. Forest managers and ranches often use

insloped fills because trucks with trailers track better over an insloped crossing and the road surface doesn’t have to be as wide as it would otherwise have to be. Depending on expected vehicle speeds, outsloping may be the best alternative on rural roads used by the public.

More traditionally, you can construct the roadbed with an outsloped road shape through the crossing. Road surface runoff can be controlled with an outside berm and then discharged onto native ground at the down-road edge of the fill, or carried to the base of the new fill in a berm-drain or open top culvert or armored (rock surfaced) drain. Berms, however, are prone to failure and should only be used where regular, wet season maintenance is available. Once the roadbed has been shaped, and armor placed at the inlet and outlet areas, the bare fill slopes should be seeded with grass (preferably non-persistent or native, non-invasive species) and then mulched to reduce erosion for the first several years and until vegetation has become established. If the fill face is heavily vegetated with grass by the time of the first fall rains, the berm may not be necessary to prevent surface erosion on the new fill slope.

As a final protective measure, a trash screen or trash barrier can be installed just upstream from the inlet if there is a hazard of floating limbs and wood chunks plugging the culvert inlet (see Chapter 4—Trash barriers and screens). This is especially important on forest roads with a history of wildfire or where the upslope areas have recently been cleared or harvested, or are slated for clearing or harvesting in the future, and sufficient maintenance is possible. Trash barriers or screens increase inspection and maintenance costs by requiring intermittent cleaning of woody debris following storm events. At the same time, trash racks can prevent a stream crossing from failing and delivering large volumes of eroded sediment downstream and leaving the road impassible until flood waters recede and repairs can be completed.

4. TEMPORARY STREAM CROSSINGS

By definition, temporary stream crossings are designed to be removed. As with bridges, installation of a temporary crossing should be done with the minimum amount of disturbance to the channel bed and banks, and using the least amount of fill material possible. The goal is to leave the site in a relatively undisturbed condition that is subject to minimal erosion following removal of the crossing.

As with the installation of all other stream crossings, there should be little or no side-casting on the approaches to the channel. Colorful flagging, straw mulch or some other marker should be spread over the channel bottom so it is possible to clearly identify the bottom of the natural channel when the temporary crossing is removed. The temporary crossing is then constructed on top of this marker. If the watercourse is incised and/or is flowing at the time of installation, temporary

log, log-and-culvert, culverted fills or temporary bridge crossings can be installed.¹

For log crossings, vegetation is first pruned from along the alignment and from the streambed and banks, as opposed to being stripped or bladed with a tractor. Next, straw is placed on the bed and against the banks, to help identify the original channel margins and to protect the channel from disturbance. In a live (flowing) stream channel, a culvert capable of carrying flows expected during the period of operation should be placed at the base of the log fill. Logs are bundled into groups using choker cables and then lowered into the channel. Cabled logs make removal a simple, one-step operation using a bulldozer, loader or excavator. When the log “fill” has been built up to within about 18 inches of the temporary crossing grade, the remaining large spaces can be filled with smaller logs. Geotextile fabric and/or a 6” to 12” layer of straw is then placed on top of the logs to prevent the overlying road surface soil from infiltrating through the logs to the streambed and being washed downstream (Figure 159). Local soil is generally adequate for the running surface, and the fabric or straw layer enables easy removal of the capping soil fill.²

J. DITCH RELIEF CULVERTS

1. DITCH RELIEF CULVERT LOCATION

Ditch relief culverts near stream channels and unstable areas are the most important drainage structures to carefully locate and install. The most important elements for ditch drainage on newly constructed or reconstructed roads include location (where to discharge the road

1 The most common type of temporary bridge crossing used on forest and ranch roads is the railroad flatcar bridge. See Chapter 4, Section C(4) and Chapter 5, Section I(2) on the design and installation of bridge crossings.

2 In California, these types of temporary crossings are often referred to as “Spittler” crossings, since they were pioneered by Mr. Thomas Spittler, California Geological Survey (retired) (Spittler, 1992).

FIGURE 159. Oblique view of a temporary forest road crossing of a perennial fish-bearing stream. First, the channel above and below was electro-fished by trained biologists to remove and relocate any fish or amphibians. The crossing consists of two 18 inch diameter culverts, covered by gravel, geotextile, dozens of logs, more geotextile and a 12 inch thick running surface composed of local soil. The logs are not always necessary but were added here to bring the road surface up for easy passage. The materials comprising the temporary crossing are easily removed upon the completion of operations.



runoff), spacing (how frequently to provide for ditch drainage), and water quality (if ditch flow is delivered to a stream, is it clear or turbid?). The goal is to prevent or minimize hydrologic connectivity between the dirty road runoff and the stream, and to prevent erosion or slope failure at the point ditch flow is released onto the slope.

- When the road approaches a stream crossing, ditch relief culverts should be located such that the outlet is not too close to the stream, but sufficiently close to the crossing so most ditch flow is intercepted and directed through the culvert and into a vegetated buffer area. The remaining length of ditch will still flow to the stream crossing.
- Where a road follows alongside but slightly upslope from a stream channel, it is important to be aware of the best locations to place the outlet of the culvert so it does not deliver road runoff to the stream. The outlet is flagged and the ditch relief culvert is then installed based on this outlet location.

- When operating near unstable or potentially unstable hillslopes, you should be careful not to discharge road runoff onto a slope instability and instead choose stable ridges, rocky slopes or stable benches to release the runoff.

The outlet area for ditch relief culverts should be examined carefully to identify the best possible site for the discharge. On existing roads, most inside ditches either drain to stream crossing culvert inlets or to ditch relief culverts that discharge to downslope areas.

The key factor in new road construction, as well as in road upgrading, is to make sure hydrologic connectivity is minimized by dispersing road surface and ditch runoff before it can reach a stream (Figure 160).

2. DITCH RELIEF CULVERT INSTALLATION

Once the proper locations have been identified that will avoid or minimize hydrologic connectivity, standard construction practices can be applied to install ditch relief culverts.



FIGURE 160. Ditch relief culverts on riparian roads that are very close to a stream channel are difficult to hydrologically disconnect. Here, an end cap and twin perforated flex pipes have been attached to the outlet of a ditch relief culvert. The perforated flex pipe is then staked along the slope's contour so turbid ditch runoff is slowly released and broadly dispersed along its length.

Ditch relief culverts should be installed at a 30 degree angle to the ditch to turn the ditch flow and thereby lessen the chance for inlet erosion and plugging. Take care not to dig a large inlet basin that causes the cutbank above the culvert inlet to ravel, erode or slide into the inlet. If the culvert is correctly angled down road then a large basin is not needed to turn the flow into the culvert inlet. **Like rolling dips, the outlet location of the culvert should be identified first, because it influences where runoff will end up on the slope and where runoff will travel.** Once the outlet is set, the inlet can be located for an effective design.

Ditch relief culverts should have a slope at least 2–4 percent steeper than the ditch grade leading to it, or at least 5 inches every 10 feet (Figure 48). Preferably, ditch relief culverts should be set at the grade of the natural hillslope so they exit at the base of the fill and drain directly onto the natural hillslope. This will ensure sufficient water velocities to carry sediment through the pipe. A minimum 10% culvert grade is usually self-cleaning, but steeper is better (Figure 161).

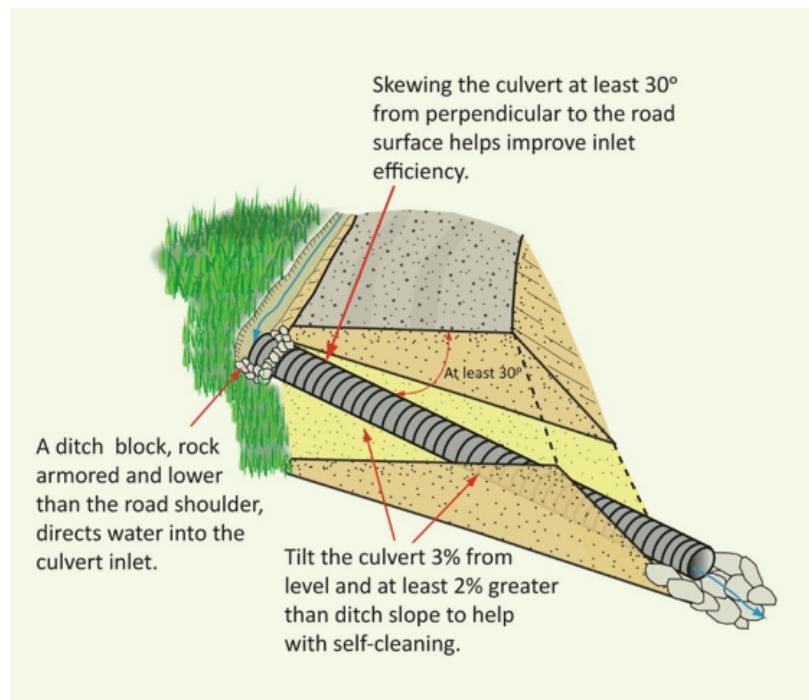


FIGURE 161. Like stream crossing culverts, ditch relief culverts should be installed at the base of the road fill and, if necessary, with armoring at the inlet and some type of energy dissipation at the outfall. If the culvert is placed higher in the fill, a downspout should be used to carry flow from the outlet downslope past the base of the fill (Modified from: MDSL, 1991).

The bedding and fill material should be free of rocks and debris that could puncture the pipe during installation and compaction. Backfill materials should be compacted from the bed to a depth of 1 foot or 1/3 the culvert diameter, whichever is greater, over the top of the culvert. The culvert outlet can empty onto an apron of rock, gravel, brush or logs (Figure 162) for energy dissipation, but if the culvert carries so much runoff that a gully forms or could form, additional drainage up the road is needed to reduce the flow volumes and eliminate hydrologic connectivity. Outlet erosion is usually not a problem unless the erosion extends downslope as a gully.

K. ROLLING DIPS

Rolling dips are simply breaks in the grade of a road. They are sloped either into the ditch or, more commonly, to the outside of the road edge to drain and disperse road surface runoff. Rolling dips are installed in the roadbed as needed to drain the road surface and prevent rilling and surface erosion (Tables 3 and 19), and are most frequently used in combination with road outsloping. As a road becomes steeper, rolling dips should be more closely spaced, deeper and outsloped at a steeper angle to adequately capture and divert road

runoff (Figure 163). Rock surfaced roads up to 20% or slightly steeper can be constructed with rolling dips, but traffic will be limited to four-wheel drive vehicles. Typically, roads up to 8 to 12% grade can be outsloped with rolling dips and still accommodate most traffic types.

It is comparatively easy to properly locate and construct rolling dips when they are designed into the original plan for new road construction. In that instance, they are made largely as cut features with little if any fill used in their construction. However, they may also be installed on existing roads to improve surface drainage.

On existing roads, rolling dips are cut out of the roadbed with the excavated fill used to create the reverse grade (broad hump) on the down-road side of the dip. Rolling dips on existing roads can be built in about one hour, or less, using a medium size bulldozer (D-5 size), road grader or an excavator. Unsurfaced roads are more easily reconstructed with rolling dips, but rocked road surfaces can also be reconfigured and then resurfaced.

Depending on road grade, excavation for a rolling dip typically begins 50 to 100 feet up-road from where the axis of the dip is planned (Table 21). Material is progressively excavated from the roadbed, slightly steepening

FIGURE 162. *As long as the slope of the culvert is significantly steeper than the contributing ditch (so they will be self-cleaning) ditch relief culverts can be installed higher in the fill. The emerging culvert should then be fitted with an elbow and a downspout to take the flow to the base of the fill. Slope anchors (see photo) should be installed about every 20 feet down the slope to prevent culvert separation.*



**FIGURE 163.**

Several broad rolling dips in close succession on a rocked, outsloped road built across moderately steep terrain. As road grade increases, rolling dips need to be spaced more closely.

the grade, until the axis is reached. This is the deepest part of the excavation, with the overall depth being determined by the slope of the road. The steeper the road, the deeper the dip will have to be in order to reverse the road grade and cause surface runoff to be shed to the outside of the road (Table 21). This is called a “grade change” or grade reversal (Figure 34). On steep roads, increased out-sloping through the axis of the rolling dip can preclude the need for dramatic grade reversals, thereby “turning” the surface runoff to the outside of the road using outsloping without requiring a true reverse grade (Figure 164).

For forest, ranch and rural roads less than about 12% grade, the length of a rolling dip (from uphill start to trough to downhill end) is dependent on the grade of the road as well as the type and speed of vehicle traffic using the road. You want rolling dips to be functional and to shed surface runoff, but you don’t want them to pose a safety hazard, to be viewed as a roller coaster ride, or to cause traffic to have to slow significantly as they drive the road. Ideally, most drivers should not even know or think that they are driving over a road drainage structure. Whether for commercial or residential traffic, higher speeds dictate longer

FIGURE 164. *On steep roads (over about 15% to 18%) reverse grade rolling dips are short and steep, and may be difficult for some traffic to pass. Alternately, a Type 3 rolling dip can be constructed where road surface runoff is drained off the road by locally increasing the outslope rather than reversing the grade with a dip. (See Figure 36).*



rolling dips so the dips and humps don't cause items to bounce or float around the inside of the vehicle during otherwise normally safe driving speeds for that road. Care should be taken to ensure that grader operators do not fill the axis of the dip with soil or rock, or cut deeply into the lower part of the rising section, thereby eliminating the change-in-grade.

In order to safely and effectively direct runoff to the side of the road, the rolling dip should be outsloped at least 2 to 4% greater than the road grade leading to the dip. If the axis of the dip is flat or too gentle (not outsloped enough) it will pond water and quickly develop potholes and puddles that will impede traffic flow. On the down-road side of the typical rolling dip axis, the roadbed slope should actually rise slightly to ensure that runoff is deflected by the dip and cannot continue down the road surface. The rise in grade (grade reversal) is carried for about 10 to 20+ feet before the road surface begins to fall again at its original slope. This transition from axis bottom, through rising grade, to original falling grade is achieved in a road-distance of 15 to 30+ feet, depending on the road grade and the traffic speeds that are anticipated.

If they are constructed properly and installed at an adequate spacing (e.g., see [Table 19](#)), rolling dips require very little maintenance. They should not collect enough runoff to develop significant erosion on the road surface between dips or on the fill slope at the outlet of the dip. Some rills and perhaps a small gully might develop on the outside fill slope where the dip discharges runoff, but this is generally not a problem if the roadbed is not significantly eroded and the fill slope erosion does not continue downslope and deliver sediment to a stream channel.

L. SUBGRADE AND SURFACING

The road surface can be a big source of fine grained stream sediment. In some watersheds,

it may be the primary source of accelerated (human-caused) erosion and sediment delivery. Proper road construction and surfacing, along with protective road surface drainage measures, can significantly reduce this source of turbidity and fine sediment.

Permanent roads that are to be used for winter and wet weather hauling and traffic, including ranch and rural access roads and roads used for commercial hauling of forest products, need to be surfaced to improve trafficability and reduce erosion. Roads which receive heavy use should be inspected regularly to discover early signs of surface damage and structural deterioration ([Figures 165 and 166](#)). Serious damage to road surfaces usually begins with the buildup of thick accumulations of dry rock powder (dust) during the summer ([Figure 167](#)), or excess water (and mud) during the winter. Standing water is a sign of poor road drainage ([Figure 168](#)) and ruts indicate that road strength is deteriorating ([Figure 169](#)).

A stable and well drained subgrade is essential for a good road. The load bearing capacity of a road depends upon the subgrade's soil strength, drainage and compaction characteristics ([Table 31](#)). Native material comprises the road's subgrade, and, if necessary, it can be excavated, improved in place (strengthened or drained) and/or capped with aggregate. Weak or wet subgrades (soils unable to support a load by themselves) need to be strengthened by adding loose or crushed rock or gravel, sometimes in concert with geotextiles, to provide ballast and distribute the stress placed on the soil ([Table 32](#)).

Wet, low strength soils may be stabilized by the use of synthetic fabrics (geotextiles) designed specifically for this application. The fabric is spread over the subgrade and then covered with a layer of base rock. Water passes through the membrane, but the wet soil remains below and does not mix with the base rock or surface aggregate. As a result, the road



FIGURE 165. Because of traffic and erosion, road surfacing has locally worn down to the lighter color, finer grained native base materials beneath. The road needs resurfacing.



FIGURE 166. Road surfacing on this steep road reach has worn down the coarse base materials, making for a rough ride and reduced traction.



FIGURE 167. Dry rock dust is formed by heavy traffic or commercial vehicles mechanically abrading and wearing down road surfacing materials. The road surface wears down and sediment leaves the road as airborne dust or in runoff during the next runoff event.

FIGURE 168. *Standing water and the development of potholes are common indicators of poor road drainage.*



FIGURE 169. *Road ruts on this seasonal road indicate a deteriorating subgrade that will either require traffic to be excluded during all but the driest periods, or strengthening with the application of a geotextile, base course, and surfacing materials.*





TABLE 31. Soil characteristics for road subgrade materials¹

Material type	Strength, compaction, and foundation suitability	Drainage	Reaction to frost	Common symbols of soil types ²
Clean gravels and clean sand ³	Good to excellent	Excellent	None to slight	GW, GP, SW, SP
Gravels and sands with non-plastic ⁴ fines	Good to excellent	Fair to poor	Slight to high	GMd, SMd
Gravels and sands with plastic ⁴ fines	Fair to good	Poor to impervious	Slight to high	GMu, GC, SMu, SC
Non-plastic and slightly plastic ⁴ silts and clays	Poor to fair	Fair to impervious (mostly poor)	Medium to high	ML, CL, OL
Medium and highly plastic ⁴ silts and clays	Very poor to poor	Fair to impervious (mostly poor)	Medium to very high	MH, CH
Peat and other highly organic soils	Very unstable, poor compaction	Fair to poor	Slight	Pt

¹Washington DNR (1982)

²Unified Soil Classification System (USCS) symbol

³“Clean” means less than 12% of the material is smaller than 1/64” (the smallest particle visible to the naked eye).

⁴Plasticity can be tested by simple field methods, including lightly wetting a hand sample, rolling the fines into a ball and then into a thread before it crumbles: The range of plasticity includes: **Non-plastic**: a thread cannot be formed regardless of the moisture content; **Low plasticity**: after 2–3 times, the molded ball will crumble; **Medium plasticity**: after 3–5 times, the ball will easily crumble with moderate force (pressed between thumb and forefinger); and **High plasticity**: the ball will not crumble, even with moderate force, after five times.

TABLE 32. Guidelines for rocking a road¹

Factors for rocking a road	Factors for not rocking a road
Road is in a coastal or valley climate.	Road is in a dry climate.
Soil type is weak and poor draining, prone to erosion.	Well drained gravelly road.
Road grade is steep, any water will have potential to run down the road and erode surface.	Gentle road grade, less than 8%
The road use is permanent and access is needed throughout the year.	This is a one time or one season road use that could be timed to occur during dry periods of the year.
It is not practical or possible to close road during unneeded periods.	The road can be decommissioned or closed after short-term use.
Heavy use is planned for the road.	Low use is planned for the road.
Rock is readily available and relatively inexpensive.	Rock is scarce, must be hauled long distances and is expensive to apply.
High use recreation area that would make it difficult to keep traffic off road during wet seasons.	Road can be easily and effectively blocked until weather permits Road is located on ridge or high on the hillslope and there is little risk of damage from erosion.

¹Modified from: ODF, 2000

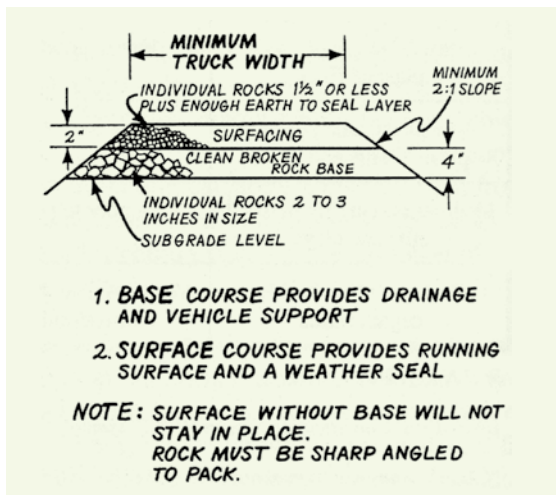
FIGURE 170. Road structural cross section showing a gravel surface course bound by finer material, overlying an angular base course spread and compacted on a stable, natural subgrade.



dries faster and the fabric spreads the wheel loading pressures over a large surface area.

First, a “base course” of 2 to 3 inch diameter angular rock with some fines (to permit compaction) is usually dumped on the compacted native road surface using dump trucks, spread to a uniform depth using a grader or tractor and then compacted. The use of true compaction equipment (instead of tractors) will provide the best, longest lasting road surface, but tracked or wheeled vehicles can also produce acceptable field compaction if soil moisture is at an optimal level. Geotextile engineering fabrics can be used beneath the base course material if soil conditions are wet. A finer “surface course” several inches in thickness is then spread over the compacted base coarse material to provide a dense, smooth running surface (Figure 170). The resulting layers of angular, interlocking rock will provide a low impact road surface that can be used all year (Figure 171). The running surface of the road (spread and compacted above the base course) should be smooth and hard-wearing, and it should not be subject to blowing or washing away.

FIGURE 171. Cross section diagram showing typical base-course and surface-course application for forest, ranch and rural roads (USDA-SCS, 1983).



For all-weather use, angular rock should be placed to a total depth of 6–10 inches, or more, which will then compact to a finished depth of 4 to 6 inches under normal use. Table 33 lists the approximate volume of aggregate needed

TABLE 33. Aggregate (yd³) required to surface or armor one mile of road¹

Road width (ft)	Depth of uncompacted rock (in)					
	2"	4"	6"	8"	10"	12"
10'	326	652	978	1,304	1,630	1,956
12'	391	782	1,174	1,564	1,956	2,348
14'	456	913	1,369	1,826	2,282	2,738
16'	522	1,043	1,565	2,086	2,608	3,130
18'	587	1,174	1,760	2,348	2,934	3,520
20'	652	1,304	1,956	2,608	3,260	3,912

¹USDA Forest Service (1978). Uncompacted 16.3 yd³ equals 1 in deep by 1 ft wide by 1 mi long. When aggregate is compacted, increase volumes required by 15-30%, depending on type and gradation of material.

to surface one mile of road, ranging from 10–20 feet wide, to a compacted depth of 1–6 inches.

M. EROSION CONTROL DURING CONSTRUCTION

Road construction, reconstruction (upgrading), use and maintenance can cause soil erosion and stream sedimentation problems. In fact, roads have been identified as one of the greatest sources of man-caused erosion and sediment delivery in forested and managed

wildland watersheds. Some erosion is the result of poor road location and design, but some clearly comes from inadequate planning for erosion and sediment control on the construction site. Proper forest, ranch and rural road construction, reconstruction, and maintenance practices reduce long-term erosion and stream sedimentation from wildland watersheds. However, even properly located, designed and constructed roads still need erosion control measures to minimize soil loss and sediment production (Table 34).

TABLE 34. Guidelines for erosion and sediment control application

Timing of application	Technique	Portion of road and construction area treated
Erosion control during construction	Hydromulching, hydroseeding	Road fill slopes, cut slopes, bare soil areas
	Dry seeding	Road fill slopes, cut slopes, bare soil areas
	Wood chip, straw, Excelsior or tackified mulch	Road fill slopes, cut slopes, bare soil areas
	Straw wattles	Road fill slopes and cut slopes
	Gravel surfacing	Road, landing and turnout surfaces
	Dust palliative	Road surfaces
	Minimize disturbance (soil and vegetation)	All areas peripheral to construction
Sediment control during construction	Sediment basin	Roadside ditches, turnouts and small stream crossings
	Sediment traps (e.g., silt fences, straw bales barriers, woody debris barriers)	Road fill slopes, cutbanks, bare soil areas and ditches
	Straw bale dams	Ditches and small streams
	Sumps and water pumps	Stream channels and stream crossings
	Streamflow diversions (e.g., temporary culverts, flex pipe, etc.)	Stream channels and stream crossings
	Surface diversion and dispersion devices (pipes, ditches, etc.)	All disturbed bare soil areas
Permanent erosion control	Road shaping	Road and landing surfaces
	Gravel surfacing	Road, landing and turnout surfaces
	Bituminous or asphalt surfacing	Road surface
	Rolling dips	Road surface
	Ditch relief culverts	Roadbed and road fill
	Downspouts and berm drains	Road fill slopes
	Waterbars	Road and landing surfaces
	Berms	Road surface and roadside areas
	Ditches	Road and landing surfaces
	Riprap	Road fill slopes, stream crossing fills, cutbanks, stream and lake banks
	Soil bioengineering	Road fill slopes, cut slopes, stream crossings, streambanks
Tree planting	Road fill slopes, cutbanks, bare soil areas, stream crossings, streambanks	

1. ROADS AND LANDINGS

Both mechanical and vegetative measures are needed to minimize accelerated erosion from roads, landings and turnouts under construction. Effective erosion prevention employs proper road location, pre-planning of cuts and fills, minimizing soil exposure, compacting fills or endhauling loose fill materials from steep slopes and stream-side areas, developing stable cut and fill slopes, providing effective road surface drainage, mulching to control surface erosion for the first year, and seeding and planting to provide for longer-term erosion prevention.

Fill slopes need to be constructed at stable angles to prevent mass failure and sediment delivery to streams. Slopes which develop instability, especially those which threaten to deliver sediment to stream channels, need to be stabilized or removed immediately. Woody debris should not be incorporated in sidecast fill material during construction because it will decompose and can lead to future slope instability and failure (landsliding) many years or even decades after burial. Woody debris and soil mixed together around the outside perimeter of landings and turnouts or within road fills built on steep slopes form a certain recipe for eventual instability and landsliding. Shallow failures or small slumps on the cutbank or fill slope can either be excavated (if they threaten to deliver sediment directly to the stream channel) or stabilized by placing large rocks at the slope base to buttress the unstable materials. Specific techniques for building rock buttresses, retaining walls, timber cribs, and reinforced slopes are beyond the scope of this manual and require advice and design by a qualified engineering geologist or geotechnical engineer.

Bare slopes created by construction operations also need to be protected until vegetation can stabilize the surface. Surface erosion on exposed cuts and fills can be minimized by mulching, seeding, planting, compacting, armoring and/

or benching prior to the first fall rains. Installing filter windrows of slash at the base of new road fills can minimize the movement of eroded soil to downslope areas and stream channels. They are installed using heavy equipment as the road is being cleared and graded. During construction, it is also important to retain rooted trees and shrubs at the base of the fill as an “anchor” for the fill and filter windrows (Figure 172).

Road construction activities should be performed during the “dry” season, and all surface drainage structures should be in-place and completed well before winter or wet season rains are expected (October 15 for forestry-related roads in California). Where construction or reconstruction activities are conducted near a live watercourse, silt fences and/or straw bale silt-dams may be needed both in the channel and on the adjacent slopes during the construction phase. Any use of roads during the winter period may require the application of road surfacing to prevent road deterioration, control erosion, and prevent sediment transport to nearby streams. Muddy runoff from unsurfaced roads can transport large volumes of sediment that flows through culverts and into streams.

2. SPOIL DISPOSAL SITES, BORROW SITES AND ROCK PITS

Erosion should also be controlled in areas where large expanses of bare soil have been created, such as spoil disposal sites, borrow sites and rock pits. Proper location, excavation and topographic development of spoil disposal sites and rock pits are key elements to assuring controlled drainage and minimizing erosion and sediment problems. When placed on slopes, spoil should be spread in lifts and compacted to develop strength in the materials. Spoil disposal sites, borrow sites and rock pits should not be located near



FIGURE 172. Newly constructed, outsloped forest road with accumulated line of slash, called a filter windrow, at the base of the fill to catch soil eroded from the new fill slope. Slash should be placed at the base of the fill, and not incorporated into the soil material. Filter windrows are most important to install where roads approach and cross stream channels. This outsloped road conforms to the topography of the land and incorporates rolling dips at natural swales to shed surface runoff.

streams or where sidecast, tailings or sediment-laden runoff could reach a watercourse.

When a rock pit is under development, top soil and overburden should be stockpiled for later use as surface soil for reclamation.

During development and use of borrow pits and disposal sites, it is also important to maintain internal and controlled external drainage. Outflows should be dispersed to prevent erosion and water should be directed through settling ponds and vegetated filter areas to trap sediment. Runoff should not be directed straight to a watercourse.

Filled spoil areas and exhausted rock pits should be permanently reclaimed. This activity may be regulated in your area. For example,

development and reclamation of rock pits and quarry sites on private lands in California may be subject to regulations under the California's Surface Mining and Reclamation Act (SMARA) if the proposed excavations are greater than 1 acre in size or 1000 yds³ in volume (Figures 173a and 173b). Spoil sites should be mulched and seeded, or machine hydroseeded using a mulch and seed slurry, before winter rains (Figure 174). Compacted areas should be ripped to promote revegetation. Areas of bare rock should be outsloped and covered with several feet of soil. Then, bare areas should be planted with brush and tree species that will be able to thrive in the altered environment.

FIGURE 173A. Rock pit before reclamation. Quarried, ripped and blasted rock was used for road base materials, road surfacing, and for riprap throughout a large watershed area now in Redwood National Park (RNP). Reclamation involved recontouring the access road and using excavated spoil materials and quarry waste to recontour the open pit and quarry face (RNP).



FIGURE 173B. View of the same rock pit after recontouring, seeding, mulching and planting. Exposed areas have been reshaped and covered with soil to promote revegetation. The area was then mulched, seeded and planted. Reclamation work was performed using an excavator and large bulldozer. Several decades later, the site is now completely reforested (RNP).



FIGURE 174. After spreading and compacting spoil material endhauled from a road project, this spoil disposal site was seeded, mulched using a straw blower and then planted with trees.



3. STREAM CROSSINGS

Stream crossings are where roads come into closest contact with flowing water. For this reason, it is critical that proper and sufficient erosion control measures be applied to ensure that erosion and sedimentation from culverted fills, bridges or other construction sites does not enter the watercourse. Erosion prevention and erosion control at stream crossings focuses around four main elements:

1. preventing stream crossing failure (erosion) caused by drainage structure failure and overtopping;
2. preventing stream diversion caused by drainage structure plugging;
3. protecting, stabilizing, controlling erosion and revegetating newly constructed (and reconstructed) stream crossing fills; and
4. minimizing fine sediment “run-on” from the adjacent hydrologically connected road approaches.

Some stream crossing types are more vulnerable to erosion than are others. Culverted crossings are more susceptible to erosion than most other crossing types, although armored fills and hardened fords are also susceptible to erosion and failure. Problems are most likely to develop at drainage structure inlets, outlets, fills, and road surfaces. A large number of design ideas for stream crossings are outlined in Chapter 4, and these address the most important potential sources of erosion and failure.

Erosion control specialists and qualified geologists can assist in designing and installing special erosion control structures.

Regardless of the measures chosen, any successful erosion control technique must be correctly installed and regularly maintained to be effective.

Erosion prevention and erosion control measures for each of these areas are commonly employed to limit construction and post-construction erosion. They include:

- Construct a “dipped” drainage design or critical dip into every stream crossing fill that would otherwise have a diversion potential.
- Install rock armor or flared inlets to protect the pipe entrance from undercutting and erosion (see Chapter 4). Trash racks (debris barriers) can prevent culvert inlet plugging and subsequent erosion of the fill.
- Culvert outlets should extend up to 6 feet beyond the base of the road fill and discharge into the natural stream channel to minimize outlet erosion. Rock armor can be used at and around the culvert outlet to prevent erosion by the fast moving flow.
- Rock surface the connected road approaches and frequently drain the road and ditches into adjacent vegetated buffer areas.
- The roadbed can be insloped through the crossing, or the road can be outsloped and bermed to keep road runoff away from the new, erodible outer fill slope.
- New fill slopes show the greatest erosion in their first several wet seasons, until they become stabilized. Install rock armor around the new culvert outlet and inlet to trap sediment that is eroded from higher on the new fill before it can be delivered to the stream.
- Silt fences or straw bale barriers can also be constructed on extremely large cuts and fills and on steep bare soil areas to retain soil that erodes from the surface.
- Silt fence barriers, straw bale check dams, and straw wattles have become standard

operating practice in many construction sites. To be successful, these measures must be correctly designed, constructed and maintained for as long as they are left in-place.

- The best treatment for surface erosion on slopes less than about 50% is to mulch and revegetate the bare areas as quickly as possible. Surface erosion is immediately controlled on these slopes by applying a continuous and complete layer of mulch, or a commercially-available mulching blanket, and by seeding the surface so a healthy stand of grass or legumes develops before major rain events occur (Figure 175).
- Longer term erosion control on new cut and fill slopes requires planting or seeding fast growing woody species.
- Successful revegetation of stream crossing fills and other bare soil areas may not always be as simple as throwing out a standard mixture of grass seed. Site conditions such as soil type, exposure, aspect, elevation, summer and winter temperatures, soil dryness or moisture and other site factors

may require use of unique or native plant species, special planting techniques, special planting times, first year watering, fertilizer or soil amendments. A trained wildland botanist, plant ecologist, your local farm advisor, Resource Conservation District or the Natural Resource Conservation Service specialist should be consulted to see what is recommended for your area.

4. GULLY PREVENTION, CONTROL AND STABILIZATION

Causes of road-related gullying—Gullies are commonly associated with poorly designed and poorly constructed roads. Road-related gullies are most frequently caused by 1) the collection and discharge of road surface runoff, 2) shotgun ditch relief culverts, 3) ditch relief culverts discharging too much flow onto erodible hillslopes, 4) long and/or steep road side ditches, 5) undersized or plugged stream crossing culverts that result in overtopping and gullying (washout) of the fill, 6) poorly installed stream crossing culverts that discharge flow onto the fill slope (shotgun culverts) or onto unprotected hillslopes, 7) diverted streams

FIGURE 175. *Mulching and seeding are effective methods for controlling surface erosion from bare fill slopes. Mulch protects the soil until the grass and vegetation is firmly established. However, because it decomposes rapidly, straw mulch is effective for only the first year. After that, well established vegetation should provide the needed protection.*



that cause road and hillslope gullies, and 8) stream crossings without a drainage structure.

Generally, the biggest gullies are those formed when stream flow is diverted out of its channel and onto steep, unprotected hillslopes. Gully erosion from stream diversions has the potential to cause severe damage to the road system as well as the surrounding hillslopes. Steep road grades and slopes,

erodible soils, unsurfaced road prisms, high traffic levels, and road use during the wet season will also contribute to the severity of rill and gully erosion (Figure 176). Over longer lengths of road, sheet erosion will progress into rilling and then into gully erosion (Figure 177).

Once formed, gullies will continue to enlarge until they encounter a hard rocky substrate or bedrock, or until the source of runoff is



FIGURE 176.

Road surface rilling on a steep seasonal road built on fine grained, erodible, native soils. Waterbars have been constructed to drain road surface runoff, but erosion occurs over even short sections of the exposed road.

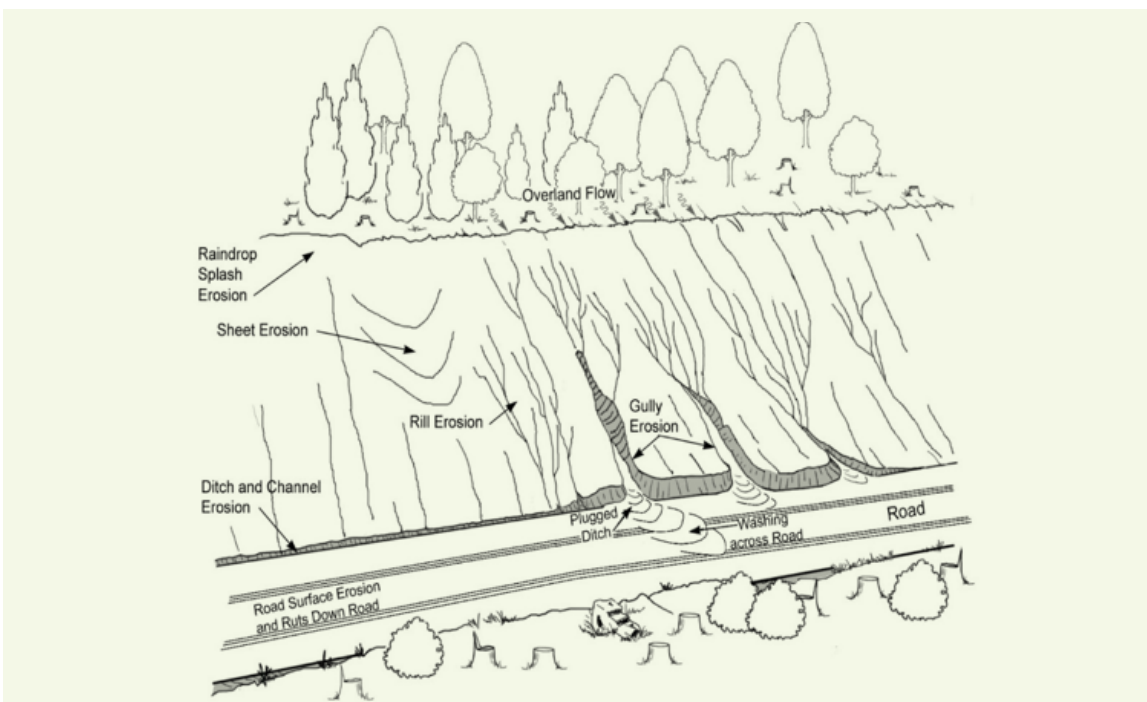


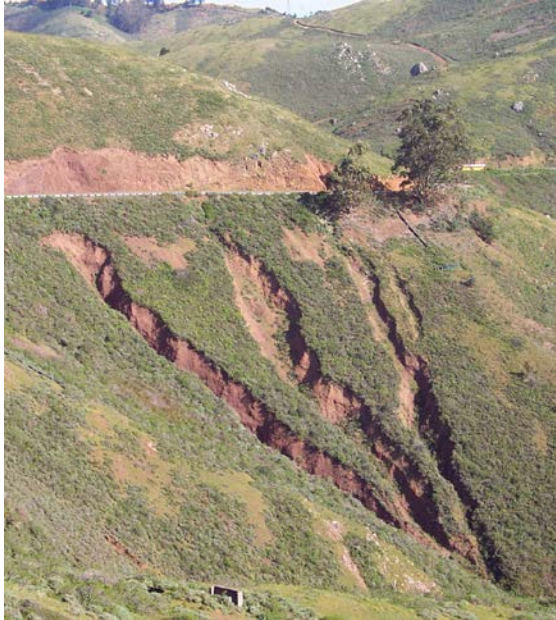
FIGURE 177.

Types of fluvial erosion on cut-banks, bare soil areas and road surfaces (Keller et al., 2011).

removed. Road-related gullying can generate large volumes of sediment, efficiently deliver it to streams and severely impact water quality and aquatic habitat (Figure 178). This is particularly the case with highly erodible soils, including weathered and decomposed granitics (DG).

FIGURE 178.

Three extremely large gullies formed entirely by long lengths of road draining to a ditch relief culvert. The gullies formed in succession, from right to left, as the landowner moved the location of the culvert when the road was beginning to be threatened by undercutting at each site.



Gully prevention—It is much easier to prevent gully erosion than to control it after it has begun. When roads are designed and built properly, road-related gully erosion should be minimal, if not non-existent. Road related gully erosion occurs as a result of collecting and discharging road surface runoff. Poor road drainage results in rills and gullies that occur in ditches, on the road surface, or on adjacent hillslopes where concentrated runoff has been released. These erosional processes can be prevented by dispersing road runoff, so there is never enough flow to cause significant rilling or gullying. The techniques are simple and straightforward.

The second source of gully erosion along roads is a consequence of erosional processes at stream crossings. As previously discussed, gullying can be prevented at stream crossings by:

1. properly designing and installing drainage structures at all stream crossings;
2. designing stream crossing culverts for the 100-year design flow, including debris and sediment loads;
3. installing critical dips at stream crossings that have a diversion potential; and
4. installing properly aligned stream crossing culverts at the base of the road fill with adequate culvert inlet and outlet projection beyond the fill face.

Gully control and stabilization—In some cases, erosion control measures will be necessary to control the expansion and enlargement of existing gullies. **The most effective gully control measure is to eliminate (remove) or reduce the flow of water entering the gully. Without flow, the gully will naturally stabilize and stop enlarging.** If that is not possible, other gully control methods may include structural or biotechnical methods, or a combination of both, aimed at stabilizing gully headcuts and lateral sidewalls, as well as preventing future channel downcutting. These methods are typically expensive and, if designed and implemented poorly, can result in continued or additional erosion.

Physical gully stabilization usually consists of 1) controlling headcut erosion and movement, 2) controlling gully downcutting along the length of the gully and 3) sloping back the oversteepened gully walls and sideslopes to a stable angle. Gully headcuts are typically stabilized by installing some type of armoring or conveyance structure at the headcut, to protect it from erosion or to carry flow to the base of the headcut. Structures may consist of gabion, concrete, wood, or rock mattress drop structures at the gully knick point or gully headcut (Figure 179). These structures are used to armor the headcut and allow

flow over the gully head to the gully bottom without initiating further headward migration.

It is important that these drop structures have a distinct cross sectional form and area (width and depth) to contain and convey peak flows. They should span the entire width of the gully and be well keyed into the bed and banks to prevent the risk of flow scouring under or around the edges of the drop structure or armor. The base of the drop structure should be armored with an apron of riprap in order to dissipate energy and prevent channel scour and sidewall undercutting that may further destabilize the gully. Similar to constructing an armored fill crossing, the rock should be of mixed sizes designed to resist plucking or significant adjustment during peak flows.

Unstable, oversteepened or erodible gully banks may require reworking to establish stable slope gradients (e.g., 3:1, 2:1 or 1½:1) and reduce significant sediment delivery. Reworking the gully banks, along with armoring or revegetating the lower gully sidewall, may help reduce the potential for gully undercutting and future sidewall failure. If flow has been removed from an existing gully, and it is no longer enlarging or downcutting, the banks may not need additional treatment as they will collapse and stabilize naturally.

Gully channels can be stabilized by reducing the slope gradient and increasing the channel roughness. This is commonly achieved by installing grade control structures, such as check dams, at intervals along the gully length. **Properly spaced check dams will actually cause deposition along the treated section of the gully floor so erosive flows cannot continue to downcut into the native ground beneath.** Check dams can effectively reduce erosive flow velocity, as well as promote the deposition of sediment that encourages stabilizing vegetative growth within the gully channel (Figure 180).

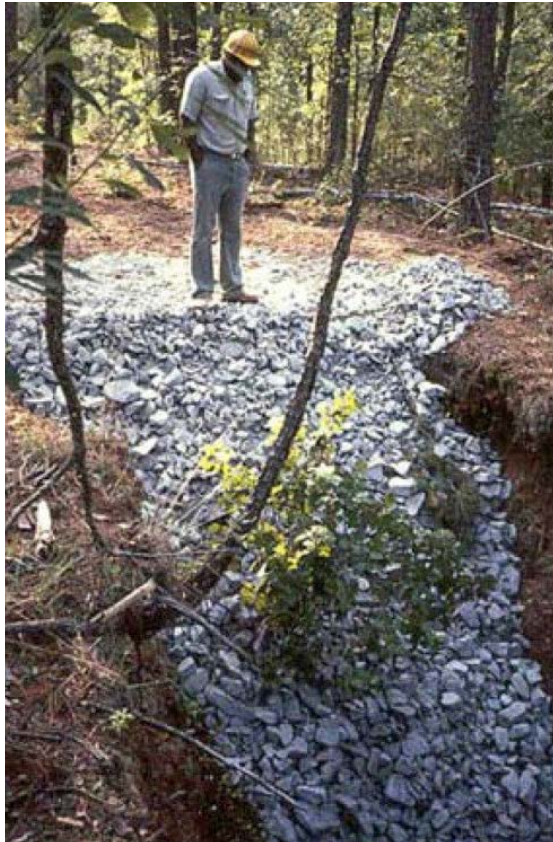


FIGURE 179. Rock mattress at gully head armors the headcut and conveys surface flow to the stable channel below (USDA NRCS, 2007).



FIGURE 180. Board check dams constructed in a gully to prevent downcutting and stabilize the bed and banks. Willow cuttings planted and growing in the bed and banks will eventually stabilize the gully once their roots are well developed.

Check dams can be built with concrete, loose rock, confined rock fences, boards, gabions, sandbags, logs, or straw bales (Figure 181). Straw bale check dams are temporary structures that will decay and fail after only one wet season. Their use is generally discouraged for all but short term, emergency situations and very small headwater drainages (1/2 to one acre).

The frequency and spacing of check dams depends on the effective height of the proposed dams and the gradient of the gully to be treated (Figure 182). The effective height of a check dam structure is the height of the lowest point in the spillway above the gully floor. **Check dams should be spaced so that water flowing down the gully is always flowing on sediment that is stored on the gully bottom behind the next downstream dam (Figure 182).** That's how grade stabilization with check dams works. The flow never touches the original gully bottom and so cannot continue downcutting. In this way, the dams will be spaced close enough to each other so

that flow from the check dam above flows into back water created by the lower check dam.

Check dam structures with heights exceeding 3 feet should be designed by a qualified and experienced professional (e.g., an erosion control specialist, geologist or engineering geologist). Poorly installed check dams with loose or un-keyed materials will result in gully destabilization, flanking or undercutting, failure of the check dam, and headcutting that will likely trigger the failure of additional check dams farther up the gully (Figure 183). Once the grade control is lost anywhere in the gully system, the channel will continue downcutting and undermining other structures.

Vegetation can also be used to stabilize gullies. Biotechnical methods are available for headcut control as well as gully bed stabilization (see below). Some low gradient gullies can also be stabilized by the use a continuous cover of vegetation grass in what is termed a grassed waterway. This works best if most of the flow

FIGURE 181.

Properly installed check dams that (1) are correctly spaced, (2) have notched weirs to contain and focus the design peak flow over the center of the structure, (3) are keyed into the gully bed and banks, and (4) armored at the base (outfall) of each structure. Note that the channel and gully banks have been planted with willow cuttings.



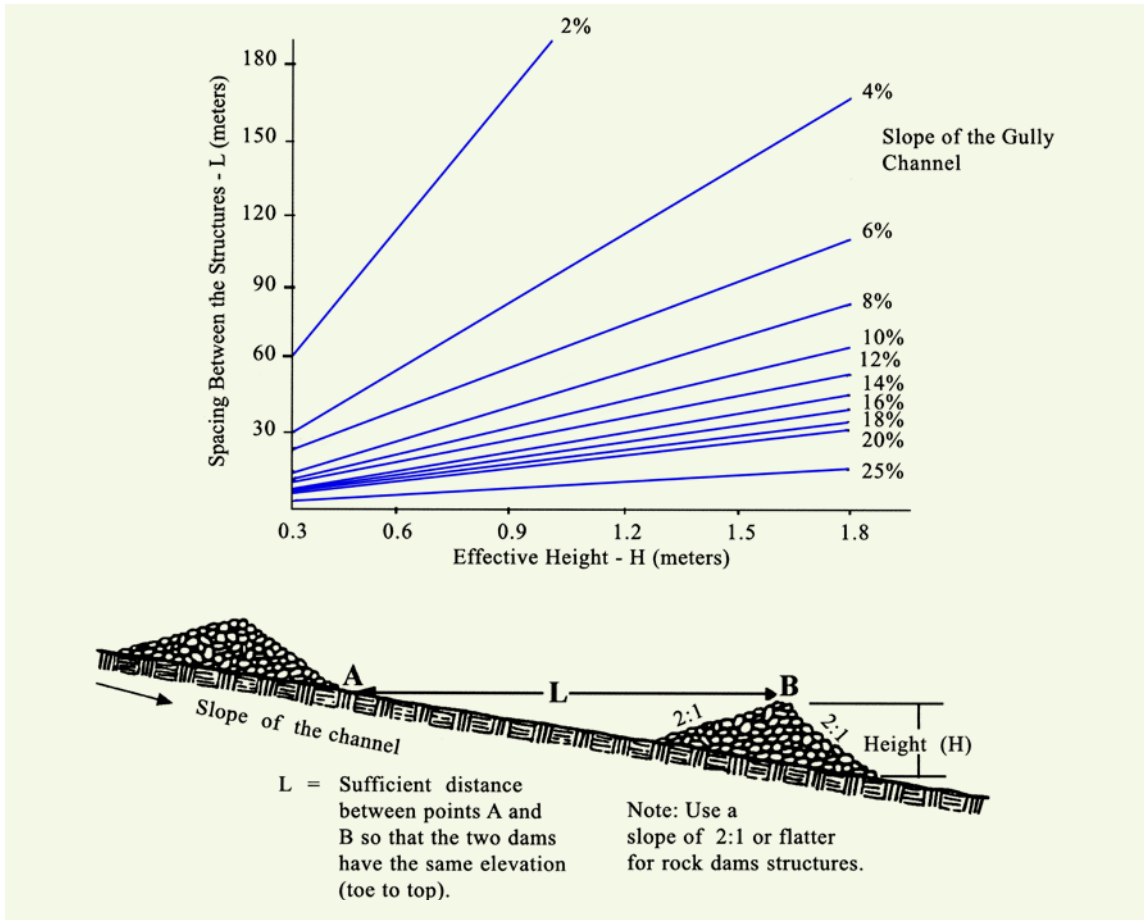


FIGURE 183.
Poorly installed rock check dams installed in a rural roadside ditch to control erosion. The rock dams were spaced too far apart (see arrows farther up the ditch for nearby dams) so that erosion between the dams led to downcutting and undermining of upstream structures. The dam in the foreground failed because 1) it was not keyed into the side walls or channel bed, 2) the spillway capacity was insufficient, and 3) there was no energy dissipation at its base.

has been removed from the gully and the gully channel is reshaped in a broad, gentle swale.

In warm, wet climates, vetiver grass can be used as an inexpensive alternative for gully erosion control. This perennial, tufted, clump grass forms dense and deeply rooted hedges that are stiff enough to resist erosive forces and hold erodible soils in place. Vetiver grass can be planted as 1–3 foot wide hedges across the gully channel and up the gully sidewalls at 6–7 foot vertical intervals. Vetiver grass is well suited in areas of intense rainfall, but is limited by cold weather and frost, and therefore cannot be used in colder and high elevation regions.

Finally, structural gully stabilization measures include reshaping and lining the gully with rock armor so that the bed and banks of the gully are protected from flowing water (Figures 184 and 185). These methods can be very expensive, especially if rock materials are not locally available. Well graded riprap should be sized for the expected flow velocities and keyed into the top entrance and bottom exit of the gully. The remaining riprap is placed across the entire gully channel surface and up the gully sidewalls to the height of the expected flood flows. Depending on the erodibility of soils, geotextiles can be placed on the gully bottom prior to riprap placement.

Once structural gully control measures are in place, it is important to establish vegetation on all bare soil areas on the gully surface. The gully bottom and sidewalls should be seeded with native perennial grasses and mulched with weed-free straw or hydromulch and, if possible, planted with native forbs, shrubs, and tree species. **Vegetation is an important component of gully erosion control because if gully erosion control structures such as check dams or rock-lined chutes fail, the established vegetation can reduce the impacts of erosion by providing channel roughness and reducing gully**

flow velocity. To safeguard gully erosion control treatments and reduce the likelihood of future erosion, livestock should be kept away from gully channels and gully sidewalls by installing exclusionary fencing around the perimeter of the treated gully system.

5. BIOTECHNICAL EROSION CONTROL

Biotechnical erosion control provides a cost effective and aesthetically pleasing option for gully control, as well as for slope and streambank stabilization, reinforcement, and protection. Vegetation protects erodible soil from raindrop impact and soil particle detachment, increases surface roughness and reduces surface runoff velocity. Plants also act as hydrologic “wicks” by absorbing subsurface flow, thereby de-watering slopes and stream banks. In addition, root systems play an integral part in soil stabilization by increasing infiltration, binding and anchoring soils, and improving soil structure. Unlike structural treatments, vegetation treatments increase in effectiveness over time. For these reasons, vegetation can provide a safeguard from surface erosion, gully, shallow mass failures, and stream bank erosion; as well as providing natural succession and critical riparian and terrestrial habitat for fish, amphibians, mammals, insects, and birds.

Biotechnical erosion control can be broken down into two approaches: soil bioengineering and biotechnical engineering. These methods can be applied individually or in combination to create hybrid biotechnical erosion control structures. *Soil bioengineering techniques* rely on the use of live plant cuttings (commonly willow, alder, dogwood, and cottonwood) to provide the basic structural elements required to stabilize slopes and streambanks, reinforce soil substrate, and reduce soil erosion. *Biotechnical engineering* also utilizes live vegetation, but integrates it with hard structural elements (e.g., logs, riprap, concrete blocks, and



FIGURE 184. Rock armored ditches, if constructed with proper rock sizes, rock gradations and U-shaped channel form, can prevent ditch downcutting and erosion, but also inhibits easy ditch maintenance using machinery. Rather than armoring or installing check dams in ditches, it is usually best to reduce the volume of flow by installing additional ditch relief culverts.

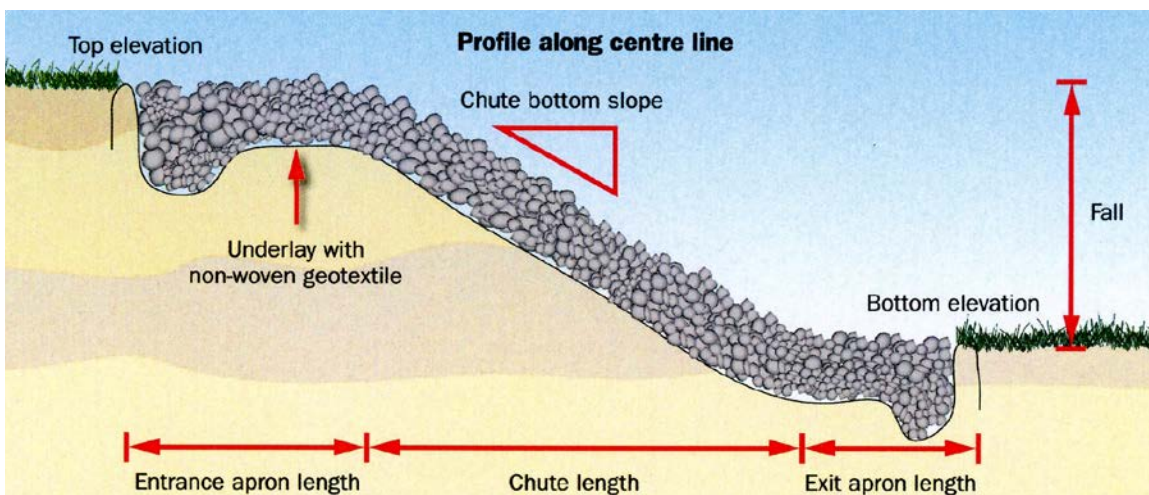
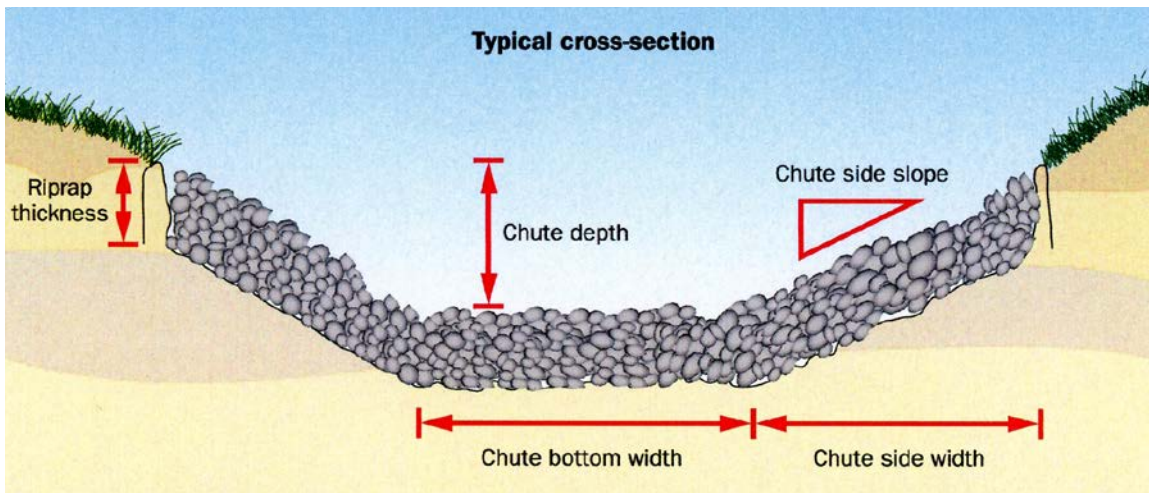


FIGURE 185. Rock-lined chute or channel (Brook, 2013)

gabions) to create complex erosion control structures that provide soil reinforcement, and increased slope stabilization and protection. Watering may be required for up to three years for plantings to become established in some environments or settings. Over time, as vegetation matures and root systems become more established, slopes and streambanks become increasingly erosion resistant.

It is important to emphasize that these methods can only be used to reinforce shallow slope or shallow stream bank instabilities because they are limited by the rooting depth of the plants used. These methods should not be used to treat deep seated slope instabilities, including translational, rotational, or complex mass wasting features; debris flows; or earth flows. Poorly designed and implemented biotechnical erosion control structures can lead to increased slope failure and soil destabilization.

Contact a qualified professional for guidance on which biotechnical erosion control design is best suited for your road project. Biotechnical engineering structures used for slope revetment and stabilization, such as live crib walls or vegetated gabion baskets, should be designed by a qualified civil engineer, engineering geologist or geologist experienced in biotechnical project work.

a. Examples of soil bioengineering methods

Brush layering involves harvesting live cuttings of woody plants, such as willow and alder, and embedding them at intervals parallel to the slope contour (Figure 186). This method is used to stabilize cut slopes and strengthen fill slopes that are prone to surface erosion or shallow mass wasting. Brush layering stabilizes slopes by providing slope reinforcement from established root systems, creating a vegetative filter that traps sediment, and reducing surface runoff velocities through regular slope breaks.

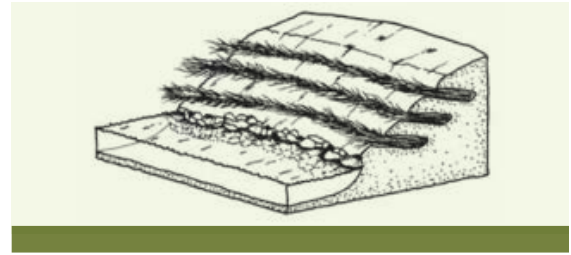


FIGURE 186. *Brush layering (Holanda and Pinheiro da Rocha, 2011)*

Branch packing is similar in design and implementation to brush layering but is used in localized areas to repair small voids or slumps in stream banks or other fill or cut slopes (Figure 187).

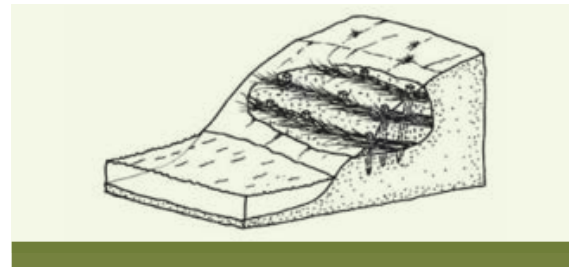


FIGURE 187. *Brush packing (Holanda and Pinheiro da Rocha, 2011)*

Live staking is used for slope and stream bank stabilization and involves planting of woody plant cuttings, such as willow or dogwood, deeply into the slope at a regular spacing to provide vegetative cover and root strength necessary for slope reinforcement and buttressing (Figure 188). The specific spacing is

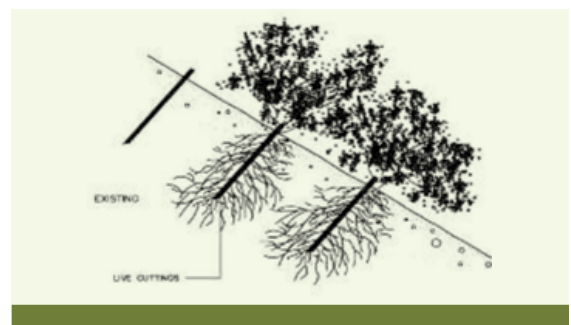


FIGURE 188. *Live staking (Keller and Ketcheson, 2012)*

dependent on slope steepness and soil characteristics. This is the simplest method of soil bioengineering and is commonly used as an element of other soil bioengineering and bio-technical engineering structures (Figure 180).

Live fascines or willow wattles are used to stabilize slopes, stream splash zones, stream banks and road cutbanks. These structures consist of live plant cuttings, typically willow or dogwood, which are interwoven and bundled into 6–8 inch diameter and 4–20 foot long brush logs. Live fascines are staked end to end parallel along slope contour within shallow trenches and mostly or partly covered with soil (Figure 189). The spacing of live fascines is dependent on slope steepness and soil erodibility. These

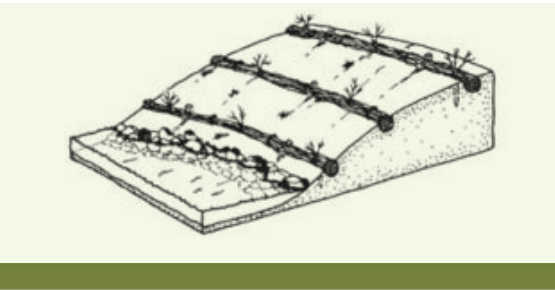


FIGURE 189. *Live fascines (Holanda and Pinheiro da Rocha, 2011)*

structures provide energy dissipation, slope stabilization, and sediment entrapment (Figure 190).

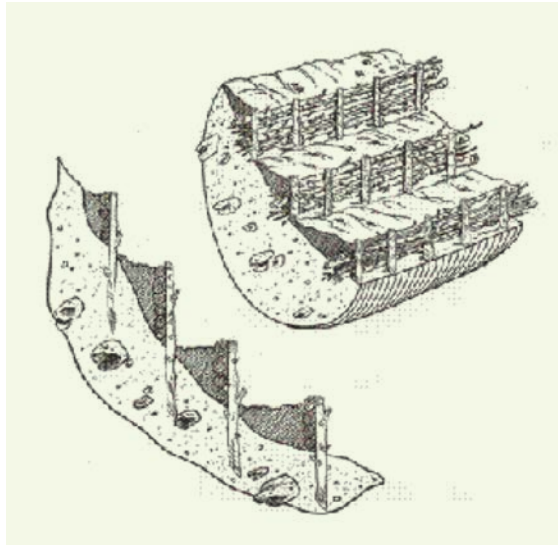
Wattle fencing is typically used as short retaining walls to stabilize wet, oversteepened slopes, as well as stabilize small, shallow slumps. They are also employed to stabilize small gullies, much like living check dams. The structures are constructed beginning at the base of the slope by inserting live cuttings like structural “rebar” in a row along the contour of the slope (Figure 191). Live plant cuttings are stacked horizontally on top of one another directly behind the “rebar” supports. The space behind the horizontally stacked plant cuttings is backfilled with soil to create a stepped or terraced slope. These structures effectively reduce slope gradient, trap sediment, reduce runoff velocity, and reinforce the slope.

Live pole drains are constructed in a similar manner as live fascines. The cylindrical live plant bundles are used as drainage structures in unstable wet areas, such as saturated unstable slopes, and shallow slope failures and slumps exhibiting seepage. The live cutting bundles are laid and staked in shallow excavated trenches



FIGURE 190. *Live fascines installed on a bare soil area that was prone to rapid soil erosion.*

FIGURE 191.
Wattle fencing
(Polster, 1997)



or within an existing slope failure void where seepage is apparent and oriented downslope in the direction of flow (Figure 192). If seepage within the unstable area is diffuse, the structure can be built in a “Y” formation to collect moisture from a broader area. The concentration of flow along the live pole drains initiates the development of a zone of hydrophilic vegetation and effectively dewateres the saturated unstable area. These structures are not effective in well-defined channels that exhibit concentrated flow.

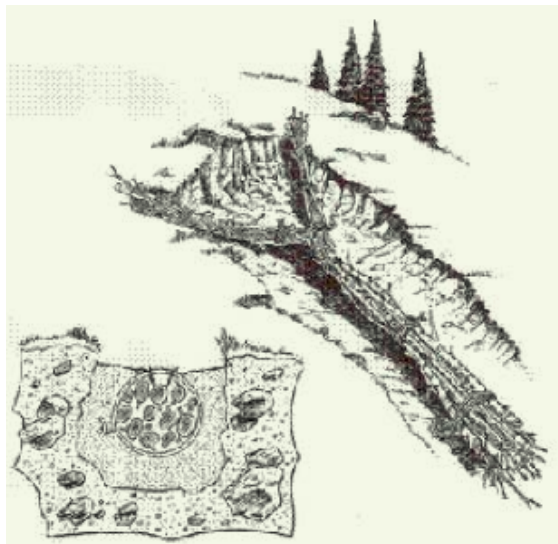


FIGURE 192. *Live pole drain* (Polster, 1997)

b. Examples of biotechnical engineering methods

Vegetated riprap is used as a slope toe or stream bank revetment. This method incorporates soil bioengineering methods including live staking, brush layering, pole planting, or live fascines within the interstices of the riprap (Figure 193). This aesthetic approach provides slope reinforcement and promotes native plant succession and riparian enhancement. Riprap should be placed over geotextile or a layer of filter rock aggregate and keyed into the base of the slope to ensure stability. Live vegetation should be deeply embedded into the underlying native soil during riprap placement at a spacing dictated by slope steepness and underlying soil characteristics. This method reduces the likelihood of shallow slope failures, reduces erosive flow velocities, and traps sediment.

Live crib walls are constructed of interlocking logs to form a hollow box-like frame at the toe of the slope. These structures are primarily used for stream bank protection. The crib structure is typically built against an oversteepened stream bank at an outside meander bend where flows are the most erosive (Figure 194). Crib wall heights

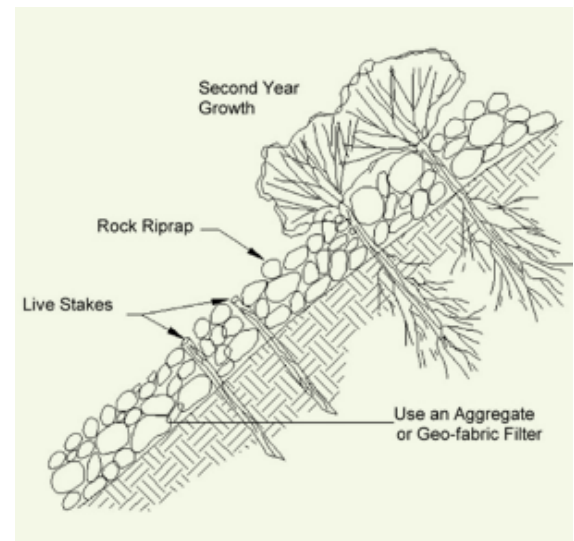


FIGURE 193. *Vegetated riprap* (US EPA, 2000)

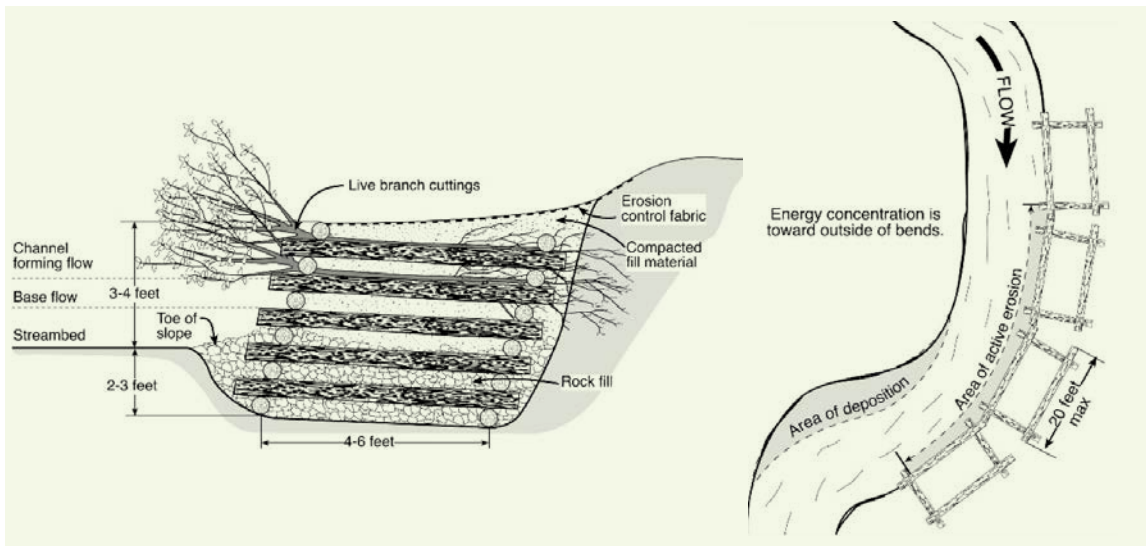


FIGURE 194.
Live crib wall
design and
placement (Ohio
Department of
Natural Resources,
1997)

should not exceed 7 feet and the length of an individual structure should not exceed about 20 feet. The crib frame is backfilled with live plant cuttings, and rock and soil. Live plant cuttings should be long enough to be able to protrude from the crib frame and extend deeply into the native soil. After time, the logs will decompose and the established vegetation and root system within the crib frame will provide the slope reinforcement.

Vegetated gabion baskets or mattresses— Gabions are rectangular galvanized steel wire mesh baskets that are filled with small and medium sized riprap and used for slope toe revetment and stream bank protection (Figure 195). The first gabion layer is fastened together in position over geotextile and keyed in at the base of the steep slope or streambank. Remaining gabions are stacked to create a terraced vertical wall. The area behind and between each gabion layer is backfilled with soil materials. Live plant cuttings are placed horizontally between layers of gabion baskets with the basal ends embedded in the fill material behind the gabions. The plant cuttings will establish over time, developing root systems that will entwine around the riprap and anchor into the native soil. Ultimately, the gabion baskets will deteriorate leaving behind the rock and vegetation as the structural elements. Gabion structures may not be suitable for use in streams or where fish are present so check

with your fish and wildlife regulatory agency before they are designed and constructed.

6. PROTECTING WATER QUALITY DURING CONSTRUCTION

Road construction and road upgrading activities at stream crossings and in live streams, springs, or wetlands require construction site water management measures to prevent the discharge of turbid and sediment-laden water to the downstream watercourses, water bodies or wetlands. Construction activities expose erodible bare soil that can be easily entrained in surface flows creating turbidity and sedimentation. Heavy equipment, such as excavators and bulldozers, pose a water quality

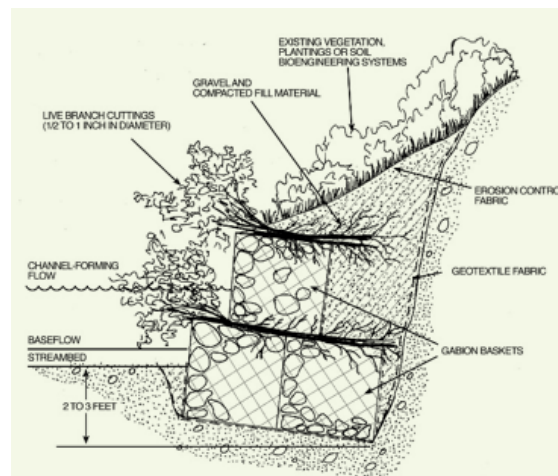


FIGURE 195.
Vegetated gabion
(Ohio Department of
Natural Resources,
1997)

risk from leaking vehicle fuels and fluids that can contaminate soil, streamflow and surface runoff. Sedimentation, turbidity, and chemical contamination pose serious risks to aquatic organisms, as well as aquatic and riparian habitats. Because road construction activities typically occur in the dry season (from June to October in California), aquatic organisms are even more vulnerable when groundwater levels and surface flows are at their lowest.

Temporary diversion measures are necessary to maintain water quality during road construction activities (e.g., stream crossing culvert installations, upgrades and decommissioning) in live streams or in areas that actively discharge flow. **Clean water above the work site should be isolated from the construction zone and transported around the work area so it can be discharged to the stream channel or wetland below with minimal effects on surface flow rates and water quality. In addition, “dirty” water generated within the construction area should be collected and transported off site and discharged in a safe location where it can settle out sediment or infiltrate into soils or gravel and not deliver contaminants to a watercourse or wetland. By providing temporary stream diversion, clean runoff is kept away from the project area and the construction site is kept relatively dry and workable for heavy equipment operations.**

Local, state, and federal laws and regulations require safeguards to protect water quality during construction activities and may require specific permits prior to any equipment operations in or near streams and wetlands. Check your local, state, and federal agencies to determine what permits are required to operate equipment and to control runoff in stream channels and wetlands in your project area and what specific water management measures will be required.

Clean runoff above a construction area is typically routed away from the construction site using a system of temporary water bypass structures.

The water diversion techniques, and the necessary diversion structures, are dictated by the type of work conducted, the drainage area and type of the water source, and the rate of discharge.

Common structures used to isolate and divert flow include pipes, flumes, excavated basins and channels, berms, slope drains, sheet pile dams, cofferdams, rock, gravel bags, wood, and sediment filtration measures, including silt fences, straw bales, and filter fabric or turbidity curtains. Isolated flow is transported away from and around the work site and discharged downstream through a gravity fed system or by electric or gas-powered pumps (Table 35). The water diversion system may need to be moved periodically during the project as needed to provide for heavy equipment access.

Gravity-fed pipe diversions involve transporting isolated clean runoff via flex pipe extending around the project area and downslope to the watercourse or wet area below (Figure 196, middle). This type of diversion requires enough topographic relief to initiate and continuously maintain flow downslope below the construction site where it is discharged back into the natural channel or wet area (Figure 197). Gravity-fed diversion systems are more cost-effective and require less maintenance than pumped diversions. They can also be left in place overnight and on weekends when construction work is not occurring.

Pump diversions are employed in areas where gravity-fed systems are not feasible. Pumps provide more flexibility in complex terrain where the diversion pipe needs to traverse topography to access the discharge point below (Figure 198). The size of the pump required is based on the volume of flow that must be pumped (Figure 199). It is also important to have a backup pump and backup hose on-site in case of breakdown. Clean runoff is isolated by a temporary dam and is pumped by electric or gas powered pumps and discharged via pipe to the clean water source below (Figure 196, top).



TABLE 35. Temporary water bypass structures¹

Type	Advantages	Disadvantages
Pumped diversion	<ul style="list-style-type: none"> Downstream sediment transport can almost be eliminated De-watering of the work area is possible Pipes can be moved about to accommodate construction operations Increased flows can be managed by adding more capacity 	<ul style="list-style-type: none"> Flow is limited by pump capacity Requires 24-hour monitoring of pumps Sudden rain can overtop dams Minor in-stream disturbance to install and remove dams
Excavated channels and flumes	<ul style="list-style-type: none"> Isolates work from water flow and allows dewatering Can handle larger flows compared to pumps 	<ul style="list-style-type: none"> Bypass channel or flume must be sized to handle flows, including flood flows Channels require stabilization Flow diversion and then re-direction with small dams causes in-stream disturbance and sediment

¹Modified from: Department of Environmental Services, Gresham, OR, 2011

The disadvantage to using pumps for stream diversions is that they require refueling and regular monitoring.

For large construction areas, pumps may need to be run overnight to properly de-water the site. Use of an electric pump can eliminate the need for someone to be onsite 24-hours a day to monitor and maintain the pump. If site conditions allow, a pump diversion system can be utilized during the day and a gravity-fed system through the active construction zone at night so that 24-hour monitoring and maintenance is not required.

“Dirty” water, or wastewater generated within the construction site, requires removal to prevent pollution from reaching the stream, and to keep the construction area as dry as possible. Ideally, onsite wastewater is isolated in two sumps excavated in the stream channel; 1) one at the top of the construction area to either remove and pump dirty water away before it contaminates the work site, or to temporarily lower the water table through the work area, and 2) the other excavated near the downstream end of the construction site to collect wastewater before it reaches the clean stream or water source below. Wastewater is pumped from the sumps and, if necessary, sprayed onto stable benches, terraces or slopes well away from the clean stream or water source. It can also be used within the construction area to improve soil compaction or

for dust control, or discharged into an excavated sediment pond where it is allowed to infiltrate.

Erosion control measures including straw bales, silt fences, or other filtration barriers should be used at the base of the construction site as an additional safeguard against contamination of the clean water source below. Special requirements will also apply if you are going to work in a fish-bearing stream. Prior to construction, fish and amphibians must be removed from the project reach and relocated to a nearby clean water area upstream or downstream from the area to be disturbed. Fish relocations are normally done by a qualified fisheries biologist according to approved methods and permitting requirements. Additionally, listed terrestrial species (e.g., listed frogs and salamanders) may also need to be surveyed for and removed from the work site.

For larger construction projects (e.g., bridge installations and plate arch culvert installations) conducted in perennial unconfined streams where flow cannot be isolated or easily pumped, temporary diversions can be constructed with large berms, cofferdams, sheet pile dams, or barrier walls that direct active flow to one side of the stream, to a high flow channel or into an excavated side channel (see **Figure 196**, bottom).

FIGURE 196.
Examples of water diversions.

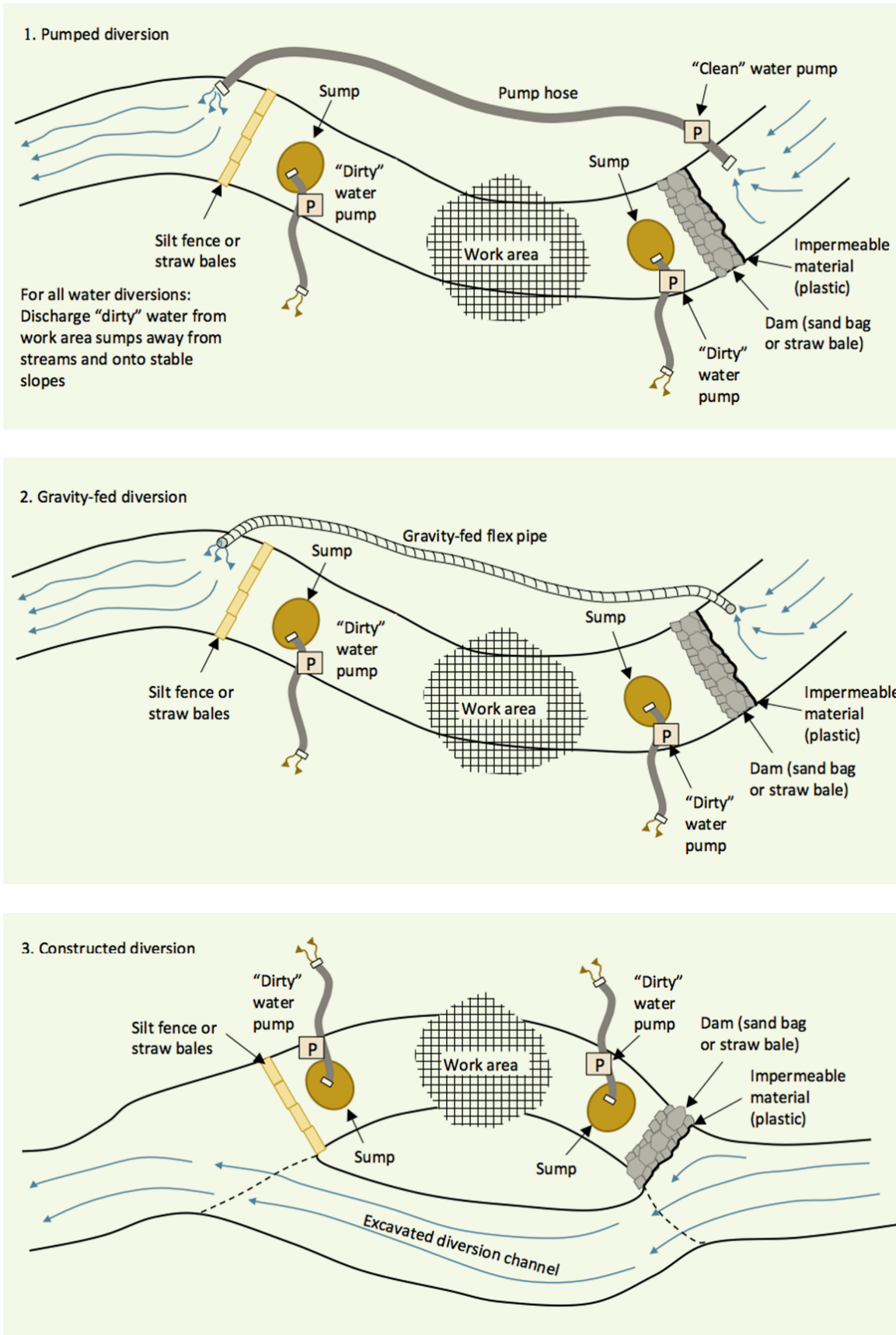




FIGURE 197. Flex pipe stream diversion around a road construction site. The inlet to this 6 inch diameter flex pipe inlet collects clear streamflow from a retention dam above the project site and gravity feeds it around the project area and back into the natural channel downstream from construction work (see photo).



FIGURE 198. Sand bag retention dam on this small stream was used to pond streamflow so it could be pumped around a culvert installation site. The green intake hose is screened to keep out rocks and debris while the red pump hose extends several hundred feet around the project work area.



FIGURE 199. For larger streams, pump trucks, large pumps or multiple small pumps can be used to pump streamflow around project work sites. Here, a pump truck is used to temporarily divert flow in a fish bearing stream where dual culverts are being replaced with a railcar bridge. Young fish were removed from this fish bearing stream before project work started.



6 RECONSTRUCTION AND UPGRADING

A. INTRODUCTION TO RECONSTRUCTION AND UPGRADING

Road reconstruction provides an opportunity to upgrade and improve a substandard road in one or more elements of its design. Culverts can be upgraded to current standards, additional drainage structures can be installed, the roadbed can be reshaped for improved surface drainage, and fills which exhibit instability can be removed and/or stabilized. **In general, stream crossings, unstable fills and cut slopes, and poor road surface drainage present some of the greatest challenges to road reconstruction, and the greatest opportunities for future erosion prevention, water quality protection and aquatic habitat restoration.**

Upgraded roads are sometimes referred to as “storm-proofed” even though they still retain the potential for flood damage. However, **properly upgraded roads should have a significantly lower chance of failure and the failures that do occur should happen less frequently and are smaller in magnitude.** Storm-proofed roads are significantly more resilient to storms and floods, and typically require less maintenance and lower reconstruction costs when and where they do fail.

B. RELOCATING PROBLEMATIC ROAD REACHES

Problem road reaches can occur on roads that are open and maintained, or closed and

abandoned. Some of these roads contain especially severe problems and should be permanently closed and relocated to more favorable slope locations, rather than to be rebuilt and maintained. Examples of problematic roads or road segments include the following:

- Roads with excessively high maintenance requirements and costs.
- Roads that persistently cause environment damage to streams and water quality and that cannot be economically corrected.
- Roads with frequent and significant slope instability that may result in intermittent road closure, including roadbed slumping,

roadbed debris slides, cutbank and hillslope failures, rock falls, or stream undercutting.

- Roads that have failed at one or more locations and cannot be rebuilt cost-effectively.
- Abandoned roads or road segments that have multiple road failures along their length.
- Abandoned roads or road segments that cannot be rebuilt because of regulatory or environment restrictions – if they were to be proposed for construction today they would not be permitted.
- Roads or road segments that are too steep for the desired land use activity or traffic types.
- Roads or road segments which are unsafe for users.

Road relocation consists of two activities: decommissioning and restoration of the road to be permanently closed, and rerouting the alignment to a more favorable location, using current design and construction standards (Figure 200).

When road reaches are closed they must be inventoried and assessed for existing and potential erosion and slope stability problems. Road closure and decommissioning treatments should then be implemented to prevent or greatly reduce the potential environmental effects of the road (see Chapter 7). These treatments include complete removal and restoration of all stream crossings, excavation or stabilization of all existing and potential road fill instabilities that could deliver sediment to stream channels, decompacting and/or permanently dispersing road surface drainage, and treating all other road-related sediment sources.

Road relocation is new construction, unless an abandoned or low standard road can be upgraded to access the desired location(s).

All the same environmental regulations and permits pertaining to new road construction are required to relocate a road to a new location. The relocation process involves virtually all the steps already described for effectively planning, designing and constructing a new road.

FIGURE 200.

The road on the left used to go along a perennial stream and riparian zone, eventually reaching the ridge crest in the distance. To eliminate its impact, the riparian road was decommissioned and a new bypass route (right) constructed along a dry hillside to the same ridge crest location.



Relocating a road or road segment can be as simple as identifying, designing and constructing a nearby alternative route that avoids the environmental problems that occurred or existed along the old alignment (Figure 200). Alternatively, it might entail revising the local transportation plan and require the relocation of the problematic road, and the spur routes that it served, to more favorable, stable terrain. This will achieve the desired transportation needs while having a minimal impact on the environment. Rural roads may be more problematic to relocate, because of multiple land ownerships and property boundaries that could be involved in the relocated alignment. However, you should identify the most stable and environmentally friendly road alignment or route, and if this involves a neighbor's property, at least talk with them about your ideas.

C. EVALUATING AND DESIGNING UPGRADES FOR EXISTING ROADS

One of the most common road-related activities for rural road systems, both from the perspective of road design and environmental protection, is the upgrading of existing roads and structures to current standards. In many locations in the USA, the core network of forest, ranch and rural roads has already been built, and new construction is a relatively minor part of overall land development and management. New roads are often those needed to access a new residential development or home sites, or spur roads that may be required to access a stand of trees proposed for harvesting, but the core network of primary and secondary roads is often already in existence.

Design standards for new road construction have evolved and improved substantially over the last several decades. This means that **most of our existing roads need to be thoroughly analyzed and updated, both to reduce the potential for road**

failures and continuing pollution, as well as to implement road improvements that will reduce long term road maintenance requirements and costs (Figure 201).

Most existing roads on the landscape were constructed decades ago and the lower standards that were applied then are now seen as representing serious potential threats to downstream, off-site resources as well as to the infrastructure of the transportation system itself. **Stream crossings are often considered the “weakest link” in wildland road systems and it is primarily in these locations that the lower standard designs are likely to still have the greatest adverse consequences.**

For example, threatened or endangered fish cannot pass through many old culverts that were installed too high in the fill and are now barriers to their migration. Elsewhere, many stream crossing culverts that were installed



FIGURE 201. A road inventory crew surveys stream crossings and other under-designed elements of a road, identifying needed upgrades along the route. The most important things to identify, and upgrade, are those that could cause road or stream crossing failures (like this perched, undersized stream crossing culvert), or that deliver road runoff and fine sediment to the stream system.

twenty or more years ago are now seen either as dramatically under-designed (undersized), or rusted through and failing, or both. **Undersized or poorly designed or installed culverts are seen as “loaded guns” that can fail during even moderate size floods, costing both money to repair and severe downstream environmental degradation.**

Road drainage practices and goals have changed dramatically. For example, past engineering design “best practices” for road drainage called for collecting, concentrating and discharging surface runoff from the road so that the road and its infrastructure would not be damaged by erosion. Efficiently delivering road surface and ditch drainage off the road and into the nearest stream channel was considered the standard goal of road surface drainage. This design typically called for insloped roads with inboard ditches, and long ditch lengths between ditch relief culverts (Figure 202). **At that time, the main concern was with protecting road infrastructure within the right-of-way; not downslope lands, downstream water quality or aquatic resources.**

Today, road redesign and upgrading is intended to bring the road up to current

standards by protecting the road infrastructure, but also minimizing the potential for environmental damage from road erosion and failures caused by substandard designs.

The most serious design flaws in older, existing roads include those that threaten road integrity, those that threaten to cause catastrophic road failures with significant downstream impacts, and those that contribute to persistent, chronic water quality pollution. Most of these design flaws were considered to be common and acceptable “field” designs and construction practices several decades ago, and their presence can be found along wildland roads in steep mountainous watersheds almost everywhere. Updated design standards and practices are now available to correct or remediate most of the potential problems created by old designs on existing roads. The most serious and threatening design problems for which updated design standards now exist include the following:

1. Non-standard stream crossing structures, including unculverted fills, log culverts, log bridges, and poorly located or designed fords.

FIGURE 202.

Three culverts on a rural road have developed (see arrows) long gullies below their outlets that connect the road to the stream channel at the base of the hillslope. The distance between ditch relief culverts was too long and each culvert carried too much flow. Additional ditch drainage is needed to disperse road runoff and prevent new gullies from forming.



2. Stream crossings whose drainage structures are under-designed (undersized) for the calculated 100-year peak flow, including sediment and floating woody debris passage.
3. Stream crossing culverts that are poorly aligned, too short, too high in the fill (not at grade), prone to plugging, or that are deteriorated or have suffered storm or mechanical damage since installation.
4. Stream crossings in debris flow channels that are not designed to withstand or pass debris flows without washing out or diverting.
5. Culverted stream crossings that have a diversion potential, especially those in steep midslope and lower hillslope positions such that if the culvert plugged, streamflow would be diverted down the road alignment and discharged onto unprotected hillsides or into other stream channels.
6. Stream crossings that are barriers to anadromous or resident fish migration.
7. Roads built by sidecast (cut-and-fill) construction techniques on steep, unstable inner gorge slopes.
8. Road fill slopes constructed on steep slopes that show signs of instability or potential instability, and that threaten to deliver landslide debris and sediment to streams or other water bodies.
9. Road fills built across steep headwall swales with visible signs of instabilities or emergent groundwater, especially in areas where debris torrents (flows) have originated in the past.
10. Poorly drained and insloped roads with widely spaced ditch relief culverts and road surface drainage structures that carry sufficient flow during storm events to develop large and long gullies on road surfaces or on hillslopes downslope from their outlets.
11. Hydrologically connected ditches and road surfaces, especially on mainline and main spur roads that have high traffic levels, significant commercial traffic or that are located in areas of highly erodible soils.
12. Roads built parallel to and immediately adjacent to stream channels, especially streams that support resident or anadromous fish populations or serve as domestic water sources.

Many existing forest, ranch and rural roads can be proactively upgraded and treated to help protect them and the downstream areas from potential impacts. However, a **poorly located road can almost never be as effectively remediated or negated by implementing improved design standards, especially once the road has already been reopened and rebuilt.** Regardless of advances in road design standards and road building techniques now available, some roads are not fit to be upgraded and should be permanently closed and decommissioned (Figure 203).



FIGURE 203. Sidecast constructed road built on a very steep inner gorge slope where a road should not have been built. Bulldozer constructed road perched large volumes of erodible spoil on the slope and debris slides have already delivered landslide debris to the stream channel below. This road is poorly located and upgrading will not reduce the failure potential. It is scheduled for permanent closure and the excavator (top of photo) is ready to begin decommissioning work.

This may be an economic decision, because of high maintenance and repair costs, but it should also be heavily influenced by the level of threat or potential impact represented by the road itself. Instead of developing and implementing updated standards for their reconstruction, landowners should evaluate their options for road closure and, if necessary, realign or relocate the road to more favorable, stable terrain.

D. REDESIGN CONSIDERATIONS FOR ROAD RECONSTRUCTION AND UPGRADING

1. REDESIGNING AND UPGRADING EXISTING ROADS

Storm-proofing upgrade treatments to an existing road are designed to: 1) bring the road up to current standards following best management practice guidelines, 2) make the upgraded road more resilient to storms and floods, 3) lower the on-site and downstream impacts of any failures that do occur along the alignment, 4) reduce chronic road-related inputs of fine sediment to stream channels, and 5) reduce long term road maintenance requirements and costs.

To achieve this, the **upgrading treatments to existing roads should address three main treatment categories: 1) stream crossings, 2) road, landing and turnout fill slopes, and 3) road surface drainage.** Other sites may need to be upgraded and addressed, but these three treatment categories are the ones most likely to threaten road integrity, erosion and sedimentation, water quality, and downstream aquatic habitat. **When completed, treatments will have met certain design standards and performance characteristics for storm-proofed roads** (see [Figure 204](#)).

Road redesigning includes 1) reopening and upgrading roads that have been closed or abandoned for some time, as well as 2)

upgrading existing, maintained roads to current design standards. The upgrading processes are similar but deciding to reopen an old abandoned road will require additional economic and environmental analysis.

The most efficient equipment for road reconstruction and upgrading includes hydraulic excavators, bulldozers, water trucks, dump trucks and a grader for final road shaping. These versatile pieces of equipment can complete reconstruction with a minimum of soil disturbance and loss of vegetation. A standard size backhoe is generally too small to perform the excavations required for many stream crossing reconstructions and removal of unstable road and landing fills. Dump trucks are often needed to endhaul slide debris and spoil materials generated during reconstruction and upgrading, and compactors may be needed, depending on the type of expected traffic.

2. REOPENING AND UPGRADING OLD ABANDONED ROADS

Reopening and upgrading old “orphan” or abandoned roads, even if they have been unmaintained and are currently overgrown, is often preferable to constructing new roads. Applying new design standards to the old alignment usually has less environmental impact and will be less expensive than building a brand new road bench across unroaded terrain. The weak points and problem areas along the old alignment will already be evident. Cutbanks and fill slopes will have largely stabilized over the years and those that haven't can be targeted for appropriate treatments. However, most of the constructed features along the old road will not be up to modern standards, and there may be a number of environmental risks along the road that must be treated. These will be identified during detailed field inventories and inspections.

CHARACTERISTICS OF STORM-PROOFED ROADS

Storm-proofed stream crossings

- All stream crossings have a drainage structure designed for the 100-year flood flow (including woody debris and sediment).
- Stream crossings have no diversion potential (functional critical dips are in place).
- Culvert inlets have low plug potential (trash barriers or deflectors are installed where needed).
- Culverts are installed at the base of the fill and in line with the natural channel.
- Any existing culverts or new emergency overflow culverts that emerge higher in the fill have full round, anchored downspouts that extend to the natural channel.
- Stream crossing culvert outlets are protected from erosion (extend culverts at least 6 feet beyond the base of the fill and use energy dissipation, where needed).
- Culvert inlet, outlet and bottom are open and in sound condition.
- Deep fills (deeper than a backhoe can reach from the roadbed) with undersized culverts or culverts with high plugging potential are fitted with an emergency overflow culvert.
- Bridges have stable, non-eroding abutments and do not significantly restrict 100-year flood flow.
- Stream crossing fills are stable (unstable fills are removed or stabilized).
- Approaching road surfaces and ditches are “disconnected” from streams and stream crossing culverts to the maximum extent feasible using road shaping and road drainage structures.
- Class I (fish-bearing) stream crossings meet State Fish and Wildlife and National Marine Fisheries Service fish passage criteria.
- Decommissioned stream crossings are excavated to exhume the original, stable, stream bed and channel sideslopes, and then stabilized with mulch and vegetation.

Storm-proofed road and landing fills

- Unstable and potentially unstable road and landing fills that could deliver sediment to a stream are excavated (removed) or structurally stabilized.
- Excavated spoil is placed in locations where eroded material will not enter a stream.
- Excavated spoil is placed where it will not cause a slope failure or landslide.

Storm-proofed road surface drainage

- Road surfaces and ditches are hydrologically “disconnected” from streams and stream crossing culverts. Road surface runoff is dispersed, rather than collected and concentrated.
- Ditches are drained frequently by functional ditch relief culverts, rolling dips or cross road drains.
- Outflow from ditch relief culverts does not discharge to streams.
- Ditch relief culverts with gullies that deliver to a stream are removed or dewatered.
- Ditches and road surface drainage does not discharge (through culverts, rolling dips or other cross drains) onto active or potential landslides.
- Decommissioned roads have permanent drainage and do not rely on ditches.
- Fine sediment contributions from roads, cutbanks and ditches are minimized by utilizing seasonal closures and installing a variety of surface drainage techniques including berm removal, road surface shaping (outsloping, insloping or crowning), rolling dips, ditch relief culverts, waterbars and other measures to disperse road surface runoff and reduce or eliminate sediment delivery to the stream.

FIGURE 204.
Characteristics of storm-proofed (upgraded) roads.

When reopening roads that have been abandoned for many years it is possible that some large stream crossings or short sections of road on steep, unstable slopes may have entirely failed by past erosion or landsliding. These may not be worth rebuilding and it may be preferable to reroute the road alignment around the problem areas with a section of newly constructed, stable road using current construction techniques and standards. In other cases, washed out stream crossings may appear impassable and problematic but it is often comparatively simple and inexpensive to upgrade the crossing to current design standards (Figure 205).

In many cases, temporarily reopening a poorly built road (for a single summer season) may provide substantial positive environmental

benefits if subsequent rehabilitation or decommissioning could reduce continuing or future erosion and sedimentation from the old alignment. All reconstruction work should be conducted in a manner that minimizes soil disturbance. Only areas which truly require earth moving should be disturbed. Typically, most of the old road surface will still be intact and require only minor grading to become passable. Ditches and cutbanks should be left undisturbed unless there are specific areas needing repair work or they are to be converted to an outsloped configuration. New sidecasting should be avoided in areas of steep slopes, near stream channels or where fills are unstable or oversteepened. As a general rule, landings should not be enlarged by new sidecasting.



FIGURE 205. Under-designed or unmaintained stream crossings on older roads are prone to failure during large storms. This 8 foot diameter culvert was partially plugged (note wood at entrance) and flood flows overtopped and washed out the fill. During road reconstruction, stream crossings should be redesigned as temporary (and then removed) or upgraded for the 100-year flood flow, including passage of debris and sediment loads. When reconstructed, this crossing would either be fitted with an upstream debris screen or debris deflector, or a bridge would be installed.

Decisions about reopening an abandoned road should be made on-site, after having inspected the entire route and reviewing the pros and cons of re-disturbing the area. **As a general rule, it is often worth removing even abundant revegetation along the abandoned route if there are substantial erosion prevention projects that could be completed during or following reconstruction.** That is, it is often preferable to remove vegetation than to leave the vegetation intact and not treat potential and ongoing erosion “hot-spots” along the old road alignment.

Removing vegetation and regrowth from the road prism, by itself, rarely causes serious erosion problems. When in doubt, you should seek technical assistance and guidance from the experienced resource specialists (qualified geologists, engineering geologists,

erosion control specialists, etc.) as well as input from regulatory agencies that will eventually have to approve any proposed project.

Some old roads may not be suitable for reopening and permanently upgrading. Those should be fairly self-evident upon field inspection and analysis. Only after careful consideration, weighing the economic and environmental benefits against the potential impacts, is it ever justified to reopen roads that 1) cross unstable hillslopes, 2) were constructed up the axis of a stream channel or valley, or 3) would require considerable earth moving with the potential for significant erosion and stream sedimentation. Some roads simply may not be located in a good hillslope location and there is little or nothing that can be economically done to improve their design or stability (**Figure 206**).



FIGURE 206. *This rural road traversed a large unstable hillslope that showed widespread movement during an exceptionally wet winter. The road did not cause the instability but it is no longer useable. Alternative access should be developed wherever roads cross highly unstable terrain. This road should be decommissioned so no additional erosion and instability is caused by the road and its drainage structures.*

a. Stream crossings

Existing stream crossings along the road alignment require close examination and analysis. If the road is to be permanent, all stream crossing drainage structures should be checked to determine whether or not they are properly designed and capable of passing the 100-year flood flow. Any stream crossings that require reconstruction should be redesigned for the higher level of protection. Any significant design flaws that could lead to stream crossing failure should be immediately addressed.

Washed-out stream crossings present one of the most common obstacles on older abandoned (orphan) roads that are to be reconstructed. Usually part, or all, of the fill has been eroded and lost downstream because the drainage structure was too small, not maintained, or not

installed in the first place (Figure 207). Washed-out stream crossings are reconstructed just like new ones, with all the same techniques and requirements. If the fill was only partially eroded from the crossing, the remaining material in the channel bottom will likely need to be excavated (down to the original channel bed) before a new culvert is installed. This may include removal of sediment and buried stumps and logs.

Other stream crossings may still be completely intact, but have poorly constructed, undersized or worn out culverts that need to be replaced and/or upgraded (Figure 208). Some crossings may have buried logs or trash that was placed in the channel before it was filled in, and it is now characterized by sink holes (Figure 209). Even if the crossing is still intact, the fill should be excavated down to the original streambed and a new, stable fill and properly



FIGURE 207.

The culvert inlet on this abandoned (unmaintained) stream crossing partially plugged with wood and sediment. The culverted fill “washed out” (eroded) and continues to erode and deliver sediment to the channel and to downstream areas. “Walking away” from an old road does not prevent potential erosion problems, especially when they contain culverted stream crossings.

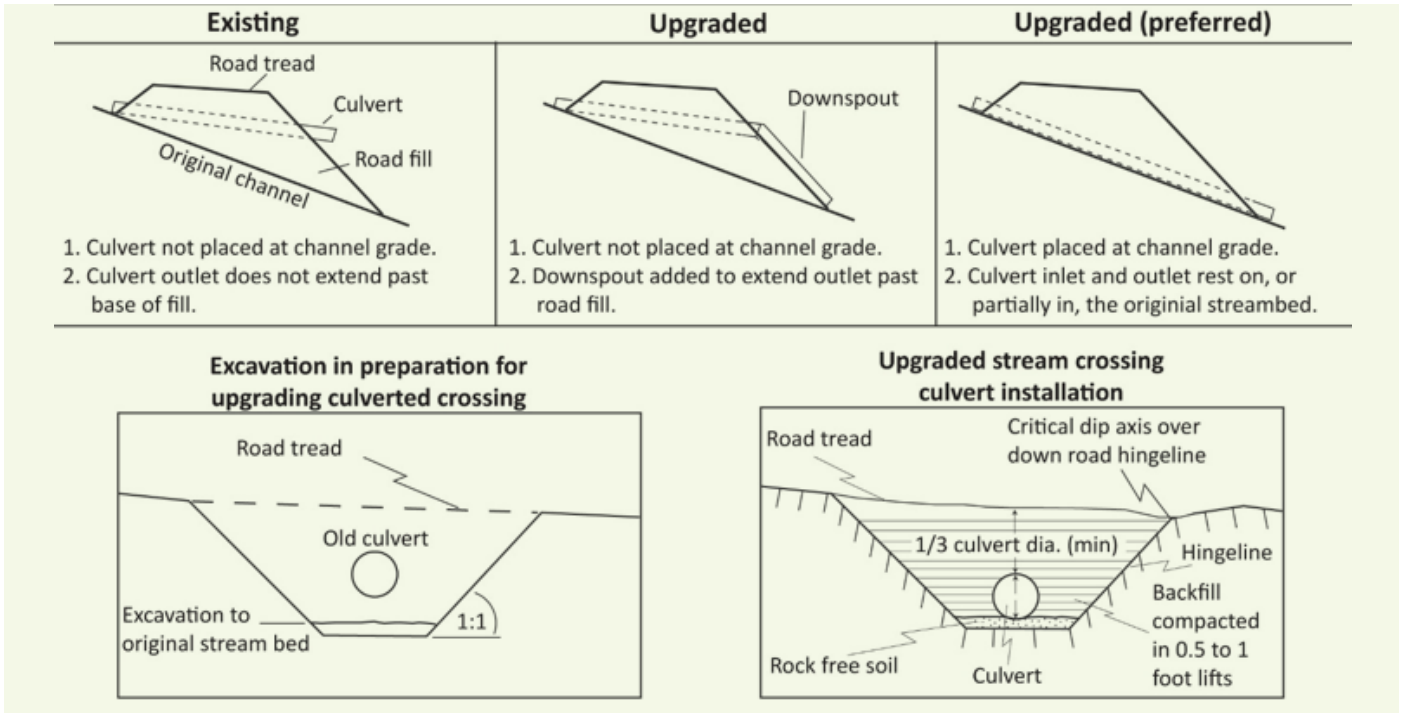


FIGURE 208. Typical upgraded culvert installation on non fish-bearing streams.



FIGURE 209. Sink hole in recently reconstructed seasonal road. The plastic culvert separated (see arrow) when the poorly compacted fill settled during the first wet season. Flow in the culvert caused the fill to erode and the sink hole to form. All the eroded sediment was delivered downstream.

designed and sized drainage structure should be installed (Figures 210a and 210b).

If a temporary or permanent bridge is to be installed, the entire fill should be removed from the old crossing, and the banks should be graded or excavated back to a stable

angle. You can often tell that you have removed all the fill material from the former crossing when rounded boulders, old uncut logs and branches, roots, in-place stumps and other features of the original bed and banks are exposed during excavation.

FIGURE 210A.

This Class I (fish bearing) stream channel exhibits several previous upgrading attempts, none of which were designed to allow fish passage. The original crossing consisted of logs piled in the channel and covered with fill. When that plugged, a culvert was installed on top of the logs, and another smaller culvert was later installed above it, to add more flow capacity.



FIGURE 210B.

The recent upgrading consisted of removing all the stream crossing fill (including the logs and old culverts) and installation of a large, embedded culvert to allow for aquatic passage.



b. Road and landing failures

Road and landing fill slopes along a road proposed for reconstruction should be examined and any that show signs of instability or potential instability, where fill slope failures would impact stream channels downslope, should be stabilized or removed (excavated) (Figure 211). Similarly, road surface drainage should be analyzed to ensure that road runoff is not adversely affecting the stability of fill slopes or hillslope areas below the road. Road shaping and drainage structures should be modified to protect slope stability, especially where slopes are steep and potentially unstable.

Failed road benches can present a serious obstacle to reconstruction. In areas of steep inner gorge slopes, failures of the entire width of the roadbed can extend all the way downslope to a fish-bearing stream. Side-casting into the void in hopes of developing a new road bench at the same spot will usually result in direct sediment delivery to the stream. The resulting fill would also be highly unstable. Road reconstruction, where failures have removed most, or all, of the former road bench, are likely to require an engineered solution such a reinforced fill or a crib wall (Figure 212). A qualified geotechnical engineer or engineering geologist should be consulted to design solutions for these difficult reconstruction sites.

In many cases, the outer 10–50 percent of the road prism may have been lost as a result of fill slope or sliver fill failures along the former road, in which only sidecast materials have moved downslope. If there is sufficient road width remaining for vehicles to pass, the unstable area should not be disturbed. Where some additional road width is needed, consider cutting into the inside bank rather than trying to build the fill back out (Figure 213). If fill material has not moved off-site, but is showing signs of pending failure (e.g., scarps displacing or



FIGURE 211. *Unstable landing fill excavation. Oversteepened fill is removed from the landing edge and endhailed off-site to a stable location (Adams and Storm, 2011).*



FIGURE 212. *Engineered fill constructed where a fill slope failure had removed the entire roadbed.*

FIGURE 213.

Most road fill failures leave at least half (the cut half) of the roadbed intact and passable. If additional road width is required for vehicle passage, the most cost-effective solution is to widen the road into the cutbank, rather than building an engineered fill where the road slumped.



offsetting the road prism), and the failed soils will be delivered to a stream, then the unstable material should be excavated and hauled to a stable storage site for disposal (Figure 214).

Although a far less common practice today, unstable landing fills or fills around the outside of rock pits present similar problems on a larger scale, except that vehicle passage is usually not affected. Unstable landing fills on roads used several decades ago usually resulted from mixing soils and woody debris together in the uncompacted sidecast around a landing perimeter. The fill face was often oversteepened by continued blading and sidecasting of landing wastes over the outside face of the landing. On steep slopes, these unstable fills and waste deposits can saturate with water and develop into debris slides or fluid debris flows that travel great distances downslope and into larger stream channels, threatening downstream residences or other important habitat or infrastructure. In other cases, failed landing fill material may not be delivered to a stream channel, and only the

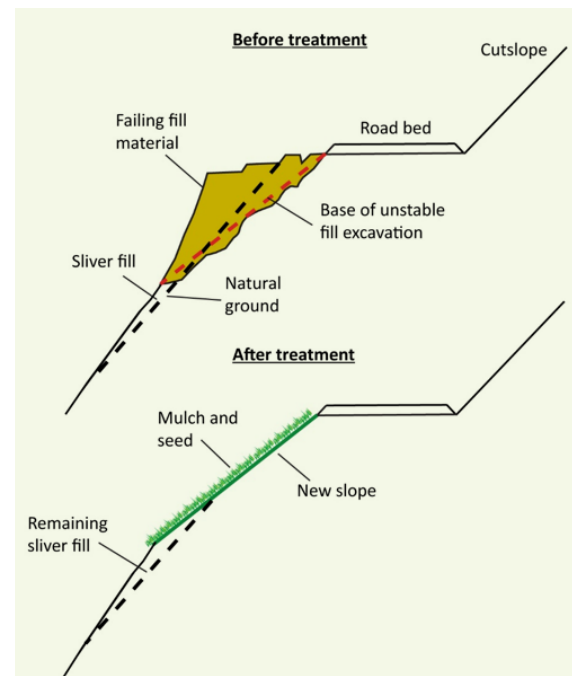


FIGURE 214. Unstable road fill excavation, before and after treatment.

“run-out” area is impacted through damage to regeneration and reduced site productivity.

Each unstable turnout, landing or rock pit fill should be evaluated to determine if it threatens downslope stream channels, human developments or other important resources. If it does, the unstable fill should be excavated and hauled to a stable storage site for disposal. Often, the inside of the landing or the rock pit itself is carved into bedrock and can serve as a suitable storage site for excavated fill materials.

Cut slope failures which block the road surface generally represent a less serious erosion and water quality problem than fill slope failures, since the roadbed may store much of the failed cutbank material and prevent it from moving downslope (Figure 215). Failed materials can usually be excavated off the roadbed and hauled to a suitable storage site. Unless slopes are gentle and the road is not close to a stream channel, debris should not be sidecast from the road surface

and onto the slopes below. Sometimes the material can be spread or “drifted” over the roadbed, thereby raising the road surface and avoiding the need for expensive endhauling.

c. Road surface drainage

Road and ditch connectivity to streams should be minimized as an important part of any road upgrading and storm-proofing project. This might include road shape conversions (e.g., converting roads from insloped to outsloped), adding and relocating ditch relief culverts, adding rolling dips to disperse road surface runoff onto stable slopes below the road, and hydrologically disconnecting any connected gullies, ditches and any other drainage structures to the extent feasible.

Many older roads were initially constructed with an insloped surface and an inside ditch. If conditions are appropriate, the rebuilt road can be converted to a low-impact outsloped surface with rolling dips to disperse road runoff. In ditched road segments, ditch relief culverts

FIGURE 215. *Unstable cut slopes usually pose less of a threat to water quality than unstable fill slopes, but they may still be difficult to stabilize. Soil that is cleared from the road surface and ditch should be end-hauled or pushed to a stable storage site and not sidecast over the outside edge of the road. In some instances, a slope buttress may need to be designed and installed to prevent further instability and road closures.*



and other surface drainage improvements should be made to quickly direct water off the road surface and into buffer areas downslope where it can infiltrate. Many older seasonal and permanent roads have an outside berm which has been created and perpetuated by years of poor grading technique (Figure 216). Poorly drained roads can often be dramatically improved by outsloping, berm removal and/or other surface drainage improvements.

d. Slash and spoil disposal

Reconstruction of abandoned roads often involves substantial vegetation removal from the road surface. Slash should not be mixed in and sidecast with soil materials. Instead, it can be piled and burned on landings, or windrowed along the outside edge of the cleared fill. Spoil materials generated from road reconstruction (largely from cutbank failures), should be safely disposed in a stable location where it will not erode or enter a watercourse. Spoil disposal techniques are the same as for new road construction (see Chapter 5, and

sections on construction and erosion control, and reconstruction techniques, above).

E. STREAM CROSSING UPGRADES

When upgrading and storm-proofing any low volume forest, ranch or rural road, stream crossings are one of the most important elements to evaluate and upgrade. The field inspection and office analysis will tell you what needs to be done to bring the crossing up to current design standards and to reduce its failure potential. These actions can be summarized in a discrete number of “actions” that are undertaken to upgrade and make each stream crossing more resilient to storms and floods, contribute less to chronic fine sediment delivery, and have a minimal impact on aquatic organism passage (Figure 204).

As a start, map analysis and field inspections will tell you if the culvert is undersized for the design flood flow (100-year return interval), and inspections will help inform you if bridges or other non-standard stream crossing structures

FIGURE 216.

Surface runoff problems caused by wet weather use of a bermed, unsurfaced, seasonal road. The running surface is rutted and this acts to collect runoff and cause additional erosion. Lack of waterbars or rolling dips, together with the berm along the outside edge of the road, now act to keep surface runoff on the unsurfaced roadbed.



need to be replaced. Most older, culverted stream crossings (those built more than about 10 to 20 years ago in many western states) will be undersized for the 100-year peak flow. At 20 years old, many of these will be showing signs of rust and wear and will likely need to be replaced anyway. If the culvert is undersized,

displays any rust holes in the bottom, shows signs of leakage or internal separation, or has a dented or ripped inlet it will likely need to be upgraded (Figures 217a and 217b).

In upgrading a stream crossing culvert, make sure to determine if the stream is fish-bearing



FIGURE 217A.
Culverted stream crossing on a permanent forest road before upgrading to the 100-year design standard (including debris and sediment). The before and after photos of the culvert outlet are taken from the same location.



FIGURE 217B.
The same stream crossing after culvert upgrading. The culvert has been set in the original streambed and the fill dipped to prevent stream diversion.

and, if so, to provide for passage for all life stages of the species that use the channel at any time of the year. Some large culverted streams may be candidates for installing a bridge, a plate arch or an arch culvert instead of an embedded round culvert (Figures 218a and 218b). Ask the regulatory agencies with jurisdiction for the protection of aquatic species, including fish, for comments on your proposed design before you start planning for construction.

If the stream channel shows signs of past culvert plugging or significant transport of large woody debris during flood events, you will want to provide increased protection against future

plugging of your new installation. This can be done by upsizing your culvert even larger than required to carry the 100-year peak discharge, by using an arch culvert instead of a round one, or by installing a bridge, ford or plate arch (bottomless arch) instead of a culvert. Suggestions for culvert sizing methods and calculations to account for passage of organic debris during floods are described in Appendix A.

Finally, stream crossing upgrading also involves upgrading road surface drainage on the approaches to each crossing. Road surface runoff and ditch flow should be diverted off the road as close to the stream crossing

FIGURE 218A.
Dual, undersized culverts were a partial barrier to fish migration on this rural road.



FIGURE 218B.
The culverted stream crossing was upgraded to a steel I-beam and plate metal bridge to provide for passage of adult and juvenile fish. Note the concrete abutments, armored fill slope and naturally wide channel bottom through the crossing after bridge installation.



as is possible without runoff entering the stream somewhere downslope. The remaining connected road surface should be rock armored, or mulched and seeded if the road is a seasonal, native surfaced road.

The road surface over the crossing can be insloped or outsloped, as long as the remaining local road surface runoff is not directed over the new fills and the bare fills are protected from erosion with seeding, mulch, and/or erosion control blankets. Rock armor is typically installed around the culvert inlet and outlet to protect it from erosion, and that armor also serves to trap any sediment eroded from the new fill before it can be delivered to the stream. Ultimately, revegetation of the fills will provide for long term erosion control and fill slope stability.

F. TRENCHLESS TECHNIQUES FOR CULVERT REPLACEMENT

Trenchless technology can be defined as the use of construction methods to install or repair underground infrastructure without digging a trench or opening an excavation cut. Rapid development and expansion of trenchless technology has been observed over the past several of decades due to the desire to cost-effectively install or rehabilitate stream crossing culverts with minimal environmental impacts.

Culvert-lining methods are classified as a specialized trenchless rehabilitation method for repairing certain existing stream crossings without having to excavate and replace the existing culvert pipe. Although mostly confined to use in culvert replacements on public roads, where traffic cannot be closed, the simplest trenchless methods are also suitable for some large culverted fills on forest and rural roads.

The trenchless techniques suitable for rural roads can be divided into techniques for installing new pipes and techniques for rehabilitating existing pipes. New pipe

installations are completed using pipe jacking or earth boring methods. Alternatively, pipe rehabilitation is accomplished using lining methods or by applying maintenance repairs to the existing culvert. The increasing cost of replacing long culverts under high fills warrants an evaluation of all repair techniques currently available.

Maintenance of culverts may include major repairs of corrosion and abrasion damage to the culvert invert. Techniques employed for metal culverts may include recoating; lining with concrete, cement grout, and plastics; plugging of leaks with expanding bands, grouting, and welding; and insertion of a smaller diameter pipe (sleeving). Concrete culverts may be repaired by relining with grout; removal and replacement of deteriorated concrete; with the insertion of clay or plastic liners; and by applying polymer coatings.

As the name implies, these methods have the ability to retrofit or completely replace a pipe with minimal trenching, and therefore minimal effect to the roadway traffic. Project sites that favor trenchless technology for a pipe rehabilitation include sites with deeper cover, larger pipes, and longer detour routes. The hydraulic analysis for a rehabilitated pipe should be the same as required for a new pipe or culvert. **Any type of liner used to rehabilitate a culvert will reduce the diameter of the pipe, thus reducing capacity. However, due to the smoothness of the new liner, the improved efficiency of the pipe may compensate for the lost capacity.**

A number of rehabilitation methods are available which can restore structural integrity to the pipe including: fold and form, sliplining, tunneling, horizontal directional drilling, and pipe jacking, among others. Most are designed for highway use and only a few of these would be cost-effective for forest, ranch or rural roads.

Various types of liners can retrofit the pipe interior. One of these techniques is called ‘fold and form’ and involves pulling a folded HDPE pipe through the existing (host) pipe. The liner pipe is then inflated with hot air or water so the liner molds itself to the host pipe, thereby sealing cracks and creating a new pipe within a pipe. Another method is a close-fit folded lining or a **fold-and-form** lining. Before installation, a polyethylene liner is heated and folded to reduce cross-sectional area for insertion. The folded liner is then inserted into the host culvert and pulled into place with a winch. Once in place, the liner is reformed to a shape, with applied heat and pressure (generally steam), that forms a close fit with the host culvert (**Figure 219**).

Sliplining is a technique that involves inserting a full round pipe with a smaller diameter into the host pipe and then filling the space between the two pipes with grout (**Figure 220**). It is the most

common and easiest lining method and costs range from \$25 to \$200/ft. Sliplining involves inserting a flexible, usually thermoplastic, liner of smaller diameter directly into a deteriorated culvert. Liners are inserted into the host by either pulling or pushing the liner into place. After insertion, the space between the existing culvert and liner is generally grouted with a cement material providing a watertight seal (**Figure 220**).

Continuous sliplining involves the lining of a deteriorated culvert with a continuous liner. No couplers are required so this allows for a larger diameter liner. Liners are generally made from polyethylene or high-density polyethylene pipe segments that are butt fused (melted) together. The continuous liner is pulled, pushed, or simultaneously pushed and pulled into the host culvert. Sliplining works best if the original pipe is already larger than the required culvert diameter for the 100-year flow, so the smaller pipe insert will still pass the design

FIGURE 219.
*‘Fold and form’
culvert liner.*

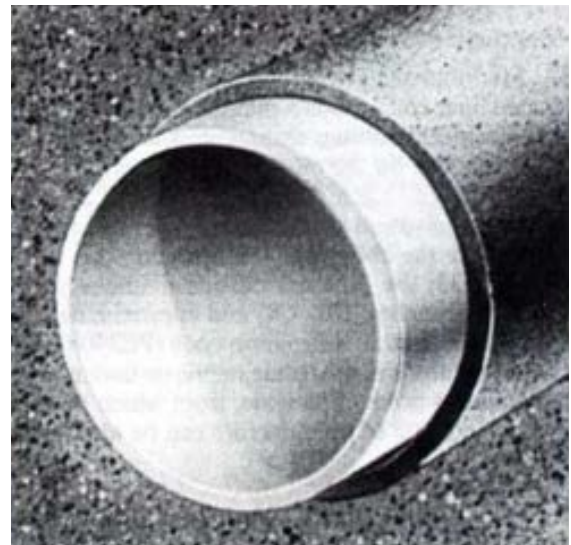


FIGURE 220.
*Sliplining
technique for
trenchless pipe
installation.*



discharges. While the smaller diameter lining may reduce the flow capacity of the culvert, the smooth interior surfaces may make up for some of the flow loss caused by the pipe insert.

Fish passage through newly lined pipes may become an issue if velocities are increased enough in the smooth walled pipe that fish cannot swim upstream.

Tunneling is typically more expensive than the other methods of in-situ culvert replacement, but it allows for installing a larger diameter culvert than currently exists at a site. It involves auguring through the fill and simultaneously inserting a new, larger culvert as the auguring progresses (Figure 221). There must be good access for heavy equipment to the upslope (inlet side of the stream crossing fill (Figure 222).



FIGURE 221.

Tunneling is sometimes used to install a culvert in a deep road fill without opening an excavation or disrupting traffic. The large, powered soil auger drills and removes soil materials and fill from the hole and the new steel pipe is hydraulically jacked into the hole.

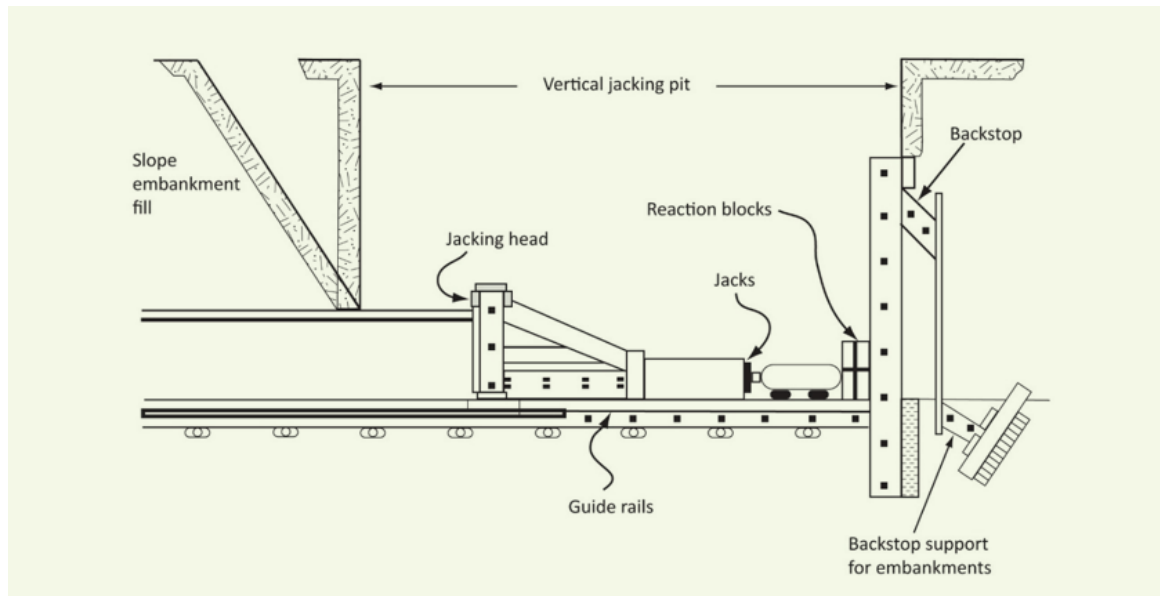


FIGURE 222.

New pipe section is welded to the previous "jacked" section and the process is repeated until the outlet is exposed at the base of the outside fill slope. Guides along the ground are used to keep the pipe and auger aligned and straight. Soil removed by the auger is endhauded to a spoil disposal site.

FIGURE 223.

Pipe jacking technique for trenchless culvert installation.



Pipe jacking or ramming is probably the most widely known and most commonly used method. Pipe Jacking is done to install pipelines and culverts under roadways, railroads, runways, canals and other immovable structures. In roadway projects the pipe jacking operation is commonly used to install piping with minimal or no interruption to the vehicular traffic or any type of utility service. Pipe jacking requires sufficient surface area to provide an access pit. This pit is used to set up jacking equipment and to remove the earth excavated from the jacked pipe. All utilities must be located prior to commencing the jacking operation. This method advances pipe through the ground with thrust from hydraulic jacks (Figure 223).

Pipe diameters less than 48 inches can be jacked both economically and easily. Excavated material is usually removed through the jacking pipe installation in carts or by a conveyor system. Once the installation is complete, soil cement, grout or sand is pumped into the void between the excavated bore and the outside of the pipe. Design and construction guidelines, and engineering oversight, are required to accomplish pipe jacking in a cost-effective manner.

G. ROAD DRAINAGE UPGRADES—ROAD SHAPE CONVERSIONS

In past decades, classic road engineering on forest, ranch and rural roads in many parts of the country was to construct insloped roads with ditches. The theory was to be able to have complete control over road surface runoff; where to collect it, how much to accumulate, where to direct it, and where to get rid of it. Runoff was also collected from swales and small, ephemeral streams along the inside edge of the road and diverted to the inside ditch. Runoff was almost always directed to the nearest stream crossing culvert inlet as the preferred way to get it off-site quickly and effectively. Streams were considered as the best place to dispose of road runoff without harming the road prism. The road right-of-way was considered the most important part of a road and protecting the right-of-way infrastructure was paramount. Little consideration was given to the impact this might have on downslope or downstream areas or the consequent environmental impacts.

More recently, as the on-site and off-site environmental impacts of road surface drainage practices have been identified and quantified,

and their causes clearly revealed, practices have changed significantly. Dispersing road surface runoff is now considered the best and most environmentally sound engineering practice for managing road surface runoff. **The theory is to make the road as hydrologically invisible as is possible, such that runoff from upslope is taken directly across the road alignment and any runoff generated from the road itself (including the cutbank, roadbed and fill slope) is dispersed and discharged onto the native slope below the road as quickly as is possible.** The only caveat is that when directing runoff onto those downslope areas, it might cause slope instability or other serious problems.

There is a place for insloped, ditched roads but their historic prevalence on the landscape is usually far greater than needed or desired. Ditches are needed where emergent water and runoff from the cutbank needs to be collected so it will not damage the road subgrade or surface. Where cutbanks are dry and free from emergent water, most roads can be outsloped for more effective surface drainage. **High maintenance insloped roads can be converted to low maintenance outsloped routes as one method for improving road drainage and reducing hydrologic connectivity** (Figures 224a and 224b).



FIGURE 224A. *Ditched, gullied, deeply rutted, and bermed seasonal road before being converted to an outsloped road with rolling dips.*



FIGURE 224B. *The same road after being converted to an outsloped road with rolling dips to improve road drainage and decrease maintenance requirements and costs. The road was also gravel surfaced so it could be used during wet weather periods.*

Road shape conversions may be part of a fill slope stabilization project, where potentially unstable fill material is excavated from along the outside edge of a road and then used to fill the ditch at that or another location (assuming the material is suitable) (Figures 225a and 225b). **Typically, the most common conversion is changing an insloped road to an outsloped road with rolling dips.** This type

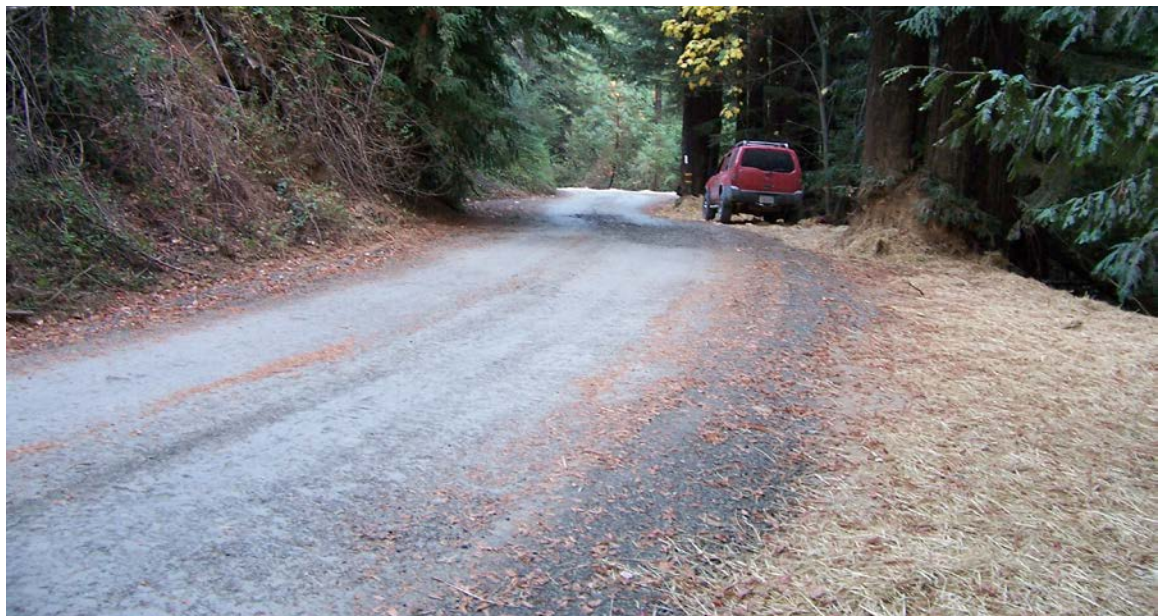
of conversion is often performed on the road approaches to stream crossings, as a method of eliminating the inside ditch and hence eliminating its connectivity with the stream (Figures 226a and 226b).

Excavated fill material needed to fill the ditch may be derived by excavating the outer half of the road bench (using an excavator and/or a bulldozer with hydraulic rippers and a 6-way

FIGURE 225A. Native surface permanent road on a rural subdivision was insloped, bermed, deeply rutted and hydrologically connected to a nearby stream prior to upgrading.



FIGURE 225B. The same road was converted to a gravel surfaced outsloped road with no inside ditch or outside berm. The shoulder has a steeper outslope to provide for free, continuous drainage of road surface runoff.



blade), or it may be hauled to the site from a nearby borrow site. The roadbed is ripped (decompacted) and fill is placed, shaped and compacted in the ditch and along the inside edge of the road bench. A dozer, and then a grader, are used to provide a final, even outslope to the new outsloped road bench. The new shape should be watered (if it is too dry) and a vibratory rolling compactor can be used to harden the materials and the

driving surface. As with any outsloped road, you will need to construct regular rolling dips along the alignment to make sure you achieve regular, dispersed road surface drainage.

Depending on site conditions, other road shape conversions can be employed. If a ditch is needed, the insloped road bench can be converted to an outsloped road while the ditch is retained to collect and drain surface runoff



FIGURE 226A.
Rural subdivision road was insloped and rutted prior to treatment. Runoff from the eroding roadbed was delivered directly to a stream channel.



FIGURE 226B.
The same road was converted to an outsloped shape, with broad rolling dips constructed at regular intervals, to disperse road runoff onto the adjacent grass covered slope and to disconnect road runoff from the nearby stream. Note that the ditch was filled and gravel was added to the low maintenance road surface.

and clean emergent water from the cutbank. This is an excellent method of “cleaning” ditch flow so that it can be safely discharged into a nearby stream crossing culvert inlet without adding the fine sediment or turbidity that would have come from road runoff.

Similarly, an insloped road could easily be converted to a crowned road, and the crown could be moved from the traditional centerline position of the roadbed to a location closer to the inside of the road. The crown still provides the safety factor sometimes needed on rural roads that get an occasional winter snow cover, but greatly diminish the amount of fine sediment and turbid runoff that would otherwise enter the ditch from a fully insloped road surface.

H. EROSION CONTROL

Erosion prevention and erosion control can actually be improved by road reconstruction. Upgrading or removing stream crossings and removing unstable fills can significantly reduce the likelihood that road failures will occur and sediment will be delivered to stream channels. Even the temporary, single reuse of an abandoned road can serve as an opportunity to perform erosion control and erosion prevention when the road is then permanently closed.

Erosion control during reconstruction of permanent and seasonal roads is largely the same as for new construction. Surface erosion can be minimized by keeping excavation and soil exposure to a minimum, and by retaining as much roadside vegetation as possible. The largest potential erosion prevention benefit will be at reconstructed stream crossings. Use of temporary bridges, as well as protective measures at culvert inlets, culvert outlets, road surfaces, and fill slopes will help reduce the potential for accelerated erosion on reconstructed roads (see Chapter 5 (I) and Chapter 6 (E)).

The timing of reconstruction and upgrading, especially stream crossings, can also help prevent and control unnecessary erosion.

Stream crossing reconstruction and upgrading should be performed during low water conditions. Wet season road work should only be performed during dry periods and when erosion control measures (mulching, waterbars, etc.) can be installed concurrently with road rebuilding. Large sections of road should not be “opened” during the wet season without performing concurrent erosion control work.



7 INSPECTION AND MAINTENANCE

A. INTRODUCTION TO ROAD INSPECTION AND MAINTENANCE

Regular road maintenance is essential to protect the road and to prevent environmental damage. All roads should be regularly inspected and maintained, whether they are main line arterial routes or local, dead end spur roads receiving minimal traffic (Figure 227). Limited budgets sometimes cause landowners to defer maintenance until they have sufficient funding. The longer maintenance needs are not addressed, the greater is the threat of future road damage and downstream impacts, and the greater will be the eventual cost of performing the work. **If adequate personnel and financial resources are not available to provide for regular, long term inspection and maintenance, roads should be built (or rebuilt) as temporary, and then properly abandoned or closed at the end of the planned operations.** Temporary roads that have been properly abandoned and roads that have already been decommissioned do not need continued maintenance and pose little threat to downstream resources.

B. EVALUATING AND MONITORING ROADS FOR THREATS

Assessing and monitoring roads for threats is different than identifying maintenance needs. Threat identification is determined by inventorying a road for potential weak points that could fail during a large storm or flood. These typically include sites and road structures that could

fail catastrophically, such as stream crossings and unstable road fills and fill slopes. **Threat identification and treatment is intended to make the road more resilient to failure and less impacting on watershed ecology.** In contrast, maintenance inspections are conducted to determine what structures or features of an existing road are in need to repair so they function as designed and intended. **Maintenance is generally not conducted to**

FIGURE 227.

Low standard, unmaintained spur road shows no evidence of recent inspections or maintenance. In spite of lack of regular use, many low standard spur roads have ditches, culverts, fill slopes and stream cross-ings that could fail and impact the road, as well as downslope and downstream areas, during storm events. If funds are not available for inspection and maintenance work, the roads should be closed and decommissioned so they do not pose a continuing threat to the watershed.



improve design or resilience, only to make sure the road and its components function as originally designed and constructed.

1. INTRODUCTION TO THREAT ANALYSIS

Threat sites are features of the road that are vulnerable to failure during a stressing event, or that chronically degrade the aquatic system. These are both ecological and structural threats. Identifying and treating these sites is a risk reduction strategy that can be prioritized throughout an entire watershed or road network, or along a single road. It involves identifying what is likely to fail, or at risk of failing, before it does. It also targets improvements along a road to reduce the chronic impacts of the road or road system on downstream aquatic ecology and water quality.

Features that are adversely affecting or at risk of impacting watershed hydrology, stream channels, aquatic habitat or water quality are mostly identifiable and treatable prior to failure.

Most chronic threats are easily identifiable and treated. Catastrophic threats can be identified by thorough analysis of the weak points along the road or road system and then prioritized for treatment. It requires a

site-by-site forward-looking assessment of likely outcomes of a road feature to large magnitude storm and floods. The risk of failure depends on local conditions and current designs at each site. Not all sites have the same risk of failure and not all sites that are at-risk will fail.

The risk analysis is based on 1) field measurements and observations of each site, 2) professional judgment about the most likely events, outcomes or scenarios that would ultimately result in failure of the site, and 3) the magnitude and off-site consequences of that failure. It is not clear or certain that the predicted events would actually occur, but local evidence allows you to evaluate that possibility and to assign a risk level to the various possibilities. Treatment of these at-risk sites can reduce the likelihood of their occurrence as well as the overall consequences of major storms and long term chronic impacts caused by the road or road system.

Once the threats are identified, treatments can be designed to:

- Lower or eliminate the risk of catastrophic road-related slope failures, especially debris slides and debris flows from unstable road fills and fill slopes.

- Reduce the risk of stream crossing failures caused by flow exceedance, culvert plugging, overtopping, washout and stream diversion and its off-site impacts.
- Reduce the magnitude (volume) of sediment delivery to streams from roads and stream crossings that do end up failing.
- Reduce the chronic delivery of fine sediment and road runoff to streams caused by hydrologic connectivity between roads and ditches and streams.
- Reduce the cost of road repairs and the time roads are out of service as a result of failures during large magnitude storms and floods.
- Reduce future maintenance efforts and costs needed to keep roads open and in good repair.

2. THREAT IDENTIFICATION AND TREATMENT

Road-related threats in a watershed are of two basic kinds. They include those elements of a road and its integrity or use that are threatened by a storm event and those elements of a watershed (including water quality and aquatic ecology) that could be impacted by the same hydrologic event. Road system threats and watershed threats derived from forest, ranch and rural road systems typically come from three sources:

- stream crossings,
- unstable cutbanks and fill slopes, and
- road surface drainage.

Threats are identified by conducting a systematic inventory and analysis of the current design weaknesses of these three road-related features, comparing them to current design standards, and then developing recommended

and prioritized solutions to lower or eliminate the risk associated with each feature.

a. Road-related instabilities

Identification (cutbanks)—Road cutbanks and fill slopes are inspected to identify any existing or potential instabilities that could significantly damage the road or impact downslope areas. Qualified geologists are often needed to interpret the size, activity level and failure potential of unstable features that are identified. For cutbanks, existing instabilities are categorized by their current size and aerial extent, as well as their current activity level, to determine if there is any physical evidence they could expand beyond their current size. Aerial photos can sometimes be used to see if upslope areas have been destabilized and ground observations can be used to map the current boundaries of unstable features as expressed by scarps, ground cracks, leaning trees and other evidence of instability.

Treatments (cutbanks)—Cut slope-related landslides are difficult to treat except by expensive engineering methods. These methods are usually not selected for implementation along forest, ranch and rural road systems in wildland and rural areas. Simpler treatments may employ revegetation and some simple dewatering and buttressing methods. A qualified engineering geologist or engineer should be consulted for site-specific treatment strategies or prescriptions because each instability is unique. When they fail, most cutbank slides will end up depositing the failed material on the road bench downslope, and only a few will be large enough or fluid enough to travel over the road bench and continue downhill. In this sense, the road bench actually is an effective sediment control structure (Figure 228).

Traffic may be interrupted until the debris can be removed, but the road bench itself is rarely lost.

Most cutbank failures do not have significant or long lasting impacts on water quality or downstream aquatic systems. The most important issue is what you do with the slide

FIGURE 228. Cut slope failure on a permanent forest road adjacent to a newly upgraded stream crossing. Almost all the slide debris from this failure ended up on the road bench, with only a small amount continuing downslope onto the rock armored stream crossing fill. Cut slope failures may block traffic but, unlike fill slope failures, most do not deliver sediment to a stream channel. The slide debris will have to be excavated and endhailed to a stable spoil disposal site.



material; sidecast it where it could enter a stream, or endhaul it to a safe disposal site.

Identification (fill slopes)—Road fill slopes should be inspected and any which have previously failed, slumped, have scarps or cracks, or show other overt signs of instability or potential instability should be inventoried and categorized. For cut-and-fill and sidecast constructed roads, the signs of potential failure are usually visible on the outside half of the road, in the fill portion of the roadbed. Things to look for include road-parallel scarps showing minor vertical displacement, cracks, or leaning/bowed trees on the fill slope. Scarps and cracks may be continuous or intermittent and may be arc-shaped in plan view, tailing out to the outer edge of the fill slope at both ends (Figure 229). They are sometimes visible and will retain their appearance on abandoned roads but are easily obscured by maintenance grading and road surface erosion.



FIGURE 229. Unstable fill and potential fill slope failure threatens to deliver sediment to the stream at the base of the slope. Part of the fill along the outside edge of this forest road developed cracks and small scarps, signaling instability. Fills can become unstable years after the road was constructed, as buried organic debris rots or pore water pressures change within the hillside. Unstable or potentially unstable fills that could fail and deliver sediment to a stream should be excavated (removed) or stabilized as soon as feasible.

Arcuate cracks and small scarps show up well and are always visible on paved and chip-sealed road surfaces.

Some road fill slopes show no overt signs of potential or pending instability and failure, but the character and location of the fill slopes makes them prime candidates for treatment. For example, road fill slopes perched on steep, wet slopes and in close proximity to a stream channel, especially a fish-bearing stream, are often inventoried and prescribed for treatment. This is especially true for “threatening” fill slopes found on roads that are to be permanently closed or decommissioned and will not be accessible for future treatment if scarps and cracks develop later. Such fills are often found on the approaches to crossings of incised stream channels where fill slope failures would almost certainly deliver sediment to the channel if and when they fail.

Treatments (fill slopes)—Not all the identified fill slopes will fail and not all are actually unstable (some may reflect simple settlement) but this inventory will provide a group of potential fill failures that warrant additional analysis. Once identified, the estimated failure potential, failure volume and travel path is reviewed and those with a relatively high failure potential, sufficient volume to deliver sediment to a stream, and a clear travel path to the water body may be prioritized for treatment. **On most cut and fill roads, potential fill slope failures are treated by direct excavation of the unstable or potentially unstable road fill (Figure 230).** This treatment is the simplest and least expensive method, and is usually suitable because enough of the roadbed will still remain to accommodate traffic. If the road is too narrow, the cutbank can be excavated to provide more road width, or an engineered fill can be reconstructed along the outside of the road where the unstable fill was removed.



FIGURE 230. *The most cost-effective treatment for unstable fills along the outside of a forest, ranch or rural road is simply the direct excavation of the unstable material. If road width is too narrow, additional width can often be derived from cutting into the bank. The excavation should encompass the unstable fill materials, beginning at the inside crack or scarp, and extending out and down the fill slope as far as possible. For proper surface drainage, and to retrieve most of the unstable fill, the excavation should have a concave profile when completed. Typically, the bulk of the fill is within 20 to 25 feet of the outside edge of the road and is easily reached by a midsized excavator. Any remaining fill is likely to be small enough that it will not fail or travel far enough to reach the stream.*

The spatial extent of the instability and the fill to be “treated” is typically defined by the most proximal (inside) cracks or scarps on the roadbed, laterally by the ends of the arcuate cracks and scarps that terminate on the outside edge of the outer road fill, and downslope by the length of the fill. The downslope extent is a function of the slope of the sidecast fill, but even on the steepest fill slopes most of the unstable fill volume is contained in the first 35 feet of the slope – about as far as a large excavator can reach from the roadbed.

b. Stream crossing threats

Identification—Most stream crossings on existing roads are in need of at least some storm-proofing treatments to improve their resiliency against failure. Stream crossings are known as the weak links in forest, ranch and rural road systems. They are the points along the road alignment that are subject to the greatest stresses during large storms and floods, and **they have weaknesses that make them susceptible to failure and potentially catastrophic physical and environmental damage** (Figure 231).



The weak points in stream crossings are catalogued by inventory and analysis. Some of these weaknesses include the following:

- Bridges or plate arch abutments are unprotected and/or they are subject to undermining and erosion during peak flow events.
- Bridges or plate arches are underdesigned for the 100-year peak flood flow. They may be overtopped or plugged by large floating organic debris.
- Plate arches (bottom-less arches) with lateral foundations and natural streambeds are subject to undermining and failure when channel downcutting occurs during flood events.
- Culverted stream crossings are undersized for the design flood flow; usually the 100-year peak discharge, including floating organic debris and sediment. Look for high rust lines (approximately $\geq 30\%$ of the culvert diameter) on steel culverts as a rough indicator of the pipe being undersized.
- Culverts are poorly aligned vertically or horizontally with the natural stream channel either at their outlet or, most importantly, at their inlet.
- Culverts are prone to plugging by floating woody debris or sediment, or both. They may already be partially plugged, or show physical

FIGURE 231. *This 48-inch diameter culverted stream crossing in a steep, cobble and boulder bedded channel is dramatically undersized for the 100-year flow. The coarse bedload material and floating woody debris increase the potential for culvert plugging and overtopping of this large fill. Culverted stream crossings are considered the weak points of a road system. Not only can things go wrong easily, but the impacts of stream crossing failures are usually felt far downstream.*

evidence of a history of past plugging and overtopping, such as depositional terraces or a delta of sediment upstream of the pipe inlet that formed during periods when streamflow was ponded at the culvert inlet. Examine the pipe diameter in relation to the active channel width (see Appendix A).

- Culverts are worn out, eroded through, leaking, separated and otherwise in need of replacement.
- Culvert inlets are damaged; including crushed or ripped inlets that reduce flow capacity and increase plugging potential.
- Culvert inlets are threatened by slope failure from one or both sides of the channel.
- Culverted stream crossings have a diversion potential; that is, if the culvert plugs and flood flow reaches the road surface it will be diverted down the road and to another stream or hillslope.
- Stream crossings are historically subject to debris flows and torrents of sediment and debris, and crossing designs are not resistant to that process.
- Culverted fills are deep and volumetrically large; representing a significant threat to downstream areas if and when they fail and wash out.
- Armored fills and fords do not have sufficient capacity or protection against flood flows and are likely to fail and require rebuilding after a design flood event. By their nature, the environmental consequences of these failures are usually much less than for culverted stream crossings elsewhere on the hillside.
- The stream crossing, regardless of what type, does not provide for passage for all life stages of migratory fish.

Bridge failures are much less frequent than culvert failures and are not likely to cause such significant environmental consequences. The greatest consequence is often to the transportation system and the inconvenience and inability to access areas once provided by the bridge route. Sometimes, bridges provide the only access to parts of the road system that will also need to be inspected and maintained, so loss of the bridge makes maintenance much more difficult or impossible.

Treatments—Stream crossings, while susceptible to a variety of failure mechanisms, can usually be made much more resilient to failure and able to withstand design storm events (Figures 232a and 232b). When and if they do fail, the magnitude of the failure and its environmental consequences can be made much less severe. The weaknesses listed above can all be addressed and lessened in some manner. Some treatments are fairly effective and relatively inexpensive, while others are likely to require more financial investment.

Without installing a new bridge, bridge treatments are typically limited to adding armor protection to eroding or threatened abutments, or perhaps widening the channel beneath the bridge by removing and replacing the channel-constricting riprap with a poured concrete or engineered abutment that is vertical and thereby adds to flood flow channel width. If the bridge does not provide sufficient clearance for flood flows, it will have to be raised, re-engineered or moved to increase its capacity.

Bottomless arch stream crossings have lateral foundations and a natural stream bottom. If the arch significantly constricts the channel through the crossing, this will cause increased flow velocities and flow depths, thereby triggering channel downcutting. Foundations that may be or are being compromised by flood flow undercutting and degradation of the channel bed will have to be extended vertically into the streambed, below

FIGURE 232A.

This 48-inch diameter culvert is significantly undersized for the design flow event. The culvert inlet has plugged during past storm events and flood flows were diverted down the road, creating a large hillslope gully.

**FIGURE 232B.**

The stream crossing was upgraded with an 84-inch diameter culvert, the inlet area was armored, and a critical dip was installed on the left hingeline of the fill to prevent future stream diversion if the culvert was to plug.



the potential limit of scour. This is a dry season work project and mid-winter maintenance or emergency repairs are probably limited to adding protection with rock armor. The alternative repair would be to redesign the crossing with a bridge or install a new arch that is sufficiently wide to allow flood flows without constriction (Figure 233).

Fords, especially hardened fords, that suffer from inadequate flood flow capacity, constricted flood

flows or insufficient downstream energy dissipation should be retrofitted or rebuilt (Figure 234). Often times, riprap protection or extension of the concrete apron can be used to provide protection against downstream scour. The consequence of failure of a ford is usually less of an environmental concern and more about loss of access.

Culverted stream crossings have a host of upgrades that can often be applied to



FIGURE 233. View looking upstream through the inlet of a newly installed bottomless arch. The stable boulder bed of this stream ensures the foundations will not be undermined by channel downcutting. For flow capacity, and to prevent plugging with debris, the basal span of the arch has been built wider than the natural channel.



FIGURE 234. This hardened (concrete) ford failed by undercutting due to the lack of energy dissipation on the downstream side of the structure. Unfortunately, when the ford was "repaired" they simply replaced the failed concrete section and dumped gravel to fill the scour hole that had formed, ensuring that it would fail again. Drainage structure failures always have to be analyzed and the cause of the failure addressed in the redesign. Here, only the symptoms of the problem were treated.

lessen their risk of failure during storms and flood events. These are aimed at addressing the weak points listed above, and have been described in detail in Chapter 4 (Design) and [Figure 204](#). Briefly, they include:

- Upgrading culvert size upgrading for the 100-year flood flow, including sediment and debris.
- Improved culvert alignment to reduce plugging potential.
- Reducing plug potential by increasing culvert capacity and trapping floating debris.
- Adding an emergency overflow culvert as a backup to the main culvert.
- Dipping the stream crossing fill, to reduce its erodible volume and prevent diversion.
- Adding a critical dip to prevent stream diversion.
- Adding an overflow culvert on steep roads to prevent stream diversion where a dip cannot be built.
- Hardening stream crossings that are subject to debris flows.

Finally, **for stream crossings of channels that support or could support migratory fish populations, you will need to accommodate fish passage into the design or redesign of any newly installed or reconstructed stream crossing structure.** These requirements often call for an engineered design that recognizes and accommodates the abilities of each species and each life stage to move through the channel at various critical streamflows and you will probably need to consult with a qualified and experienced hydraulic engineer specializing in fish passage to help you with a proper design.

c. Road drainage threats

Identification—Road surface drainage affects roads and adjacent slopes and streams in several ways. The threats to the stream and aquatic ecosystem are mostly chronic and persistent, but some episodic erosion processes can also be triggered by errant or large discharges of road surface runoff.

Road drainage discharged onto hillslopes can lead to gullying and slope failures that impact downslope and downstream areas. This is most common where long lengths of road surfaces and ditches are drained to widely spaced discharge points (usually ditch relief culverts) ([Figures 178 and 202](#)). Peak flows during flood events or even local downbursts can be significant and create large gullies or trigger debris landslides on steep slopes.

Road surface drainage itself can cause erosion along the road. **Road ruts, road surface rills and eroding ditches are symptoms of excessive road runoff that is not being dispersed and directed off the roadbed.** Eroding fill slopes are often caused by the discharge of too much road runoff onto erodible, unprotected soils, even if that runoff never reaches a stream. These road surfaces and ditches are often well connected to the stream system and discharge runoff and eroded fine sediment to streams during most runoff events.

Inventories can help determine the location and potential magnitude of this threat. The amount of fine sediment and turbidity discharged to streams depends on the rainfall volume and intensity, the erodibility of the road and ditch, and the level of traffic that uses the road. High traffic levels, especially commercial truck traffic, rapidly wears down the road surface and produces fine sediment that is washed away and into streams during runoff events ([Figure 235](#)).

When conducting an inventory and assessment of road drainage and its impacts you should look at the current road surface, road fill slopes, and areas downslope from road drainage points (e.g.,



FIGURE 235. This road surface has worn down over years of use, grading and erosion to the point that a formerly buried ditch relief culvert has been exposed in the roadbed. When installed, the culvert was probably 2 or 3 feet below the road surface. Both gravel surfaced and unsurfaced (native) roads wear down over time, due to traffic and erosion. It is often not noticeable until the gravel is gone, the road becomes entrenched (through cut) or the top of cross drain culverts become exposed.



FIGURE 236. For large landowners, maintenance tasks can be identified on a data form, and staked on the ground by inventory crews. This small stream crossing needs a critical dip to prevent future stream diversion, and the inlet needs cleaning; tasks to be completed by maintenance crews or contractors.

road dips, rolling dips, ditch relief culverts, etc.). Excessive erosion is identified for future treatment and dispersal (Figure 236). The inventory should also include a measurement of the length of inside ditches and the area of road surfaces that currently drain directly to stream crossing culvert inlets or to road drainage structures (mostly ditch relief culverts and rolling dips) that drain to streams.

Treatments—Ideally, surface runoff is supposed to leave the road as rapidly as possible so that it does not infiltrate and degrade road strength or erode surfacing materials. It should be discharged to the ditch or off the outside edge of the road as quickly as possible, and only at points where the discharge will not trigger or increase slope instability or erosion, or be delivered to a stream.

As described in Chapter 4, **road surface runoff is dispersed by road surface shaping (mostly outsloping), the addition of rolling dips and waterbars on the road surface, and the addition of ditch relief culverts.** These measures are the primary tools used for dispersing road surface runoff so the roadbed is not damaged, the fill slope shows only minor erosion, and there are no gullies or slope failures below the points of discharge that lead to streams. Road use limitations can be employed on seasonal roads to restrict vehicle use and prevent road damage and rutting during the wet season or during wet weather conditions (Figure 237). The road surface can be hardened with additional road rock, but that does not treat the cause of the problem—too much concentrated runoff. **If significant erosion still occurs at any of these road sites (road surfaces, ditches, fill slopes, or downslope hillsides) then additional flow reduction and dispersion treatments are probably needed.** It's that simple.

Hydrologic connectivity can be significantly reduced, but rarely completely eliminated on roads that contain stream

crossings. There will almost always be a short stretch on one or both the road approaches to crossings that discharge road runoff to the stream. To disconnect or decouple road runoff from the stream system requires you to strategically locate road surface and ditch drains near each crossing. You will need to use a short enough spacing of each discharge point so that no single drainage structure carries enough flow during a design runoff event to cause sediment delivery to a stream. **Thus, the closer the road gets to a stream channel, the more frequent and closely spaced the drainage structures will need to be.**

There is no formula for the spacing required to hydrologically disconnect roads from streams because slopes vary, infiltration rates in the receiving areas vary and distances to each part of the active channel vary. As the road approaches a stream you should pick discharge points that look to have the capability to receive and infiltrate runoff from the road without discharging to the live stream. These might include gentle slopes, benches, terraces and even floodplain areas that are only occupied during large floods.

In some cases you might choose to install settling basins alongside the road or in the ditch to retain and settle storm runoff and fine sediment before it is discharged to the stream (Figure 238). In other cases, you could employ perforated flex pipe attached to the outlet of ditch relief culverts to spread out and disperse culvert outflows along a narrow zone between the road the stream. Both these and some other methods can be highly effective but they add to road maintenance requirements and costs.

C. MAINTENANCE INSPECTIONS AND MAINTENANCE SCHEDULES

Road surfaces and drainage structures along all roads should be inspected annually, at



FIGURE 237. Roadbed structural deterioration caused by vehicle traffic (especially commercial traffic) on wet subgrade soils with little or no surfacing. Wet weather road use limitations (gating) or road surfacing (with base and surfacing materials) are preventive solutions to this potentially expensive maintenance problem.



FIGURE 238. Traffic and surface runoff from graveled roads often produces surface erosion, turbid runoff and fine sediment transport that can be delivered to streams. Where ditches can't be eliminated, sediment traps and roadside settling basins can be installed to capture and remove most of the eroded sediment. This settling basin has been constructed along the inside ditch just before a stream crossing culvert inlet (see arrow). Eroded sediment from the road and ditch are deposited in the basin before flow is released to the stream. Fine sediments have filled about 1/3 of this basin and vegetation is now growing. Sediment basins require periodic maintenance to maintain their storage capacity.

a minimum, prior to the beginning of the rainy season. Large landowners sometimes break their holdings up into smaller parts and perform inspections on the most-at-risk roads and structures first and the lower priority roads and sites second.

Inspections are designed to focus on high risk sites and road segments; ones that have shown to be problematic in the past, but also identifying any symptoms of problematic roads or sites. The weakest links in forest, ranch and rural road systems are usually stream crossings, and these warrant close inspection. Inspections should cover culvert inlets and outlets on stream crossings, fill slopes on steep hillsides and near stream crossings, ditch relief culverts near streams, and road surface drainage features such as waterbars, rolling dips and ditches. Most of the major, threatening problems are likely to be found at stream crossings and on roads built across steep hillsides near streams and rivers.

Over time, each existing drainage structure or problematic maintenance site within an ownership should be inventoried and placed on a master list for quick reference. For annual inspections this can now be accomplished using GPS coordinates and a portable database to identify locations, site conditions, and maintenance needs. During the annual inspection, people can take this information into the field and note current conditions and any maintenance requirements that should be addressed before the next wet season.

In addition to annual, pre-winter road and drainage structure inspections, crews are needed to inspect and perform emergency inspections and maintenance during and following moderate to large size storms and floods. Shovel work at a culvert inlet that is beginning to plug can save the expenditure of thousands of dollars needed to rebuild an entire stream crossing after it has washed-out. Although usually delayed until after the storm

event, fill slopes showing signs of active movement and displacement can be excavated before they fail and deliver sediment to a stream channel.

Some drainage structures are more prone to problems than others. For example, culverts on streams with heavy sediment loads or floating woody debris may be more likely to plug. Landowners or land managers frequently know which culverts in their road system have had the most problems, and which are most likely to plug during a winter storm. In contrast, many culverts, ditches and road surfaces almost never have erosion problems, no matter how severe the winter storm. These may be lower on the priority list to inspect during storm events.

This background information can be used to develop a rating system and storm inspection plan for drainage structures in a watershed. Culverts can be coded by signs along the road. These signs note 1) where the culvert is located (road name and milepost), 2) the diameter of the culvert, and 3) a number or color coding (e.g., red, yellow and green) that signifies how likely the culvert is to plug, and, therefore, its relative need for inspection during winter storms (**Figure 239**).

The number or color coded rating system is based on past maintenance experience with that culvert, and is used in the field to alert inspection crews to which culverts should be inspected first during and following winter storms and floods. **Culvert coding schemes are especially useful for large landholdings or companies with many miles of road who may rely on employees unfamiliar with the road system to perform inspections and field maintenance.**

Storm period inspections are aided by the physical signage in the field, and a map showing where the high priority sites are likely to be located. Culvert marking is also useful to grader operators, so they can avoid damaging culvert inlets when grading the road or ditch.



FIGURE 239. *Culvert signing is an integral part of developing a culvert and drainage structure inspection and maintenance plan. Included at this crossing are the stream name (Puter Creek), the name of the road (5000 Road), the diameter of the culvert (84") and its location (0.6 miles from the beginning of the road). The signing can also be color coded (e.g., green, yellow, red) to indicate whether or not it is prone to plugging or other maintenance needs.*

D. MAINTAINING PERMANENT ROADS

Road maintenance should address the road surface, cutbanks, and fill slopes, as well as drainage structures and erosion control measures. A poorly maintained road surface will channel water, reduce road life and increase erosion and sediment pollution to streams. It may also be difficult or hazardous to drive on and damage vehicles and equipment. Every permanent or all-season road should be adequately rock surfaced (or paved) to allow for expected traffic types and intensities without damaging the road.

Proper and protective road management is key to minimizing road damage and minimizing a road's impact on water quality. Thus, the first rule of maintaining a stable road surface is to minimize commercial traffic, hauling, and grading during wet weather conditions that would otherwise degrade it, especially if the road is unsurfaced. But even the best surface can be severely damaged by overuse during wet or thawing ground conditions. Be aware of early signs of road damage. Serious damage to road structure and road surfaces begins with loss of road drainage and excess water standing on the surface (Figure 240). Ruts and mud indicate that road strength is deteriorating (Figure 237). For commercial



FIGURE 240. *Slightly through cut, flat road exhibiting poor road drainage. Flat roads, with no gradient along or across the road, do not drain effectively and will develop potholes and mud puddles from continued traffic. Vehicles passing through standing water splashes the water and fine sediment from each hole or depression, gradually enlarging their size and depth. The through cut on this road developed by annual maintenance grading and the consequent gradual lowering of the road surface. Poor surface drainage will not improve until the road is raised and crowned, or paved.*

forest and ranch lands, shutting down for several days can save thousands of dollars in road repairs and prevent unnecessary erosion and sedimentation. For rural roads accessing homes, maintenance will have to be performed either during wet weather when problems arise, or as soon as conditions dry sufficiently to work on the sites.

Similarly, commercial hauling on a dry roadbed in the summer can churn and pulverize road surface material and create thick, loose layers of soil and rock powder (dust). These fine grained, loose materials can then erode and flow into streams with the first fall runoff. Summer hauling

should be accompanied by dust control and watering to maintain a stable and hard road surface condition (Figure 241). Some dust abatement products can be pollutants, so caution should be used in their application near streams and drainages or where ditch flow leads to a watercourse. Check with local regulatory agency personnel to see which products are preferred.

Road surfaces should be graded only when needed to maintain a stable, smooth running surface and to retain the original surface drainage (Figure 242). Over-grading results in unnecessary erosion and increases road surface

FIGURE 241. Water trucks can be used to apply water needed for compaction or dust control at project sites or along high traffic routes, or for applying a dust palliative (e.g., MgCl) for longer term dust control.



FIGURE 242. Grading a road to make a smooth running surface is beneficial for traffic, but it may also be treating the symptom of the problem rather than the cause of road roughness. Grading should have the dual purpose of 1) providing for a smooth running surface and 2) maintaining or improving road surface drainage. Grading for drainage will lower maintenance costs, as grading won't be needed as frequently. Grading only to produce a smooth road surface is a recipe for developing the exact same road problems that caused you to call for a grader.



rock wear. Steep road sections will quickly lose their running surface with frequent grading, so **raise the blade wherever grading is not needed!** In addition, grading should only occur when the materials are slightly damp. Road surfaces graded when they are too dry will not compact and will generate dust and subsequent erosion. Unplanned berms created by grading can concentrate runoff during winter rains and should not be left along the outside edge of the road.

Maintenance grading should cut deeply into the road surface, especially if there are potholes, washboarding, or exposed base materials, so loose material on the surface will mix, compact and bind with underlying materials. If deep potholes or ruts cannot be graded out, the surface should be ripped and then graded and compacted to achieve proper binding. Otherwise, individual holes and ruts that are patched will quickly reform in the same locations.

Over years of residential and/or commercial use and maintenance grading, road surfacing materials gradually break down or are inadvertently moved off to the side of the road. Steep sections of road and curves experience the highest rates of wear (Figure 243). Often after the road surfacing has worn down, larger rock fragments are left jutting out of the roadbed, and fine materials have been washed or blown away. This makes for a rough ride, and can significantly decrease traffic speeds and increase commercial hauling times. When this occurs, it is time for the road to be resurfaced or restored. The roadbed should be ripped and new loads of properly graded rock aggregate spread, mixed, and compacted into the existing materials (Figure 244). If past grading has piled good surfacing materials along the outside edge of the road, it can be retrieved and worked back into the roadbed.

Where inside ditches are used, ditch maintenance is important in order to clear blockages



FIGURE 243. Steep road section where the road surfacing has broken down and moved off the road (maybe into a nearby stream), leaving behind the coarse base materials sticking up through the surface and making for slow traffic and a rough ride. This road needs scarification and the application of a new layer of road surfacing materials.



FIGURE 244. Well graded, pit-run rock from a nearby quarry is used to resurface a road that had deteriorated after years of forest traffic. The roadbed was first scarified, rolling dips were constructed, and then layers of road rock were compacted onto the surface. An inside ditch was retained but the roadbed was outsloped to shed water to the outside while keeping ditch flow clean.

and maintain the flow capacity required to quickly remove surface runoff (Figure 245). Inspecting ditches during periods of high runoff will tell you which ditches need grading to improve their capacity, and which ditches are carrying too much water. When cleaning a ditch (mechanically grading and removing fine sediments) avoid bringing fine silts and clays across or into the surface rock of the road. This unfortunately common practice creates muddy surface conditions and potential for sediment pollution in streams during the next heavy rains. Ditch spoil can be endhauled to a disposal site by loader, backhoe and/or truck. Often, nothing more than shovel work at problem spots is required to solve ditch drainage problems.

In general, ditches should not be carrying large volumes of runoff. If they are, it probably means that additional ditch relief culverts or ditch drainage structures are needed to lessen flow volumes and

further disperse surface runoff. Additional ditch relief culverts can be installed to drain ditches that show signs of erosion or down-cutting or where the culvert discharges onto the native hillside below the road (Figures 246a and 246b). Where sections of ditch cannot be drained, such as within a through-cut road reach, rock armor can be installed.

Where ditches are still hydrologically connected to streams it is important to keep soil disturbance to a minimum and to actually encourage deposition in ditches. Connected road ditches should be viewed as elongate sediment filtering and trapping devices (like a sediment retention device or structure) so that mostly clear water reaches the receiving stream channels (Figure 247). When hydrologically connected ditches need to be graded or cleared to maintain capacity, they should be immediately seeded to reestablish a vegetation cover.



FIGURE 245. *Over time, the ditch on this insloped road has filled with sediment. Road surface runoff now runs out of the ditch and onto the road surface, causing saturation and weakening of the road's structural section. Maintenance grading or excavation is needed to reestablish and deepen the ditch, thereby removing water from the road surface, draining moisture from the road base and surface materials, and re-strengthening the roadbed.*



FIGURE 246A. Scoured roadside ditch carried runoff from the adjacent hillslope and from long lengths of the insloped road. The ditch gullied down to hard bedrock and discharged its runoff and eroded sediment to a stream just down the road.



FIGURE 246B. The road was upgraded by crowning and additional ditch relief culverts were installed to disperse ditch flow. The pasture was also fenced to keep cattle off the erodible sideslopes.



FIGURE 247. Vegetated ditch is used to trap sediment eroded from the surface of the rural road. Although the road is in need of resurfacing, and surface erosion rates of the exposed subgrade are relatively high, the vegetated ditch acts to filter out the fine sediment before it is discharged to a stream. Typically, good road surfacing and vegetated ditches act jointly to protect water quality on insloped road sections.

Frequent, routine mechanical grading of ditches is usually unnecessary and can cause erosion of the ditch, undermine cutbanks, and expose the toe of the cut slope to erosion. Ditches should be graded only when and where necessary, since it has been shown to greatly increase sediment yields. If cutbank slumps have blocked the ditch, clear out the material and move it to a stable storage site. Remove other sediment or restrictive brush and weeds from the ditch only if they create obvious drainage problems that affect the road surface. Do not remove more grass and weeds than is necessary to keep water moving. Vegetation prevents scour and filters out sediment. **If the ditch is not a problem, don't "fix" it. Routine mechanical ditch grading should be avoided.**

E. MAINTAINING SEASONAL ROADS

Unsurfaced seasonal roads require almost the same maintenance effort as permanent roads, but are much more sensitive to wet weather use. These roads should not be used when wet, and hauling or other intensive vehicle activity should be limited to dry periods when soils retain their maximum natural strength. Road surface grading to maintain trafficability and proper drainage may be required after each period of intensive commercial use and prior to each rainy season. Dust control and watering during dry summer conditions is almost always necessary during intensive, dry season use to prevent excessive loss of surface materials (Figure 248a).

Seasonal, unsurfaced roads can be badly damaged by even occasional use during wet periods when the roadbed is soft (Figure

FIGURE 248 A & B. Excessive road dust during the summer (248a) and excessive mud during the winter (248b) are conditions which directly threaten water quality and result in high road maintenance costs. Both conditions produce and deliver large quantities of fine sediment to nearby streams during periods of surface runoff. This fine material can be especially damaging to fish and fish habitat.



248b). Damage to road surfaces can occur almost as easily by a pickup as by a log truck. Traffic control (temporary or seasonal road closures) can be an effective method to protect the road surface, minimize erosion problems and reduce road maintenance costs (Figures 249a and 249b). However, **the use of gates or other barriers does not eliminate the need for annual and emergency winter maintenance inspection and repairs.**

In many cases, traffic control may require physically blocking the road. Gates are most often used for this because they provide temporary

closure while still allowing access for emergency inspections and maintenance of drainage structures by authorized personnel. Gates should be strong and well anchored to prevent removal by vandals. More permanent alternatives to gates include large berms, ditches (tank traps), logs, stumps or boulders and physical outcropping. These barriers make it very difficult to access and inspect the rest of the road for maintenance needs, and their use should be limited to spur roads with no stream crossings, roads which do not cross or come close to stream channels and roads which have been “permanently” closed.



FIGURE 249A. *There are a variety of ways to close a road to off-season traffic, but it should always be remembered that barricading the road does not by itself prevent erosion along the alignment. Gating closes the road to unauthorized traffic but still allows for winter maintenance and inspections.*



FIGURE 249B. *If barricades or physical barriers are used, they must be removed with heavy equipment before maintenance activities can be performed. They should not be used on roads which have stream crossings since these need to be inspected and maintained during and following storms.*

F. STREAM CROSSING MAINTENANCE

Summer culvert inspections and maintenance is often performed at the same time as ditch maintenance. Stream crossing culverts also need to be inspected and cleared during and immediately following significant storm and flood events to prevent plugging and consequent stream crossing failure. Problems found during storm event inspections should be corrected immediately, because delay can result in road damage requiring costly road repairs. The critical

component of successful culvert maintenance is to fix problems before complete failure occurs.

During the dry season, hand labor, shovel and chain saw work can take care of most culvert maintenance needs. Floatable debris should be removed from the culvert inlet and from the channel immediately upstream from the culvert. Debris which has been screened or hung up in the debris barrier should be removed and placed where it cannot reenter the watercourse (Figures 250 and 251). Sediment deposits or large rocks at the culvert

FIGURE 250. *Most culvert maintenance involves cleaning the inlet of sediment or woody debris. This poorly designed trash rack, built over the culvert inlet, was nearly plugged during a normal winter storm. Without storm maintenance inspections such minor culvert plugging often ends up causing severe gully erosion when the stream-flow is diverted out of its channel, or it flows over the road and erodes the stream crossing fill.*



FIGURE 251. *This single post trash rack accumulated woody debris and sediment during a large flood event, but the culvert inlet remained open and at full capacity. Inspecting culverts, and cleaning trash barriers and culvert inlets, are important storm-period maintenance tasks that are usually conducted during or immediately after a significant runoff event. Trash racks require regular and storm-period maintenance to remain effective.*



inlet which block flow or threaten to plug the culvert may need to be moved or removed.

Culvert ends (inlets or outlets) that have been bent, ripped or damaged during grading, by backhoe cleaning or by falling trees or branches, should be straightened and re-opened (this can often be accomplished with a car/truck jack for small pipes). Outlets that are experiencing erosion should be armored or fitted with a downspout if the erosion threatens to undercut or compromise the fill, and culverts that show signs of overtopping may need a larger pipe, or a second, overflow pipe installed higher in the fill.

Bridges, arches and fords may also require maintenance. Permanent fords that show channel widening or undercutting of the ford structure may need additional rock armor or widening of the armored area. Except for emergency repairs, equipment should avoid operating in the flowing water of a ford, and re-armoring may have to wait until low flow conditions, or at least until peak flows subside.

In contrast, riprap and other bridge and arch abutment protection should be repaired as soon as damage is noticed to prevent loss of foundations and abutments. Floating trees, logs and other debris that becomes lodged in the bridge structure or against the inlet of the arch should be cut free and removed or floated downstream. When cleaning bridge decks, soil and debris should be scraped to the adjacent road or hauled off. Material should not be dumped, scraped or washed into the stream. This is especially important during low flow conditions in the summer or fall dry period.

All road surface and ditch grading should take material away from the bridge, and loose spoil should be kept away from the stream. If the approaches are persistently muddy during wet conditions, and cause trucks to bring dirt onto the bridge decking, then the approaches should be rock surfaced or paved.

G. MAINTAINING CUTS AND FILLS

The key to maintaining cut and fill slopes, including sidecast materials, is to observe and note when and how changes to these features occur. Corrective measures can then be implemented, depending on the problem (see Chapter 7, Section B(2)(a) (Road related instabilities)).

Typical cut slope problems include excessive raveling, rilling, and slumping which may block the ditch or require frequent ditch cleaning and maintenance (Figure 252). In the long term, it may be necessary to flatten the cut slope, revegetate bare soil areas, widen the ditch (so that it does not plug as easily), install ravel barriers on the slope and at the base, and/or build a retaining structure to contain or prevent slope movement (Figure 253). Often, simply loading the toe of a small cutbank slump with heavy riprap can provide sufficient mass to stabilize the feature. Stabilizing or controlling the movement of larger unstable features may require analysis by a qualified geologist, engineering geologist or geotechnical engineer.

Instability in fill slopes and sidecast materials often shows up on the surface or along the outside edge of the road as tension cracks and small scarps along the boundary between the roadbed's stable cut on the inside half of the road and the unstable fill materials on the outer half. The outside perimeter of landings built using sidecast construction methods commonly shows such developing instabilities. Some settling of newly placed sidecast can be expected, but if movement persists and scarps continue to develop, the unstable materials should be excavated and removed, including organic debris, before they fail. If the potential instability is perched above a stream channel, immediate treatment is usually required.

Regular inspection and prevention (including excavation) is the key to maintaining stable

fill slopes and sidecast areas. Local slides and slumps in the roadbed often occur where material was placed or pushed over groundwater springs or seeps, where the road crosses steep swales, or where rotting roots, stumps or organic debris were buried, sometimes many years before. These areas should be closely monitored and require fast action if cracks or scarps develop or enlarge. Improved drainage (e.g., extra ditches), excavation of unsuitable soils or buried materials, or retaining walls may be needed. Left untreated, these unstable features can fail suddenly and develop into debris flows

and landslides that deliver large amounts of sediment directly to downslope stream channels. Unstable fill slopes that do not threaten to deliver sediment to streams may receive a lower priority for treatment and stabilization.

H. “WINTERIZING” ROADS

Before winter or the wet season, all permanent, seasonal and temporary roads should be inspected and prepared for the coming rains. Winterizing consists of maintenance and erosion control work needed to

FIGURE 252. *This nicely outsloped road was originally (and unnecessarily) constructed with an inside ditch. High ravel rates from the rocky cutbank quickly filled the ditch and plugged the inlet of the low gradient ditch relief culvert. The culvert carried very little runoff from the dry slope and caused only minor gullying of the fill slope, but numerous attempts to open the inlet, or grade the ditch, ripped the metal inlet (see arrow). The road would have been better constructed as outsloped with no inside ditch (Mary Scurlock).*



FIGURE 253. *An armor ravel barrier or rock buttress has been constructed to keep the inside ditch open at the base of a wet cutbank slump. The steep gradient road has also been insloped to drain road runoff to the ditch where it is culverted onto a stable slope just down the road.*





drain the road surface, to ensure free flowing ditches and drains, and to open all culverts to their maximum capacity. On unsurfaced roads, waterbars may be required at spacings dictated by the road gradient and the erodibility of the soil, as well as the proximity of the drainage structure to a stream (Table 3). Trash barriers, culvert inlet basins and pipe inlets should all be cleaned of floatable debris and sediment accumulations. Ditches that are partially or entirely plugged with soil and debris should be cleaned and heavy concentrations of vegetation which impede ditch flow should be trimmed. This is also the best time to excavate all unstable or potentially unstable road fills and sidecast which could fail and be delivered to a watercourse during the coming wet season. All bare soil areas which were disturbed by maintenance work or other activities should be seeded and mulched with straw. Once seasonal and temporary roads have been winterized, they should be gated and closed to “non-essential” traffic.

I. SPOIL DISPOSAL

If excavations, grading, debris removal or culvert basin cleaning and maintenance produces excess material, it should be stored locally or hauled away where it cannot enter a watercourse. Spoil, if it is suitable, may be feathered over temporary and unsurfaced seasonal roads, but on permanent roads excess fine material may produce unwanted muddy conditions and sediment pollution after the first rain. Spoil materials should be hauled to a stable disposal site safely distant from streams, contoured to disperse runoff and stabilized with mulch and vegetation. Excess spoil from maintenance activities should never be sidecast near streams or where it could fail, or cause a slope failure, and deliver sediment to a water body. Berms of excess spoil along the road shoulder should be removed or frequently breached prior to the rainy season.



8 CLOSURE AND DECOMMISSIONING

A. INTRODUCTION TO ROAD CLOSURE AND DECOMMISSIONING

There are many reasons for closing or proactively “abandoning” a forest or ranch road,¹ most of which involve excessive maintenance costs, lack of continued need or continuing water quality problems (Table 36). Not all roads need to be part of the permanent or seasonal road system. For example, temporary roads are used once, and then “put-to-bed” until they are needed again. In addition to newly built temporary roads, there are many miles of existing roads that may no longer be needed, and older abandoned roads that are now overgrown and are not planned for reuse. The same techniques can be used to stabilize these older roads, to prevent future erosion and sediment delivery to streams and other waters, and, as an added benefit or incentive, save the work and expense of continued maintenance.

¹ California Forest Practice Rules (Appendix C) officially refers to “road abandonment” as the method of proactive road closure and stabilization for private forest lands in California. The treatments are more commonly known as road closure or road decommissioning. There are a number of different terms used to describe the process of permanently or temporarily closing roads so as to minimize their erosion potential and threat to the watershed and its streams. Regardless of the name that is used, the treatments that are applied to prevent and control future erosion and sediment delivery from these “closed” routes are largely the same and are described in this chapter.

Roads can be classified in a number of useful ways. In Chapter 2 (Planning), active roads were classified as permanent, seasonal or temporary. This denotes road standard and size, as well as the likely period of use. Roads can also be classified into four activity classes: active, inactive, closed (decommissioned) and abandoned (legacy).

Active roads (permanent, seasonal and temporary) are part of the overall road network that must be actively inspected and maintained. These inspection and maintenance methods have already been described in Chapter 7.

Inactive roads (including “stored roads”) are those roads needed only infrequently, for fire control, tree thinning, recreation or other

TABLE 36. Conditions commonly leading to road closure

1. Roads constructed for temporary access (designated temporary roads).
2. Spur roads which are no longer needed for management for the next few years or for many years (e.g., all timber has been cut).
3. Roads with excessively high maintenance costs.
4. Roads which have persistent erosion and water quality problems, often located in areas of extremely erodible soils.
5. Roads crossing extremely steep slopes or inner gorge locations where landsliding risk is high and sediment could enter the stream channels.
6. Roads crossing slopes with high or extreme landslide risk or on-going landslide activity caused by incompetent bedrock or unstable soils.
7. Roads exhibiting potential for large fill slope or cutbank failures, often showing tension cracks and scarps in the roadbed.
8. Roads built with excessive sidecast of fill in unstable locations or perched above stream channels.
9. Old roads built in, along, or immediately adjacent stream channels or up narrow stream channel valleys.
10. Old, abandoned roads which have overgrown with vegetation and now have washed-out stream crossings and/or fill failures.

forest or ranch management activities. These roads remain largely unused for most of the year, or for a number of years in succession. There is a tendency to not maintain these routes because they are not often used, have low traffic volumes, and may only be used intermittently for administrative purposes. **However, all drainage structures on inactive roads must still be inspected and maintained because they are just as likely (or more likely) to plug and fail as those on more actively traveled routes.**

Closed or decommissioned roads were originally constructed as active roads, but have since been proactively closed to traffic and treated to reduce their potential environmental impact. These roads were “put-to-bed” or “vacated” with stream crossing drainage structures and fills being excavated and removed, road and landing surfaces permanently drained, and unstable fill slopes stabilized or removed (excavated).

Abandoned roads (sometimes called legacy, ghost or orphan roads) were at one time a part of the active road network, but are no longer used. They are found most commonly on forest

and ranch lands and may constitute 15% to 25% of the overall road network that was historically constructed in a managed watershed. They may have been abandoned for a few years or for decades. Instead of being decommissioned or proactively closed, they were left to naturally “stabilize” and revegetate. Many are now overgrown and may show past, ongoing or future erosional problems or threats.

Because of their age and low standard of construction, and where they may have been built, old abandoned roads can still pose a significant environment threat to a watershed and its streams. **Just because a road has been abandoned and may be overgrown does not mean it is no longer a threat to the watershed (Figures 254a and 254b). Some failures may have already occurred along an abandoned or legacy road, but others are often still waiting to happen years or decades later when culverts finally plug or unstable fill slopes fail (Figure 255).**

There are thousands of miles of these abandoned or orphan roads both on private forest

and ranch lands and on public forest and range lands. They have received increased attention in recent years because of the threat they often represent to water quality and downstream aquatic habitat. These unused orphan or legacy roads may have been abandoned because they were no longer needed, or because they cross unstable areas, required excessive

maintenance or caused persistent environmental damage. **Only a sound, detailed field assessment can differentiate between those legacy roads that pose little or no threat to a watershed, from those that could severely impact downstream water quality and aquatic habitat when they fail.**



FIGURE 254A-B. Abandoned, unmaintained roads, whether in forested watersheds (254a) or in rural and ranchland areas (254b), represent a potential threat to streams and water quality.



FIGURE 255.

Gully formed by culvert plugging and stream diversion on an old, unmaintained forest road. The degree of threat posed by old roads depends on the terrain the road crosses. Typically, the most serious threats occur where roads cross stream channels and steep, wet and/or unstable hillslopes.



Many orphan roads have drainage structures, including stream crossings, which are in disrepair and are no longer being inspected or maintained. Some of the most vulnerable sites may have already failed, but others are likely to fail in the future (Figure 256). These abandoned, legacy roads often represent

a significant threat of non-point source pollution from roaded, managed wildland watersheds, especially when they occur in steep mountainous areas with heavy rainfall and unstable terrain. Landowners and resource managers should continue to work aggressively to inventory and

FIGURE 256.

Unmaintained, culverted stream crossings, like this one, will eventually plug and either wash out or divert streamflow down the road. Most abandoned roads have drainage structures that are very undersized and often rusted through. Damage from the diversion of even small streams can cause large gullies or debris slides when released on steep, erodible slopes.



proactively treat these potential sources of erosion and sedimentation. Good progress has been made over the last 20 years to identify legacy roads in the field, to prioritize them for permanent closure and to begin their treatment.

Good land stewardship requires that all roads, regardless of how frequently they are used and whether or not they are officially designated or recognized as part of the drivable road network, be regularly inspected and treated to protect water quality. Inactive and temporary roads that contain culverted stream crossings or other drainage structures *require* inspection and maintenance, and they should not be

abandoned without first employing proper road closure techniques (Figure 257).

Any road that is not regularly inspected and maintained should be formally closed (decommissioned) and proactively treated so they will not have the potential to significantly impact streams, water quality or downstream aquatic ecology. Roads should never be abandoned by simply blocking them off or letting vegetation take over without first decommissioning stream crossings and performing proactive erosion control and erosion prevention work along the road alignment (Figure 258).



FIGURE 257. Former log stringer bridge across a large fish bearing stream has been removed, with only a single log for left foot traffic. The bridge provided the only access to over two miles of forest road containing numerous culverted stream crossings that can no longer be maintained. Roads that have not been properly decommissioned require inspection and maintenance. The roads on the other side of this bridge have recently been scheduled for decommissioning.

FIGURE 258.

Recently constructed barrier blocks access to an unmaintained road, but undrained surface runoff has already gullied the road behind the barrier and now delivers eroded sediment to a stream. Road and storm maintenance cannot be performed when large barriers are constructed. Immovable road barriers should only be installed on roads that have been properly decommissioned.



B. TECHNIQUES FOR ROAD CLOSURE AND DECOMMISSIONING

It is no longer sufficient to close roads by simply installing or locking a gate or blocking the road with an impassable barrier, because those actions will not prevent future road failures, erosion, sediment delivery, or water quality problems from occurring (Figure 259).

Specific techniques, described below, are available to successfully prevent road-related debris flows, to prevent or correct stream diversions (the leading cause of serious gully erosion in many areas), to prevent stream crossing washouts and fill failures, to dewater gullies and landslides fed by road runoff, to disconnect road surface runoff from streams, and to control surface erosion (rilling and raveling) from abandoned road surfaces and fill slopes.

FIGURE 259.

Gating a road closes it to unauthorized traffic and may reduce but does nothing to protect the road from major failures. Scarps in the road fill behind this gate signal a slope failure that threatens to deliver sediment to an adjacent fish-bearing stream if it is not treated.





FIGURE 260. Untreated, abandoned section of forest road does not threaten water quality and needs little or no treatment for decommissioning. Roads to be decommissioned typically require minimal treatment for most of their lengths, and then concentrated erosion prevention work at a relatively few locations (e.g., stream crossings).

Closing a road does not imply that every foot of the road needs intensive treatment to prevent future erosion (Figure 260). **Rather, the goal of proactive road closure is to aggressively treat only those sites and road segments which have a potential to generate erosion and to deliver sediment to stream channels.** Segments of road which pose no risk of sediment delivery can be left intact and receive only minimal road drainage

improvements (Figure 261). When and if the road is again needed to provide access to the area, it can be reconstructed with minimal effort.

Planned, systematic road closure can be an inexpensive and effective technique for minimizing long-term resource damage caused by roads built in steep areas and can prevent large scale damage to road alignments that require costly repairs if the road is to be reopened



FIGURE 261. Decommissioned forest road in an area of gentle slopes and no stream crossings. Road decommissioning in “easy” terrain can be an inexpensive process that returns the former, compacted roadbed to productive forest or grasslands. Road decommissioning can be either permanent (never to be reopened) or temporary. The two treatments are generally similar and provide protection to the watershed for as long as the road is closed.

FIGURE 262. *The most important types of heavy equipment used for road decommissioning include hydraulic excavators, bulldozers (with hydraulic rippers), and dump trucks (for endhauling). Usually, the largest equipment that can easily work in the particular setting is selected to maximize productivity. Other support equipment, including water pumps and straw blowers, provide key functions for special decommissioning tasks.*



for future use. It also provides land managers with an opportunity to permanently prevent or control the majority of post-construction road-related erosion and its associated on-site and downstream impacts. In addition, implementing technically sound road closure practices also minimizes structural damage to widespread, expensive forest and ranch land road networks that cannot be economically maintained for the long time period between harvest rotations or other land uses.

There is little difference between treatments that are meant to permanently close a road and those designed for temporary closure. **When a temporary road is built, or when a permanent or seasonal road is to be closed and removed from the active road network, erosion prevention work should be performed so that continued maintenance is not necessary. All closed roads should be storm-proofed by excavating stream crossings and removing culverts, excavating unstable or potentially unstable road and landing fills, treating the ditch and road surface to disperse runoff and reduce surface erosion, and planting bare soil areas.**

The goal of road closure is to leave the road so that little or no maintenance is required for stability while the road is unused.

Heavy equipment used for road closure typically includes a hydraulic excavator (a standard backhoe is too small and generally not versatile enough to effectively perform road closure tasks), a bulldozer (D5 to D7 size, with hydraulic rippers for decompacting rocked roads) and dump trucks (when needed for endhauling spoil and debris to stable disposal sites) (Figure 262).

Road decommissioning consists of three basic tasks.

1. Complete excavation of stream crossing fills, including 100 year flood channel bottom widths and stable side slopes (e.g., ~2:1).
2. Excavation of unstable or potential unstable sidecast and fill slope materials that could otherwise fail and deliver sediment to a stream.
3. Road surface drainage treatments (ripping, outsloping and/or cross draining) to disperse and reduce surface runoff.

1. STREAM CROSSING EXCAVATIONS

All stream crossings on temporary or abandoned seasonal and permanent roads scheduled for decommissioning need to be completely removed before the first winter period following their installation or closure (if not, they should be capable of passing the 100-year flood flow for that channel).

Removing (decommissioning) a stream crossing involves excavating and removing all fill materials

placed in the stream channel when the crossing was built. Fill material should be excavated to recreate the original channel grade (slope) and orientation, with a channel bed that is as wide, or slightly wider, than the original watercourse (Figure 263). If the channel sideslopes were disturbed, they should be graded (excavated) back to a stable angle (generally less than 50% (2:1)) to prevent slumping and soil movement. The bare soils should then be mulched, seeded and planted to minimize erosion until vegetation can protect the surface, and the approaching road segments should be cross-road drained

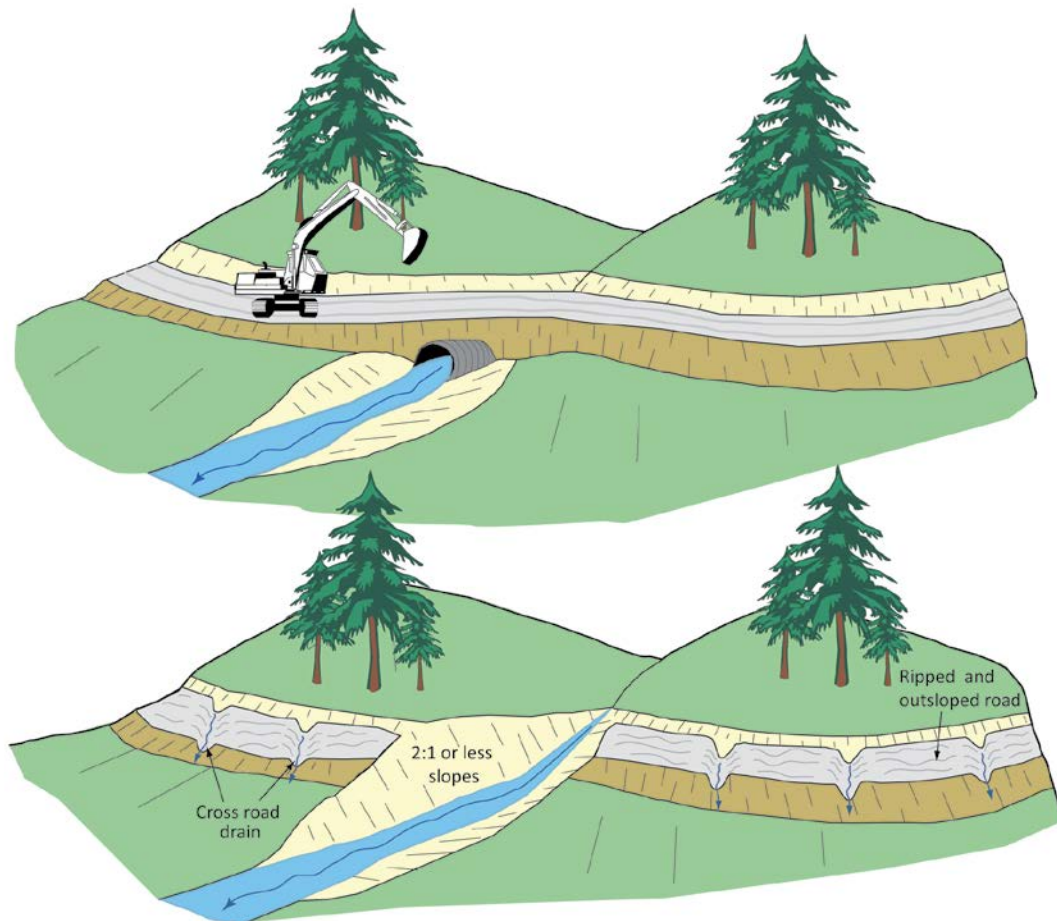


FIGURE 263. On roads that are to be closed (decommissioned), all stream crossing culverts and fills should be removed. Stream crossing excavations are best performed using an excavator. The original channel should be excavated and exhumed down to the former streambed, with a channel width equal or greater than the natural channel above and below the crossing. Sideslopes should be laid back to a stable angle, typically a 2:1 (50%) gradient, or less. Spoil can be endhauled off-site or stored on the road bench adjacent the crossing, provided it is placed and stabilized where it will not erode or fail and enter the stream.

to prevent road runoff from discharging across the freshly excavated channel sideslopes.

Procedures for removing stream crossings on abandoned, permanent or seasonal roads are similar to those used on temporary roads. Both culverted and unculverted stream crossings (e.g., culverts, plate arch crossings or log crossings) should be completely excavated or removed so that no soil materials are left in or next to the channel following road closure. It is not enough to simply excavate and remove the culvert; the entire fill must also be excavated (Figure 264). As with temporary stream

crossings, the excavation should extend down to the level of the original channel bed, with a channel as wide, or wider, than the original channel.² Channel sideslopes should be sloped back to a stable angle and spoil material removed to a stable storage site (Figure 265). Erosion control measures, such as seeding, planting and mulching, should be applied to prevent subsequent surface erosion (Figures 266a–266e; Figures 267a and 267b; Figures 268a and 268b).

² See Appendix C for California Forest Practice Rule language specifying this requirement.

FIGURE 264. Poorly “decommissioned” stream crossing where the culvert was removed by trenching and the excavated spoil was piled next to the trench (see arrow) where it could easily erode into the stream. The entire stream crossing fill will be rapidly eroded and delivered to the stream if correct excavation and decommissioning treatments are not implemented before the next runoff event.



FIGURE 265. Properly decommissioned stream crossing, with 2:1 (stable) sideslopes, adequate channel width for flood flows, and a uniform channel grade (no humps of unexcavated fill) extending between the natural channel above and below the crossing. Because the slopes were dry, excavated spoil material was used to outlope the adjacent road approaches. The sideslopes were seeded with grass and straw mulched to minimize erosion following decommissioning.





FIGURES 266A–E. This five-photo sequence shows the permanent decommissioning of a stream crossing on a former logging road. The road was no longer needed and has been permanently closed. The first step (266a) was to clear vegetation from the fill and from upstream of the crossing, where the channel had been filled with logging debris several decades earlier.



FIGURE 266B. Once cleared, an excavator excavated the fill material and several dump trucks were used to end-haul spoil material to a nearby, stable disposal site.



FIGURE 266C. The channel was excavated (exhumed), and the side-slopes were sloped back to stable angles, exposing several buried stumps that signaled the level of the original ground surface. The bare slopes were then seeded, mulched with straw, and planted with trees. All the logs visible on the right bank had been buried in the crossing fill. They were removed and placed on the final ground surface.

FIGURE 266D. Four years later, the site showed significant revegetation, and minimal channel adjustment (scour) or surface erosion.



FIGURE 266E. Finally, 2 years later (and 6 years after decommissioning) the site showed heavy alder growth that had naturally seeded in from adjacent areas. The conifers beneath the alder canopy will eventually overtake the alder trees.



FIGURE 267A. Dual, undersized, elevated culverts at this small stream crossing have been a barrier to fish passage since the road was built decades ago. The outlet of the culvert on the right has been crushed closed, probably by heavy equipment performing maintenance work. Road and stream crossing decommissioning was used to permanently reopen the channel to fish passage.





FIGURE 267B. The stream crossing fill was excavated and pushed down the alignment, away from the crossing. The gentle, excavated sideslopes were seeded, mulched with straw and covered with locally derived tree limbs and brush. The channel was excavated to the original streambed elevation, where rounded cobbles were exhumed, and constructed with the same width as the upstream and downstream channel reaches.

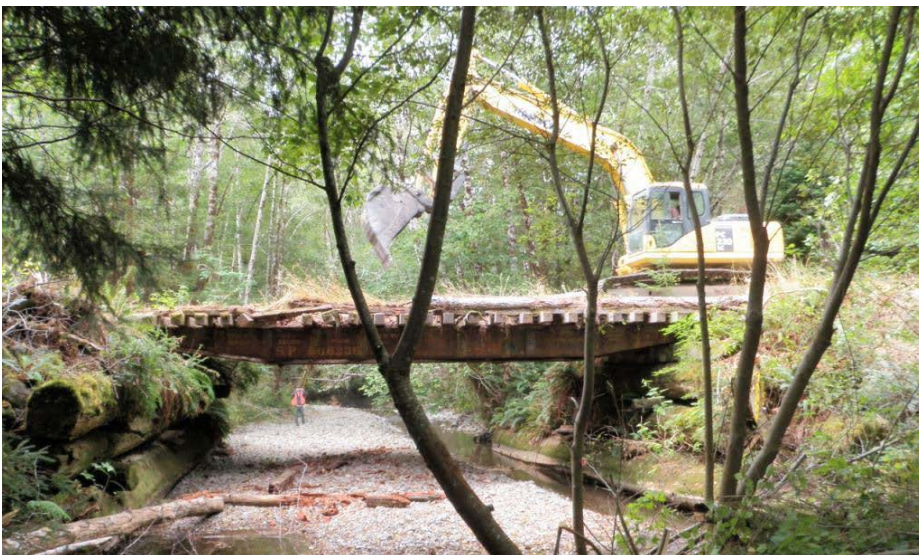


FIGURE 268A. Abandoned road and flatcar bridge over a large fish bearing stream. Unlike log stringer bridges, which are often covered with a thick layer of soil, flatcar bridges do not have a cap of soil that could enter the stream when they eventually fail. However, the log abutments were beginning to collapse and the collapsed logs and bridge would likely cause future flow deflections and channel erosion.

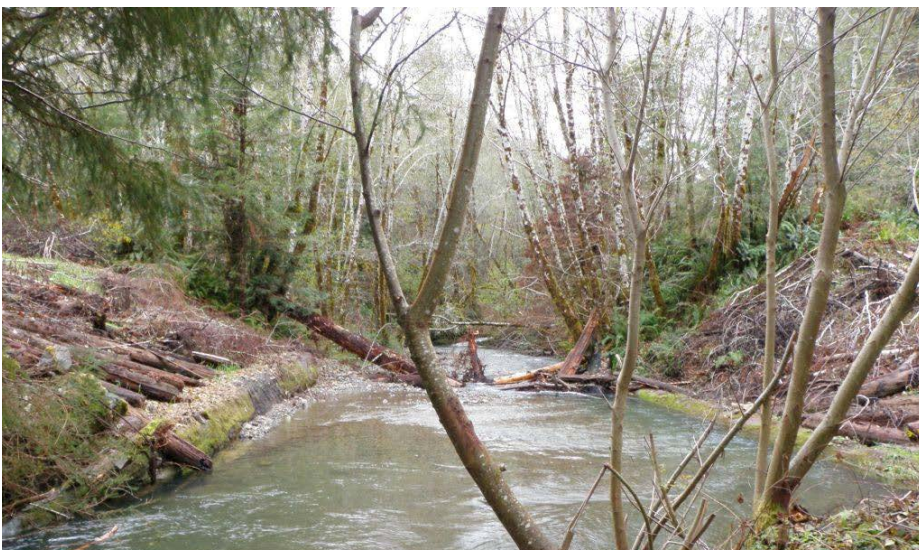


FIGURE 268B. Because the road was to be permanently closed, the bridge was removed as a part of road decommissioning. The lower, partially embedded abutment log on each side of the crossing was left in place to protect the newly excavated streambanks. The sideslopes were excavated and sloped back at a gentle angle, and then mulched with woody debris. Natural channel width was retained through the crossing.

2. TREATMENT OF UNSTABLE AND POTENTIALLY UNSTABLE FILLS

i. Road and landing fill slope excavation

Any unstable or potentially unstable road or landing fills (or sidecast) should be excavated and stabilized so material does not fail and enter a watercourse, impact off-site fish habitat, threaten bridges or homes that may be located downstream, or destroy down-slope vegetation. Such areas include sidecast and fill materials which show recently developed scarps or cracks (e.g., [Figures 269a–269c](#);

[Figures 270a and 270b](#)), or perched fill and debris immediately adjacent stream channels ([Figures 271a and 271b](#)). These potential failure sites occur most often 1) around the perimeter of landings, 2) on sidecast constructed roads built across steep slopes, especially those near stream channels, 3) where roads have been built on steep slopes over springs or seeps, or 4) where roads have been cut into steep headwater swales or “dips” in the hillside ([Figures 272a and 272b](#); [Figures 273a – 273c](#)). Cribbed fills which were installed at unstable areas during initial road construction or reconstruction should

FIGURE 269A. Hydraulic excavator loading a 10-yd³ dump truck with fill material removed from an unstable road fill slope. The road decommissioning process whereby excavated spoil is endhailed off site, rather than placed against the cutbank, is called “Export Out-slope” (EOS). EOS is used where unstable fill material must be excavated, but the cutbank is unstable or wet and cannot be buried. Spoil is endhailed to the nearest stable disposal site.



FIGURE 269B. This low standard forest road was scheduled for decommissioning because of slope stability and erosion problems along its alignment. Prior to road grading, inventory crews had identified cracks and small scarps along 50 feet of the road bench and outer fill. If it failed, the debris slide would deliver sediment to a stream just downslope.





FIGURE 269C. The fill slope has been excavated and the spoil endhauled to a nearby spoil disposal site (exported outslope: EOS). Note the buried stumps that were exhumed and the basal flair that told the excavator operator where the original ground surface was located and how deep to dig. The cutbank has not been buried so the resulting outslope of the former road bench is strictly a result of roadbed and fill slope excavation.



FIGURE 270A. Tall, dry cutbank where the road cut across the nose of a ridge. Just down the road an unstable fill was excavated to prevent a potential fill slope failure and this favorable site was used for spoil disposal.



FIGURE 270B. Spoil excavated from the nearby unstable fill slope was hauled to this section of road and placed (and compacted) against the cutbank. This type of treatment is called an “Import Outslope” (IOS), where most of the fill used to outslope the former roadbed was imported from another, nearby excavation site. Using local spoil disposal sites, provided they are suitable, can save significantly on endhauling costs.

FIGURE 271A. This abandoned, inner gorge road was targeted for permanent closure (decommissioning) because of the steep slopes, unstable road fill and the proximity of a fish bearing stream. Vegetation has been cut from the fill slope and straw bales have already been staged along the road for mulching after the heavy equipment work is complete. Most of the decommissioning involved endhauling spoil about 1000 feet down the road to a broad, low gradient area located far from the stream.



FIGURE 271B. After decommissioning, all the potentially unstable fill material has been excavated and endhauled off-site. Some excavated material has been placed along dry portions of the cut-bank, but seeps and springs have been left uncovered to freely drain down the slope. The excavated fill slope and road bench has been covered with alder trees that were growing on the slope, and the remaining bare soil areas were seeded and mulched with straw. The threat to the stream at the base of the slope has been eliminated.



FIGURE 272A. Log landing on a forest spur road had developed large cracks and scarps around its outside perimeter where soil and wood waste had been sidecast onto steep slopes above a fish bearing stream. The fresh scarps had developed over several years and were identified by an inventory crew surveying for erosion problems in the watershed. An excavator is beginning the fill slope excavation and spoil material was pushed against the inside of the landing by a bulldozer (not visible).





FIGURE 272B. The excavation required a temporary road be built across the middle of the long fill slope to reach all the unstable material. The concave excavation surface mimics the shape of a potential slide plane and thereby assures that most of the unstable fill material has been removed. Spoil materials were pushed up against the inside of the large landing, entirely on a stable, excavated bench. As in Figure 271B this type of out-sloping is called an “Inplace Outslope” (IPOS), where all the excavated materials were stored locally (note person for scale).

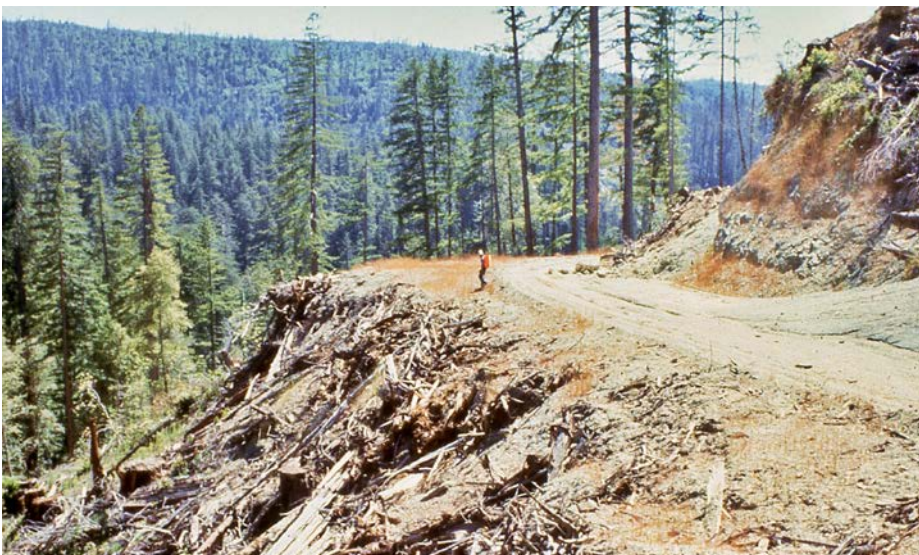


FIGURE 273A. Log landing with spoil and woody debris pushed over the edge and onto steep streamside slopes. This road and landing was previously managed for timber harvesting and had been recently added to Redwood National Park (RNP). As a part of watershed restoration, the road and landing were to be permanently decommissioned (RNP).



FIGURE 273B. Using Inplace Outsloping (IPOS) techniques, the rocky sidecast soils were excavated and placed against the tall cutbank of this dry ridge. Woody debris was separated from the dirt and chipped for mulch. Three years later, alder trees have invaded the bare soil surface and were rapidly growing. Minor surface erosion and rilling had occurred while the surface was sparsely vegetated, but there was no sediment delivery to a stream (note person for scale) (RNP).

FIGURE 273C. *By the following year, rapidly growing alder trees had completely covered the decommissioned, outsloped landing surface and surface erosion rates were near zero. The threat posed by the unstable fill was completely eliminated by the decommissioning treatment (note person for scale) (RNP).*



also be removed and outsloped if they potentially could fail into a downslope stream channel.

Potentially unstable road material that is likely to enter any watercourse, threaten life or property, or damage other sensitive resources should be excavated and treated during road closure and decommissioning operations. All spoil material should be placed in a stable location and revegetated. Spoil disposal sites often include the cut portion of closed roads, stable topographic benches, rock pits and the inside portion of landings and turnouts. Consult a qualified geologist about suitable areas for spoil disposal.

Cutbank failure materials are often completely caught and stored on the road prism. For this reason, cutbank instabilities often do not need the same amount of treatment and stabilizing as is needed on fill slopes and at stream crossings. Some buttressing, revegetation and upslope drainage control may be required to prevent larger failures and erosion that could affect water quality. No active ditches or diversions should be left at the base of an unstable or raveling cutbank on a closed road. **In fact, ditches should not be left open and functioning when a road is closed because all ditches are likely to eventually become plugged with sediment or vegetation**

and cause water to be diverted onto the road surface and adjacent hillslopes.

ii. Road recontouring or obliteration

Sometimes roads are completely recontoured and the landscape topographically restored to what it looked like prior to road construction. This may happen unintentionally, over short road lengths, when stream crossings are decommissioned (e.g., [Figures 265 and 266d](#)) or roads are outsloped with spoil generated from fillslope or stream crossing excavations elsewhere (e.g., [Figure 270b](#)). It may also occur or where roads must be fully recontoured to address concerns about slope stability (e.g., [Figure 269c](#)). Where scenic or resource values are high, and visitor use is expected, the goal in some parks, natural areas, biological preserves, and recreation sites might be to “obliterate” or fully recontour the former road prism so that there is little or no physical indication a road was ever constructed ([Figures 173a and 173b](#); [Figures 274a and 274b](#); [Figures 275a and 275b](#)).

iii. Road to trail conversions

Occasionally, in high visitor use wildland recreation areas, former roads are turned into public trail systems for hikers, bicyclists and equestrian users. A special category of road decommissioning called road-to-trail conversion, or trail outsloping,

is performed to convert from vehicle use to narrower, non-motorized visitor use trails (Figure 276). Many of these former roads are converted directly to narrow pedestrian trails along the original alignment, with detours around hazards or excessively steep pitches, or to provide access to open vistas or points of interest (Figures 277a and 277b). Other trails are kept comparatively wide and low gradient to allow for emergency vehicle access or to provide for access and use by disabled persons (Figure 278; Figures 279a and 279b). Road to trail conversions are still designed to provide for an access route that removes most of the original and most serious threats

to water quality, while requiring comparatively low levels of trail maintenance (Figure 280).

3. ROAD SURFACE RUNOFF AND OTHER DRAINAGE STRUCTURES

Roads that are to be decommissioned and no longer maintained should have adequate, self-maintaining surface drainage so that the road surface is stable and will not erode and deliver sediment to streams.

Most temporary roads should have been built as outsloped roads, and any ditched



FIGURE 274A. Abandoned forest road that was reopened for decommissioning and erosion prevention treatments. The proposed treatment was to completely restore and recontour the hillslope in this biological reserve and conservation area.



FIGURE 274B. After treatment, remnant stumps that had been buried by road construction and sidecasting were exhumed and gave the excavator operator a good idea where the original ground surface had been located. The outsloping was performed with little or no endhauling, as fill materials from the outside of the road prism were excavated, placed and compacted against the dry cutbank. Most of the cutbank has been buried and the slopes recontoured to their original form. The exposed soil was not seeded with grass, and rice straw was used as a mulch to prevent the introduction of non-native weeds. Litter from the adjacent forest quickly covered the surface.

FIGURE 275A. Switchback logging roads were constructed down a scenic grassland prairie to access redwood forests lower on the hillslopes. Shortly before this photo was taken, these roads and the forests in the distance were acquired by the National Park Service and added to Redwood National Park (NPS, RNP).

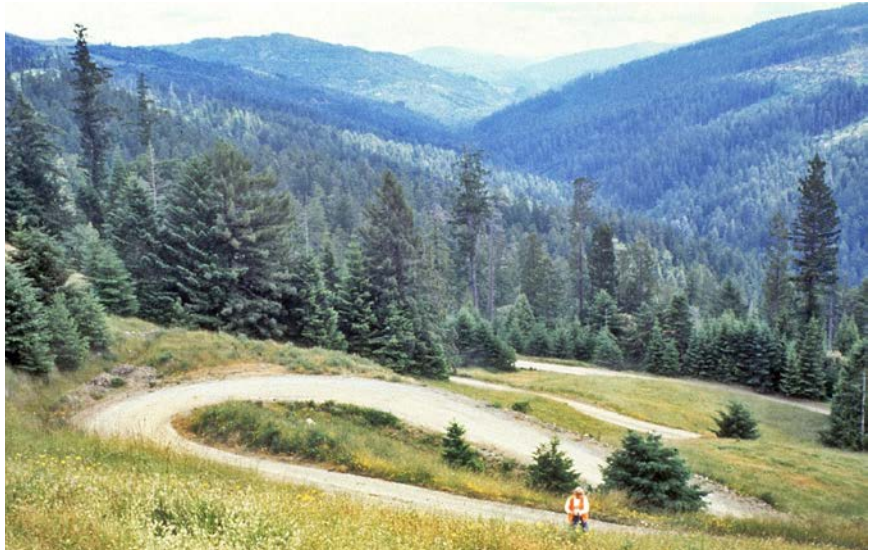


FIGURE 275B. Because of the wide and scenic vistas, and the expected use of the grasslands by future park visitors, these roads were decommissioned by full recontouring (road obliteration). Within two years, the recontoured roads and slopes had been invaded by native grasses and their presence was barely noticeable (NPS, RNP).



FIGURE 276. This road-to-trail conversion (decommissioning) was undertaken when the forested area, once commercial timberlands, was acquired and converted to a biological preserve. Part of the ecological mandate was to decommission former logging roads to reduce erosion rates to protect streams and fish habitat, while still preserving hiking access to many of the biologically unique areas. Here an excavator is recontouring a former logging road while constructing a new trail near the top of the old cut slope. The surface of the recontoured slope has been mulched with limbs and woody debris. All stream crossings and unstable road fills have been excavated along the old road alignment.





FIGURE 277A. Former private forest road, now in a U.S. BLM Biological Reserve, has been scheduled for out-sloping and conversion to a trail. The purpose of the decommissioning project was to recontour the old logging road and convert the route to hiking access for visitors and researchers. Note the stump in the right foreground.



FIGURE 277B. The former road was decommissioned by excavating the sidecast fillslopes and placing the excavated fill against the dry cut banks. The excavated fillslopes were covered with rice straw and woody debris to control erosion while preventing the introduction of exotic grass and weed species. The once-straight road has been converted into a winding trail that follows the original landscape contours. Topographic swales and stream channels have all be excavated and recontoured



FIGURE 278. An illegally constructed road had been built across this steep hillside to access a new home site. Because of high erosion rates and slope instability, and because it was not permitted, regulatory agencies required the road to be fully decommissioned and recontoured. After excavation and recontouring, the bare slopes were seeded and watered to achieve a rapid and complete groundcover of grass. The decommissioning was approved to include a narrow trail for use as an emergency fire escape route, using small quads (off-road vehicles). A new and better alignment to reach the home site was subsequently found and constructed through proper permitting processes.

FIGURE 279A. This former (abandoned) forest road crossed relatively gentle topography that had been recently converted to a public use area. The road was to be decommissioned to remove the potential erosion threats, while at the same time opening trail access to the public. Note the conifer tree partially visible in the center background, behind the deciduous alder trees.



FIGURE 279B. In the same view as Figure 279a (note the conifer tree now clearly visible), the unstable road fillslopes next to the fish-bearing stream (left, off photo) were excavated and the fill used to recontour the old road cuts and restore the site's original topography. Because it was in a new U.S. BLM conservation area, bare soil areas created during decommissioning were mulched with wood chips generated on-site. A compacted gravel surface was then installed to make the trail accessible to all visitors.



FIGURE 280. An old, abandoned logging road was converted to a trail system through the use of trail-outsloping. Here, a formerly culverted stream crossing was converted to a "reduced size" I-beam bridge (see also Figure 150) that was primarily intended for hiking access, but which was also designed for use by small vehicles in emergency situations and for occasional maintenance needs. The erosional threat has been largely eliminated along the trail by various road-to-trail decommissioning treatments.



segments of roads to be closed should be outloped or drained with cross road ditches during closure operations. Outside road berms should be removed to encourage continuous drainage off the road surface.

Inside road ditches should be eliminated when decommissioning temporary and abandoned roads so that water is not diverted and gullies do not form. Cross-road drains placed at regular intervals along the former road should be made deeper than standard waterbars and extend all the way from the cutbank to the outside edge of the road in order to intercept

all ditch flow. On steep sections of road (>10%) cross drains should be skewed at 45° to the road alignment (instead of the usual 30°) to reduce the threat of erosion at the inlet (Figure 281).

Springs and seeps should be drained straight across the former road bench, provided the slope below is stable (Figure 282). Since inside ditches will be breached and no longer carry runoff, ditch relief culverts are no longer needed on closed roads and can be removed and salvaged (recycled), or left in place if the road is to be reopened at some time in the future.



FIGURE 281. Between treated stream crossings and fill slope excavations, decommissioned roads should have permanent road drainage treatments, including road decompaction (ripping or subsoiling) and constructed cross road drains. Cross road drains are permanent road drainage features, like waterbars but much more substantial so they will function indefinitely and will not be broken down by rainfall, runoff or any kind of unwanted recreational traffic (usually bicycles or motorcycles). Like waterbars, they are usually excavated into the firm roadbed, mounded on the downhill side and spaced closely enough to prevent significant erosion on the roadbed or below the point of discharge.



FIGURE 282. Deep cross road drains are constructed everywhere there is a spring or seep on the former road cutbank. This helps drain the road and the hillslope as uniformly and frequently as possible. Except for very short sections next to a cross road drain, inside ditches should not be retained.

Cross-road drains should be placed frequently enough such that flow through individual drains will not require the use of rock armor energy dissipaters to prevent erosion at the outlet. However, cross drains that carry spring flow or flow from small upslope gullies may require a deeper excavation or armoring at their outlet and should be discharged into vegetation to filter water and sediment before runoff reaches a stream (Figure 282).

Ripping and planting abandoned roads can reduce runoff and erosion, and greatly increase the amount of forest and ranch land in production (Figure 283; Figures 284a and 284b). Ideally, the abandoned road surface should be scarified (ripped or plowed to a depth of 18–24 inches), outsloped at least 4% more than the road grade, waterbarred, seeded and planted to control surface runoff and erosion (Figure 285). Wet, spring-fed cutbanks along outsloped roads should not be covered with spoil, and roads that are not outsloped should have frequent cross-road drains installed.

Tree growth on compacted or rockered road surfaces is generally much slower than on adjacent, uncompacted sites unless the roadbed is mechanically ripped. Ripping is most effective in breaking compaction and promoting tree

growth when it is conducted with a winged subsoiler that lifts and shatters the soil. Ripping can also be performed using hydraulically operated chisel teeth mounted on the back of a bulldozer, although several passes may be required to disaggregate the entire roadbed (Figure 286).

4. EROSION CONTROL

Most erosion control work along closed roads is accomplished by 1) the physical excavation of stream crossings, unstable fills and landing sidecast, 2) installation of cross-road drains, 3) road ripping, and 4) local road outsloping. These techniques are usually performed by heavy equipment. Other hand-labor erosion control and revegetation practices that may be of use include mulching, installation of energy dissipation (e.g., rock armoring and woody debris), seeding and planting.

The banks of all excavated stream crossings, as well as all bare soil areas immediately adjacent or near a watercourse, should be seeded and mulched with straw (3,000 to 5,000 lbs/acre—or complete ground coverage to a depth of about 3 inches) or another mulching product. Straw can be hand spread or blown onto the soil surface using trailer-mounted straw blowers. On slopes over about 45%, or where high winds

FIGURE 283. *Small bulldozer with hydraulically operated rippers (three 30 inch long steel chisels) is decompacting a seasonal road as a part of road decommissioning. Road ripping should be a standard decommissioning practice. All decommissioned roads should be ripped to decompact the road bench, improve and speed revegetation and reduce surface runoff. If the road is to be outsloped, and spoil is placed on the former roadbed, the compacted road bench should first be ripped to a depth of 18 to 24 inches, or greater. If it isn't ripped, infiltrating water will pond on the compacted surface and may cause soil saturation or contribute to slope failure.*





FIGURE 284A. On forest roads which are to be formally closed, rather than just “abandoned,” the roadbed can be returned to forest or grassland production by ripping and disaggregating the surface and then planting with trees. Figures 278a and 278b show a road before and after ripping and decompaction. This simple, inexpensive treatment also helps reduce runoff from compacted areas. It is recommended that enough passes be made with the tractor so the surface is completely disaggregated.



FIGURE 284B. A road after ripping and decompaction.



FIGURE 285. Former forest road that has been ripped, slightly out-sloped and converted to a hiking trail. The decommissioning treatment needed in this upper hillslope setting was minor and yet largely eliminated surface runoff from the alignment.

FIGURE 286. *On gentle terrain, ripping (soil decompaction) may be the only treatment that is needed to decommission a road, eliminate unwanted traffic, reduce runoff and return it to native vegetation.*



are common, mulches will need to be tacked, punched or secured to the ground surface to hold them in-place and in full contact with the ground surface. Straw can be punched into loose soil using shovels, crimpers or a spiked roller, or held onto the surface using jute netting, or a “tacking” spray (Figure 287). Mulches can also be purchased in rolls, in which the mulch is bound between fine biodegradable, plastic netting, which can then be rolled out and secured or “stapled” to the ground.

If rock armor materials are plentiful, the channel-bottom of excavated stream crossings can be armored with well graded, appropriately sized rock to minimize subsequent channel downcutting or widening. However, rock armor should not be necessary for erosion control if all fill material is removed from the crossing and the original channel profile, streambed and sideslope configuration are reconstructed by excavation. If the natural channel armor was not removed during initial culvert installation, it should be sufficient to protect the channel from downcutting.

Rock and/or woody debris can be placed at the outlets to cross-road drains that are expected to carry substantial spring-flow. Rock armor is generally preferable because it is more permanent and adjusts its position when there is minor channel downcutting. But none of the cross drains should carry sufficient runoff to cause serious erosion. If they do, or you think they might, then the site and all the fill material should be completely excavated as though it was a small stream crossing.

5. REVEGETATION

Vegetation is the ultimate, long-term erosion control agent. However, because it takes time to grow a thick, effective cover, some physical erosion control measures (such as straw mulch, netted blankets or biotechnical methods) are often needed for the first year or two following road decommissioning or closure. Seeding with grass and legumes reduces surface erosion and can improve soil physical condition. Planting trees and shrubs adds longer lasting vegetative cover and provides stronger root systems which enhance slope stability. Within



FIGURE 287. Most often, a uniform cover of straw mulch is all that is needed to temporarily control surface erosion on the excavated sideslopes of decommissioned stream crossings until they can naturally revegetate. Wood chips, or native brush and slash, also work well to control surface erosion in some environments. Here, jute netting has been used instead of straw, as a trial treatment. Rolled and tacked erosion control blankets, or jute netting tacked over a layer of straw mulch, can be used on sideslopes that are steeper than about 2:1 (50%). To avoid spreading non-native weed species, many areas can employ rice straw whose seed and weed species are not adapted to growing in most upland environments. Rice straw mulch also has a roughness or “stickiness” that allows it to hold in place on slopes steeper than wheat or grass straw.

their appropriate range, conifers, hardwoods and other tree species provide for long term land stability and erosion control. Planting woody vegetation, including trees, is best conducted during the wet season or immediately after the first few wet season rain events, when there is sufficient soil moisture to aid in plant survival.

a. Seeding methods

Seeding with grass and other fast growing species can be used to protect slopes from raindrop and rill erosion, if it is planted and grows to provide a thick cover before the first wet season rains. Seeding is best performed immediately after the surface is restored, with mulch then applied to cover the seed and the bare soil. The rough surface provides miniature traps for seeds, fertilizer

(if used) and rain water, creating a favorable environment for seed germination and growth. **Mulches increase seedling establishment by improving germinating conditions and controlling erosion until the plants become established.**

The two basic methods for spreading seed are dry seeding and hydraulic seeding. Each method is suited for specific ground conditions (Table 37). Dry seeding and fertilizing along small roads is often done with cyclone-type rotary seeders. This method is usually done by hand for road-related applications, but may also be performed by truck and aerial application for larger jobs. Hand seeders, called belly grinders, are typically restricted to moderate or gentle slopes and can shoot seed and fertilizer from 15 to 20 feet. Seed can also be spread by hand, throwing the seed

TABLE 37. Guidelines for seeding method selection¹

Site conditions	Sample situations	Seeding method
Steep (>50%) or windy slopes, high to extreme erosion hazard	Steep cutbanks and fill slopes	Hydraulic seeding with a sprayed or tacked mulch
Moderate (30-50%) and steep slopes, medium to high erosion hazard	Moderate and steep cutbanks and fill slopes; stream crossing fills and bridge sites	Hydraulic seeding or dry seeding with a mulch
Gentle and moderate slopes, medium to high erosion hazard	Cutbanks, fill slopes, and spoil disposal sites not near a watercourse	Hydraulic seeding or dry seeding; mulch where needed
Gentle and moderate slopes, low to moderate erosion hazard	Cutbanks, fill slopes, and spoil disposal sites not near a watercourse	Dry seeding; mulch if needed to improve revegetation

¹Modified from: BCMF (1991)

across the surface, but its distribution will not be even. Drilling seed into the planting bed ensures an even distribution, but may not be possible due to the steepness of many road cuts and fills. In hydraulic seeding (hydro-seeding), seed, mulch (or binder) and fertilizer is applied in a water-based slurry from a pump truck or portable trailer (Figure 288). Hydro-seeding may be necessary for planting 1:1 or steeper

slopes, where the seed must be “tacked” to the slope because of high ravel or erosion rates.

Regardless of the method selected, seed must be evenly distributed to result in a continuous plant cover. Seeding onto a roughened soil surface or thinly covering the seed with soil and mulch ensures good germination. In dry climates or in



FIGURE 288. *Hydroseeding (spraying a slurry of water, mulch, seed and fertilizer) on bare soil areas can be an effective erosion control and revegetation treatment for large disturbed areas, or for bare soil areas along open roads. It is most useful for treating spoil disposal sites, after they have been graded and smoothed, and for treatments along newly upgraded roads where the truck or trailer can have easy access. Hydroseeding decommissioned roads is more difficult because access is cut off as the treatments progress. Rather, hand seeding and mulching is usually the preferred treatment.*



soils with poor water holding capacities, broadcast seeding may yield poor results unless the seeds are covered with mulch that helps retain near-surface soil moisture, or the site is watered during the first year. For best success, seeding should be completed just prior to the first wet season rains.

b. Seed types and fertilization

Severely disturbed sub-soils and cutbank exposures are usually infertile, and fertilizer applications containing nitrogen (N), phosphorous (P), potassium (K), and occasionally sulphur (S) may be needed for successful grass-legume establishment and growth. Fertilization rates vary according to the level of nutrients needed for establishment. Soils can be tested for nutrient content before fertilizer mixes are prepared. More often, commercial mixes are used which provide all the necessary nutrients for plant growth. When hydroseeding is performed, fertilizer is usually one component of the slurry application.

Parent materials and subsoils are always deficient in nitrogen. A common recommendation for deficient soils is to broadcast ammonium phosphate sulfate fertilizer (16-20-0) at the rate of 500 lbs/acre at planting time. This provides sufficient nutrients for the first growing season. However, **care needs to be taken that fertilizers or nutrient rich runoff from fertilized slopes are not transported to, and pollute, nearby streams and waterbodies.** Critical sites (e.g., stream crossings) that may need to be fertilized probably should not be broadcast fertilized simply to maintain plant vigor and an adequate ground cover. Planting legumes and nitrogen fixing species in infertile soils is often suggested because they are able to grow without nitrogen fertilizer. Before seeding, legume seeds require inoculation with a nitrogen fixing bacteria which then grows on its roots and fixes nitrogen the plants can then use.

Utilizing a mix of seeds, or focusing on native species, increases the likelihood that one of the plant species will find local conditions favorable

and produce a good plant cover. If a commercial seed mix is used, it is important that plants known to be effective in erosion control be found in the mix, that the species are adapted to grow in the local environment, and that the species are compatible in mixtures (i.e., that one doesn't out-compete the other). **In general, seed mixes should be kept simple.** The grass-legume ratio, by live pure seed, should be about 70:30 in humid regions and 80:20 in dry regions. It is a good idea to consult your local Natural Resources Conservation Service or other comparable resource agency for seeding recommendations for your specific area and need. Non-native, invasive plants and grasses should not be used.

Typically, a combination of 2 to 5 species, including sod forming grasses, bunch grasses and legumes, is used for erosion control (Table 38). Legumes are included for their deeper roots and nitrogen fixing capability. Seed mixes suitable for an area depend on the soil and climatic conditions of the site. Native seed is often preferred because of its tolerance to local soil and climate conditions. Seeding rate depends on the desired species mix, seed weight and viability of the seed stock.

In California, In California, the Department of Transportation (Caltrans) provides useful guidance on erosion control plant selection and seeding recommendations as part of the CALTRANS Erosion Control Toolbox available at: <http://www.caltrans.ca.gov/hq/LandArch/ec/index.htm>. The "Planting" Section of the on-line toolbox describes seeding rates and environmental requirements for native plants and grasses used for erosion control in Mediterranean climates. Caltrans also publishes a technical guide for selecting "sustainable erosion control measures," including revegetation techniques (California Department of Transportation, 2010). Similar guides should be available for most other regions, and public road and land management agencies are often able to provide assistance and guidance on local seed selections for erosion control purposes.

TABLE 38. Species, growth characteristics and minimum seeding rates of selected plants known to be effective in controlling erosion in western U.S. forest and ranchlands¹

Species	Characteristics	Distribution	Seeding rate (lb/acre)	Min/Max annual rainfall (in)	Growth rate/longevity
Annual Grasses (Usually fast growing, adaptable, and competitive. Life cycle is completed in one year. Act as good nurse crops for establishing perennial native species. For nonnative species, high seeding rates in mixes with other less competitive native grasses should be avoided.)					
Cereal rye (<i>Secale cereal</i>)	Nonnative, fast growing, cool season, erect, flat leaf grass; moderate drought tolerance.	Used throughout the U.S. and Alaska; considered a Class C noxious weed in Washington.	75 – drill 120 - broadcast	8/50	Rapid/ 10/90
Common barley (<i>Hordeum vulgare</i>)	Nonnative; fast growing, cool and temperate season, erect grass; wide soil tolerances; moderate drought tolerance.	Used throughout the U.S. and Alaska.	75 – drill 120 - broadcast	10-90	Rapid/ 12/30
Annual ryegrass (<i>Lolium perenne</i>)	Nonnative; fast, winter growing, short-lived grass; use only as nurse crop; very competitive.	Used throughout the U.S. in regions with moist, mild climates with moderate temperatures.	15 –if planted alone 4 – in seed mixtures	18/65	Rapid/ Short
Annual hairgrass (<i>Deschampsia danthonioides</i>)	Native; fine-textured, cool season grass; high seedling vigor; moderate drought tolerance.	Alaska to Baja California; east to Montana and New Mexico; NE U.S.	2-4	12/30	Moderate/ Short
Sixweeks fescue (<i>Vulpia octoflora</i>)	Native, cool season, loosely tufted bunchgrass; commonly found in open disturbed areas; drought tolerant; wide soil tolerances.	Used throughout the U.S.	2-3	5/67	Moderate/ Short
Biennial Grasses (Similar to annual grasses, biennial grasses are fast growing, adaptable, and competitive. Biennials require two years to complete life cycle, with leaves and roots produced in the first year and then blooms and produces seed in the second year.)					
California brome (<i>Bromus carinatus</i>)	Native; cool season bunchgrass; competitive; moderate drought tolerance; high seedling vigor; high seeding rates in mixes with other less competitive native grasses should be avoided.	British Columbia to Mexico; eastward to Montana, Wyoming, Colorado, and New Mexico	8-10 –if planted alone 1-3 – in seed mixtures	8/20	Rapid/ Short
Slender hairgrass (<i>Deschampsia elongata</i>)	Native; cool season bunchgrass; useful for erosion control on seasonally wet or recently disturbed sites; moderate drought tolerance.	Alaska to California; east to Montana and New Mexico	2-4	10/24	Moderate/ Short

TABLE 38. Species, growth characteristics and minimum seeding rates of selected plants known to be effective in controlling erosion in western U.S. forest and ranchlands¹

Species	Characteristics	Distribution	Seeding rate (lb/acre)	Min/Max annual rainfall (in)	Growth rate/longevity
Perennial Grasses (Usually restricted to sites requiring deep rooting and/or minimum maintenance; are slow growing in the first year and do not compete well with most annual grasses; flowers or annual grasses may constitute up to 50% of a mix with perennial grasses.)					
Blue wildrye (<i>Elymus glaucus</i>)	Native; large, tall bunchgrass; good competitor; germinates easily; prefers moisture, but more drought tolerant than Meadow barley.	Alaska to California; Great Plains and northern Mexico	5-7	16/60	Rapid/ Moderate
California oatgrass (<i>Danthonia californica</i>)	Native, slow establishing, long-lived bunchgrass; wide soil tolerances; moderate drought tolerance; enhances biodiversity; successful stands produced by sowing seed alone instead of in mix with other plant species.	British Columbia to southern California; eastward through the Rocky Mountain States and Provinces.	9-15 – drill 18-30 - broadcast	6/40	Moderate/ Long
Meadow barley (<i>Hordeum brachyantherum</i>)	Native bunchgrass, high seeding vigor, wide soil tolerances, best adapted to moist soils, moderate drought tolerance.	Alaska to California; east to the Rocky Mountains; sporadically in other states	5	20/80	Moderate/ Moderate
Tufted hairgrass (<i>Deschampsia cespitosa</i>)	Native, cool season bunchgrass, found in moist arctic and temperate regions, wide soil tolerances, circumglobal distribution.	Greenland to Alaska; western U.S. to North. Mexico; Minnesota to Maine; Iowa, Illinois, Ohio and Georgia	2	14+	Moderate/ Long
Idaho fescue (<i>Festuca idahoensis</i>)	Native, cool season grass, wide soil tolerances, moderate drought tolerance, cold tolerant, deep-rooting, good seedling vigor.	Western Canada to California, Colorado, Idaho, Montana, Nevada, South Dakota, Utah, and Wyoming	6-8	12/20	Moderate/ Long
California fescue (<i>Festuca californica</i>)	Native, cool season bunchgrass; drought tolerant; deep rooting; wide soil tolerances; initially slow to germinate; compatible with forbs.	Oregon and California	10	12/20	Moderate/ Moderate
Clovers and trefoils (Clover and trefoils are used because of their ability to provide their own nitrogen. This makes them suitable for low fertility areas that would otherwise need fertilizer. The seed should be inoculated with nitrogen fixing bacteria prior to planting.)					
Tomcat clover (<i>Trifolium willdenovii</i>)	Native; herbaceous; annual; sprawling to erect legume; prefers moist or wet conditions, and heavy, well-drained soils; can be grown serpentine soils; low drought tolerance.	British Columbia to California; Idaho; Arizona	Variable - depends on seed mixture	10/60	Rapid/ Moderate
American bird's-foot trefoil/ Spanish clover (<i>Lotus purshianus</i>)	Native, herbaceous; annual; prostrate to erect legume; moist to dry well-drained soils; drought tolerant.	British Columbia to Mexico; eastward through Idaho and Montana; southward to Arkansas and Texas	15	12/59	Rapid/ Moderate
Flowers (Flowers are useful for short duration cover on sites with low erosion potential; seldom persist for more than 1-2 years; do not plant with annual grasses and do not fertilize with nitrogen. Poppies and lupine have the record for persisting the longest of most flowers.)					
California Poppy (<i>Eschscholzia californica</i>)	Native, herbaceous, annual to deep-rooted perennial, moderate drought tolerance, can be planted on most weed-free soils, will not compete with grasses or weeds. Commonly associated with the Miniature Lupine.	Southern Washington to Baja California; Nevada; Arizona; New Mexico; SW Utah; west Texas	3-4	10/32	Moderate/ Short
Miniature Lupine (<i>Lupinus bicolor</i>)	Native, herbaceous, annual legume, adapted to a variety of soil types, prefers well-drained soils. Commonly associated with the California Poppy.	British Columbia to California; Arizona	8-15	10/55	Rapid/ Short

¹ from USDA NRCS PLANTS Database (plants.usda.gov). All erosion control plant species should be checked for potential invasiveness using applicable state invasive plant database (e.g., Cal-IPC; Calflora).

c. Timing of seeding

The most important considerations in seeding are timing of application, even distribution of seed and covering the seed with soil.

Planting at the wrong time is the most common reason for seeding failure. Seeding must be done early enough in the growing season so that an adequate ground cover can become established before the critical wet weather period. Seed application should begin immediately following heavy equipment operations and soil disturbance, and a minimum of 6 weeks before periods of drought or damaging frost. Fall seeding is best in areas with summer drought.

Planting and seeding for erosion control requires the development of a rapid, persistent and continuous plant cover. Annual grasses often produce the quickest protection, but are only a temporary solution and can sometimes actually impede the growth of other plants. Perennial grasses are slower to establish but provide better root systems

than annuals. Perennials may also have difficulty competing and surviving when seeded with annual grasses in the same mix. Annual legumes provide nitrogen to the soil as they grow, but they too are relatively slow to grow and may not compete well with heavily seeded annual grasses. Shrubs and trees are slow to provide a ground cover, and may not compete well when seeded with other species, but they often provide the best long term stability to a disturbed road site. Fortunately, native shrubs and trees will seed naturally on many disturbed sites in forested and grassland areas. Planting or transplanting can be used to speed their return.

Following seeding, all bare soils on newly constructed, reconstructed, upgraded and closed roads should be planted with trees and/or other woody vegetation (Figure 289).

In addition, the slopes and channel banks adjacent to excavated (decommissioned) stream crossings can be planted with willow, alder or other riparian tree species (Table 39) and shrub species (Table 40) compatible with the local site

FIGURE 289. *Tree planting (or planting woody species suitable for the specific environment of the road) is the final long term treatment for the decommissioned roadbed and for the riparian sideslopes where stream crossings have been excavated and restored for the long term. This planted redwood tree, and those conifers and hardwoods that naturally seed themselves onto the former roadbed, will eventually cover the alignment and provide for long term site stability.*



TABLE 39. Recommended tree species for revegetating riparian zones in California¹

Riparian species (common name)	Coastal	Interior valley	Interior foothill
California buckeye		✓	✓
Bigleaf maple	✓	✓	
California box elder		✓	
White alder	✓		✓
Red alder	✓		
California black walnut		✓	✓
Fremont cottonwood	✓	✓	✓
Coastal live oak	✓	✓	
California black oak			✓
Valley oak		✓	
Interior live oak		✓	✓
Red willow	✓	✓	✓
Sandbar willow	✓	✓	✓
Arroyo willow	✓	✓	✓
Oregon ash	✓	✓	✓
California bay	✓		
Dogwood	✓	✓	✓
Wax myrtle	✓		
Elderberry	✓	✓	✓
Mountain mahogany			✓

¹Modified from California Department of Fish and Wildlife (1992). When selecting species for a revegetation project, those native species found in similar environmental conditions near to the project site should be preferred. Check for appropriate species lists when developing projects in other states & countries.

conditions. These woody species take longer to become established, but they provide the long-term ground cover and soil binding needed for effective erosion prevention, soil development and slope stability on these heavily disturbed sites.

C. DECOMMISSIONING EFFECTIVENESS

Road decommissioning is performed to reduce or eliminate the threat of future human-caused sediment delivery from the former road, and its impact on downstream areas, while returning the disturbed lands to their natural watershed function. The effectiveness of road decommissioning tasks, in relation to sediment prevention and watershed protection, is usually expressed

as sediment “savings” over two time periods:

1) the volume of sediment that has been prevented from being delivered to stream channels (long term effectiveness) and 2) the volume of sediment that is eroded from the decommissioned sites and delivered to local stream channels in the first several years after decommissioning activities (short term effectiveness). **The goal of a decommissioning project is to maximize long-term effectiveness (sediment savings) and to minimize short-term sediment release from the treated sites.**

Road decommissioning treatments have been shown to significantly reduce long-term sediment production from forest and ranch roads, including those that have been

TABLE 40. Recommended shrub species revegetation for riparian zones in California¹

Riparian species (common name)	Coastal	Interior valley	Interior foothill
Blue elderberry	✓	✓	✓
Coyote brush	✓	✓	✓
Mule fat	✓	✓	
<i>Ceanothus</i> spp.	✓	✓	✓
Button bush	✓	✓	
California buckwheat	✓	✓	✓
Toyon		✓	✓
California coffeeberry		✓	✓
Red flowering currant			✓
California wild rose		✓	✓
California blackberry		✓	✓
Skunkbush sumac		✓	✓
Fragrant sumac		✓	✓
Indian Hemp		✓	✓
Snowberry	✓		✓
Oceanspray	✓		✓
Twinberry honeysuckle	✓	✓	✓
California grape		✓	✓
Oregon grape	✓		✓

¹Modified from California Department of Fish and Wildlife (1992). When selecting species for a revegetation project in your area, those native species found in similar environmental conditions near to the project site should be preferred. Check for appropriate species lists for other states and countries.

abandoned for years. **In general, the single most effective erosion prevention practice for all road decommissioning treatments, as measured by the reduction of post-decommissioning erosion and sediment delivery, is to correctly follow the generally accepted treatment prescriptions, standards and methodologies for road decommissioning, as outline above (see Weaver et al., 2006).** This is best done by utilizing skilled and experienced heavy equipment operators, and providing sufficient on-the-ground professional/technical oversight while decommissioning work is underway.

Decommissioning treatments for road surface runoff (hydrologic connectivity) and excavation of potentially unstable fill slopes have been shown to be highly

effective sediment control measures. Hydrologic connectivity from the former road can be reduced to near zero by standard road surface ripping (decompaction), cross drain installation and road outslipping (Figure 290). Likewise, **unstable and potentially unstable road and landing fills that are identified and treated (excavated) during routine road decommissioning work has been a highly successful technique** for preventing road-related fill slope failures and sediment delivery. Since not all fill slopes are excavated and removed during decommissioning, there is always the chance that instabilities could develop in the future, but the most susceptible sites will have already been identified and treated.

Decommissioning (excavating) stream crossings using established protocols has also proven



FIGURE 290. *Deep, thorough ripping is a good treatment to largely eliminate surface runoff and “hydrologically disconnect” a former road from nearby stream channels.*

highly effective. Most short-term sediment loss from all road decommissioning sites originates at excavated stream crossings. The primary sources of this sediment delivery, accounting for about 90% of the soil loss from all road decommissioning work, include channel incision, surface erosion, and slumps on the sideslopes of excavated stream crossings. Studies show that operator error (mostly consisting of an equipment operator leaving unexcavated fill in the stream crossing) accounts for about 40% of the potential post-decommissioning erosion. The remaining 60% of sediment loss is judged to be unavoidable and a natural result of the channel developing a stable profile and plan form through the decommissioned stream crossing over the first few years after it was treated.

On most roads, stream crossing excavations will be the single greatest threat reduction treatment to implement, and also the largest short term source of sediment input to stream channels following road decommissioning work. Past monitoring of stream crossing removal has shown that 1) erosion at excavated stream crossings is the principal source of post decommissioning sediment delivery from treated roads (approximately 90%), and 2) a few crossings usually produce the majority of post-decommissioning sediment. The expected short term soil loss from these sites is greatly overshadowed by the long term sediment savings attributed to the decommissioning work.

Post-decommissioning erosion from excavated crossings is minimized by excavating stable, low gradient sideslopes and by completely excavating erodible fill that was placed in the channel when the crossing was constructed (Figure 265). **Typically, stream crossing decommissioning should be at least 95% effective;** that is, 95% of the expected or predicted erosion from a complete washout of the original stream crossing fill (if it was not treated) will have been prevented by decommissioning. The 5% that is eroded is the result of post-decommissioning channel adjustments that can be expected to occur over the first few wet seasons as the exhumed channel adjusts and newly excavated sideslopes stabilize.

It is critical to carefully inspect decommissioned crossings while equipment is performing the work, and while equipment remains onsite, to ensure that prescribed excavation depths and widths are reached and stream banks are sloped back to a stable angle. For larger crossings where some fill materials may remain after excavation, use rock armor or grade control structures where appropriate. However, **the most effective practice is to completely remove all fill materials from the crossing so they are not left to erode and post-treatment**

adjustments can be minimized. Consider staging or sequencing sediment producing activities, such as stream crossing removal work, to avoid superimposing multiple sediment inputs throughout small watersheds that are sensitive to sediment pollution.

D. INSPECTIONS AND MAINTENANCE OF CLOSED ROADS

Closed roads are those temporary and “decommissioned” roads that are no longer open for vehicle traffic and have been proactively treated to remove environmental threats (Figures 291 and 292). Roads that are simply closed to traffic by barriers or gates but have not been treated for existing and potential erosion and sediment delivery problems are not truly considered closed. Gated and barricaded roads require regular seasonal and storm period inspections and maintenance, just like the open and maintained road network.

In theory, when a road is truly closed or decommissioned, all identifiable erosional threats and surface drainage problems have been treated. All stream crossings have been removed (excavated) to their pre-road condition and all permanent erosion control

measures have been implemented. The fill slopes that could fail and deliver sediment to a stream channel have been inspected and those with the potential to fail have been excavated (removed) or otherwise stabilized. Road surface drainage has been treated so that surface runoff is mostly eliminated by deep tilling or decompacting. Any surface runoff from springs or seeps is directed across the former road alignment and drainage is not reliant on functioning ditches. Road drainage structures are constructed on the roadbed to prevent runoff from traveling down the road surface.

Newly closed or decommissioned roads are most vulnerable to erosion during the first several wet seasons after they are treated. Some post-closure erosion is to be expected within excavated stream crossings, some wet areas may show signs of rilling and slumping, and occasionally a fill slope that was not treated (excavated) may show signs of instability. Inspections can be performed several times during the first wet season, and perhaps for a few years thereafter following any significant storms or floods, to look for developing problems. Minor corrective treatments may be prescribed for one or more places along the alignment but most measures will be limited to those that can be performed by hand labor. These might

FIGURE 291. Compared to gates or barriers, a more permanent closure method is to radically out-slope the first 100 feet of the closed road so that the road is too steep to drive.

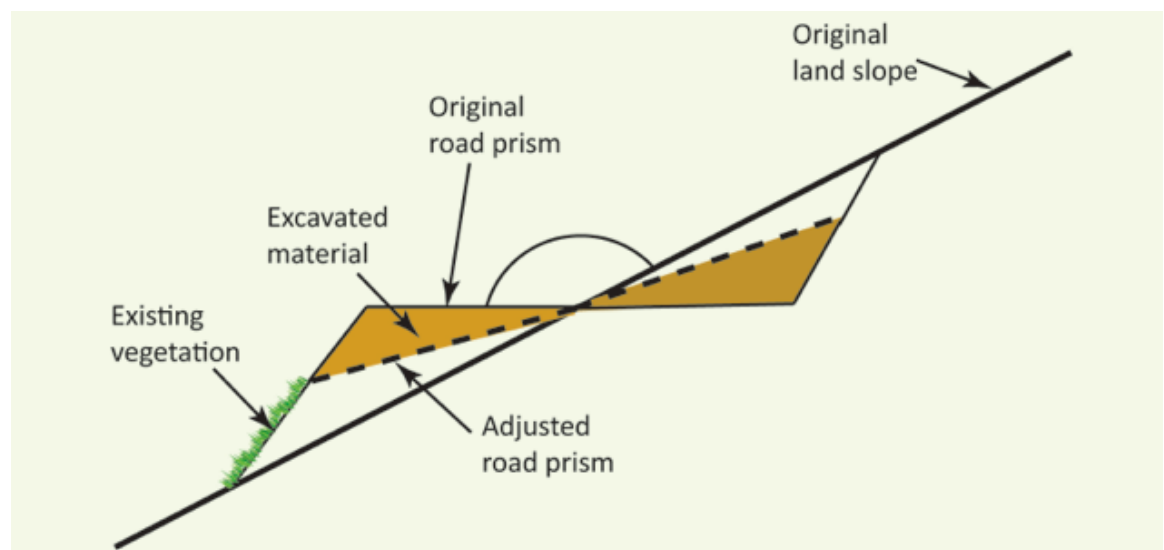




FIGURE 292. *Severe outslipping, which prevents vehicle access, should only be used on temporary roads and decommissioned roads where all stream crossings have first been removed, unstable fill slopes have been excavated or stabilized, and road surface drainage is permanently dispersed. To help ensure vehicles do not use the closed road, logs, boulders and brush can be spread over the surface, especially near the beginning of the road, to discourage unwanted traffic. These roads should need no future maintenance, so vehicle access is no longer needed.*

include planting, mulching, minor work to prevent bank erosion or gully stabilization.

Ideally, closed roads should not require significant maintenance. By definition, roads that have been formally closed (decommissioned) no longer have an open, available access route for heavy equipment to get to sites and perform emergency repairs or maintenance work. Only if there are serious, treatable problems along the alignment and the travel route is fairly easy to reconstruct is it usually worth reopening the road and applying corrective treatments. It does happen, but the problems are typically unforeseen as the road is being closed.

When wet season inspections identify significant problems, the proposed repairs typically must wait until the following dry season so damage is not done to the closed road and water quality is not impacted by heavy equipment operations. Once the repairs have been made, all sites that were disturbed or damaged by the road reopening will then have to be repaired and retreated as the heavy equipment works its way back out after performing the work. It is clearly to your advantage to do a thorough job identifying needed treatments along the road and then closing the road properly and completely the first time through. Regardless, sometimes reopening a closed road in order to treat one or more sites may still be warranted.

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Glossary of Terms

ABANDONED ROAD – A road which is no longer maintained. An abandoned road may or may not still be drivable and may or may not be overgrown with vegetation. In some instances, the term “abandon” is used to signify the process of closing or decommissioning a road (See road abandonment, road decommissioning).

ABNEY LEVEL – A hand-held instrument used to measure slope gradients and vertical angles in the field.

ABRASION – The wearing away of a material by physical processes. Abrasion here relates to both the wearing away of rock particles used in road surfacing and riprap (particle abrasion), as well as the erosion of culvert materials caused by sediment transport in flowing water (culvert abrasion).

ABUTMENT (BRIDGE) – A solid foundation, secured on each stream bank that serves as the foundation for a bridge. Naturally occurring rock outcrops or driven piles may serve as bridge abutments, but most commonly abutments are made of poured concrete foundations, driven steel sheet piles, prefabricated concrete sills, logs or piers.

ACCELERATED EROSION – Erosion which has been caused or increased, directly or indirectly, by human activities or land management. Accelerated erosion is typically thought of as erosion which is not “natural” or that which is excess of that which would have naturally occurred.

ACTIVE ROAD – A road that is part of the overall road network that is (and needs to be) regularly inspected and maintained.

ALTIMETER – A hand-held instrument used to determine elevation or altitude in the field.

ANADROMOUS FISH – Fish that are born and rear in freshwater, move to the ocean to grow and mature, and return to freshwater to reproduce. Salmon, steelhead and shad are examples. While not anadromous, resident fish can also migrate up and down stream channels and may require fish passage designs at stream crossings.

ANGLE OF REPOSE – The steepest slope angle at which a material will freely stand without failing or sliding downslope. The angle of repose of material without cohesion, like loose sand, is about 33 degrees. For material with some cohesion, the comparable term is called the angle of internal friction. Slopes which are steeper than the angle of repose or angle of internal friction are likely to be unstable.

ARCHAEOLOGICAL SITE – A geographic locale that contains the material remains of pre-historic and/or historic human activity.

ARMORED FILL – A type of stream crossing where the stream flows over a dipped road bed and down an armored fill slope rather than through or beneath the fill in a culvert of other drainage structure. Armored fills are used on relatively small stream crossings and in locations where road maintenance is infrequent or not possible during the wet season.

ASPECT – The direction a slope faces with respect to the cardinal compass points.

BACKCASTING – A road construction technique which utilizes a hydraulic excavator to cut a wide bench in front of the machine and below the centerline of the new road, while placing the excavated soil on the bench behind as the new subgrade.

BALANCED BENCHING (BALANCED CUT-AND-FILL) – A road building method used on gentle or moderate sloping land in which material excavated during road construction is used to build the roadbed and fill the low spots along the alignment. In balanced benching, the cut volumes equal the fill volumes and the road is often referred to as a “half-bench” or balanced cut-and-fill road.

BANKFULL WIDTH – The width of the stream measured at the bankfull stage and discharge. Bankfull discharge has a recurrence of 1 to 2 years (mean 1.5 years) and is considered the dominant channel-forming flow. It is typically identified as the point of incipient flooding indicated on

the ground as the upper limit of active channel processes and scour, and the lower limit of perennial vegetation.

BARRIER (FISH PASSAGE BARRIER) – See fish passage.

BASE COURSE – This is the main load-spreading layer of the roadbed immediately beneath the surface course and above the sub-base or prepared native soil materials. It is typically composed of a mix of different sizes of crushed rock or of rock fragments or gravel developed in a rock pit that are compacted in preparation for the application of a surfacing material. It has a relatively low percentage of fines to maintain good strength and drainage.

BEARING SURFACE – The driving surface of the road. Road rocking is a common method of increasing the load bearing capacity of the road surface if the subgrade soils are relatively weak.

BENCH – A naturally occurring bench refers to a relatively flat or low gradient portion of a hillside. A constructed bench is a step or flat area cut into a deep soil or bedrock in an attempt to create a more stable overlying fill and roadbed.

BENEFICIAL USE – In water use law, reasonable use of water for a purpose consistent with the laws and best interest of the people of the state. Such uses include, but are not limited to, the following: instream, out of stream, and ground water uses, domestic, municipal, industrial water supply, mining, irrigation, livestock watering, fish and aquatic life, wildlife, fishing, water contact recreation, aesthetics and scenic attraction, hydropower and commercial navigation.

BERM – A curb or dike (usually earthen) constructed to control water and prevent roadway runoff waters from discharging onto roadside slopes and/or to provide material for subsequent road maintenance. Some berms are unintentionally constructed as a part of routine grading operations and, depending on the road's shape, may or may not interfere with road surface drainage.

BEST MANAGEMENT PRACTICES (BMPs) – Practical guidelines that can be used to reduce the environmental impact of roads and road management activities (including

construction, erosion control, maintenance and decommissioning) and protect water quality. BMPs are a key component of planning, designing, constructing, maintaining and closing roads to minimize their potential impact on the environment. Best management practices for road-related activities are intended to provide simple, practical and cost-effective methods for protecting water quality and aquatic resources, and other environmental values, before, during and after road management activities are undertaken.

BEVELED INLET – See improved inlet.

BIOTECHNICAL ENGINEERING – Utilizes live vegetation integrated with hard structural elements (e.g., logs, riprap, concrete blocks, and gabions) to create complex erosion control structures that provide soil reinforcement, and increased slope stabilization and protection (See soil bioengineering).

BORROW SITE (BORROW PIT) – Locations on the landscape where sand, gravel and/or rock is excavated for use in road construction activities elsewhere in the watershed. Borrow pits and rock quarries on California wildlands may be subject to the Surface Mining and Reclamation Act (SMARA) which requires landowners to develop site reclamation plans for many such sites (See rock pit).

BOTTOMLESS ARCH (PLATE ARCH, BOTTOMLESS "CULVERT") – Three-sided structures that have sides and a top and use the natural channel for the bottom, often composed of metal plates or concrete. They range in size from a few feet to more than 35 feet in width and are supported on footings (usually concrete). Bottomless arches are available in a variety of shapes including semicircular arches, elliptical arches and boxes. They are installed in stable channel reaches where the streambed is not expected to show significant scour. Bottomless arches are an environmentally attractive alternative to box, pipe, and pipe arch culvert designs and are commonly used where fish passage is required.

BOTTOM-UP ROAD CONSTRUCTION – Road construction techniques which involve excavating a bench on the hillside and then filling and compacting fill on the bench to build up a stable roadbed at the desired elevation (as opposed to sidelaying or top-down construction).

BOX CULVERT (OPEN TOP CULVERT) – An open-top trough-like drainage structure, usually constructed of lumber or iron, built into and obliquely across the road surface. It acts to collect and discharge road surface runoff and, less often, ditch flow across the road. Open-top box culverts are more commonly used on ranch roads than on forest roads used for logging operations.

BUFFER STRIP – An area or strip of land adjacent a stream containing relatively undisturbed soils and vegetation that acts as a filter or buffer for erosion and runoff from upslope roads or other land management activities.

BUTTRESS – A gravitational structure designed to resist lateral forces, typically at the base of an unstable cutbank or an oversteepened, potentially unstable fill slope. It is typically constructed of large riprap rock, gabions, or other gravitational structures.

CENTER STAKE METHOD – A method of curve layout, especially for switchbacks, in which a stake is used to mark the center of the curve and radial measurements are taken out from the stake to mark the curve on the ground.

CHECK DAM – A temporary or permanent grade control structure placed across a natural or manmade channel or drainage ditch intended to prevent downcutting. Check dams are almost always used in a series to control the grade of the stream and to reduce or prevent scour and channel erosion by reducing flow velocity and encouraging sedimentation. Check dams have very specific design requirements that must be met or they will be prone to failure. Straw bale check dams are often used in swales and small channels below a new road alignment to temporarily collect and store sediment eroded from a work site, but will usually not provide protection against channel downcutting for more than a single season.

CLASS I WATERCOURSE (CALIFORNIA) – For forestry purposes, those watercourses serving as domestic water supplies, including springs, onsite and/or within 100 feet downstream of the forest operations area, and/or those watercourses where fish are always or seasonally present onsite, including habitat to sustain fish migration and spawning.

CLASS II WATERCOURSE (CALIFORNIA) – For forestry purposes, those watercourses where fish are always or seasonally present offsite within 1000 feet downstream, and/or watercourses which contain aquatic habitat for non-fish aquatic species. Class III watercourses that are tributary to Class I watercourses (hence within 1000 feet of a fish-bearing watercourse) are specifically excluded.

CLASS III WATERCOURSE (CALIFORNIA) – For forestry purposes, watercourses that have no aquatic life present, but still show evidence of being capable of sediment transport downstream to Class I or Class II watercourses under normal high water flow conditions after completion of timber operations.

CLASS IV WATERCOURSE (CALIFORNIA) – For forestry purposes, man-made watercourses, usually supplying downstream established domestic, agricultural, hydro-electric or other beneficial uses (See man-made watercourse).

CLEARING – The act of removing the standing vegetation along a proposed road alignment. Clearing is one of the tasks of road construction, and is followed by grubbing and grading (earthmoving).

CLINOMETER – A pocket field instrument which measures slope steepness in degrees and percent.

CLOSED ROAD – A road that has been closed to vehicle traffic, usually with barricades, berms, gates, or other closure devices, but future use is anticipated (See road closure, road decommissioning).

CMP – Corrugated metal pipe, often used synonymously with culvert. Metal culverts are typically made from galvanized steel or aluminum.

COMPACTION – An increase in bulk density (weight per unit volume) and a decrease in soil porosity resulting from applied loads, vibration or pressure.

CONTROL POINTS – Locations along a proposed road alignment that control the position of the road. Examples of control points include rock outcrops, the end of another road you must tie in to, a saddle on a ridge that

you need the road to pass through, a favorable stream crossing location, a landslide that must be avoided, etc.

CORROSION – Corrosion is the wearing away of a metal through an oxidation/reduction chemical reaction on its surfaces. Rust (oxidation of iron) is a common corrosion process for steel culverts and, combined with abrasion, is the most common reason for culvert replacement. In corrosive environments, protective coatings, linings, and pavings on the inside and/or outside of steel culverts can be used to extend its service life. Plastic pipe is not subject to corrosion.

CRITICAL DIP (DIVERSION DIP; DIPPED CROSSING) – A critical dip is a dip in the road bed at a culverted stream crossing, preferably at the down-road hinge line of the fill, that prevents stream diversion. The dip is designed to act as an overflow structure if the main culvert were to plug and ponded water overtopped the fill. Although somewhat like a rolling dip, it must have sufficient capacity (width and depth) to carry flood flows from the stream without itself overtopping and diverting down the road. An alternate solution is to dip the entire fill, centered over the hinge line.

CROSS ROAD DRAIN – A deeply cut ditch, excavated across a road surface, which drains the roadbed and inboard ditch. Cross-road drains are installed on decommissioned roads to drain springs, seeps, road surfaces and ditches. They are more substantial and deeper than conventional waterbars used to drain forest and ranch roads, and are steeper and more abrupt than rolling dips. Well-constructed cross-road drains will often be deep enough to prevent vehicular access to an area and are typically installed on roads which are being closed permanently or for several years. Cross-road drains are typically constructed (excavated) using a bulldozer, a hydraulic excavator, or a backhoe.

CROWNED – A crowned road surface is one in which the road surface slopes gently away from the centerline of the road and drains to both sides of the crown. Crowning a road surface is one method of providing for surface drainage. Typically, the inside half of the road drains inward to the cutbank and ditch, while the outside half drains out across the fill slope.

Crowns can also be placed anywhere on the running surface of the road to control road surface runoff.

CRUSHED ROCK – Rock which has been run through a mechanical crusher to produce a more uniform range of angular particle sizes. Crushed rock is useful as a road surfacing material.

CULVERT – A transverse drain, usually a metal, plastic or concrete pipe, set beneath the road surface which drains water from the inside of the road to the outside of the road. Culverts are available in many shapes and are used to drain ditches, springs and streams across the road alignment.

CULVERT CROWN – The top of a drainage culvert.

CULVERT INVERT – The floor or bottom of a drainage culvert.

CULVERT LINERS – See trenchless technologies.

CULVERT RISER – A vertical standpipe on a culvert inlet, usually of the same diameter as the culvert, used to allow water to pass while sediment is deposited in a surrounding basin. Risers are usually slotted to allow water to flow into the vertical pipe as water levels rise around it. Risers usually have an open top so water can cascade into the top when the maximum desired water level is reached.

CULVERT SNORKEL – A vertical riser or stand pipe, of the same or smaller diameter as the culvert, welded into the top side of the culvert just downstream from the inlet. While risers are usually connected to the end of a culvert inlet with a 90 degree elbow, snorkels are welded into the top of the culvert while the culvert inlet remains open. Snorkels are used as an emergency culvert inlet if the main culvert inlet becomes plugged with debris or its capacity is exceeded.

CULVERT SPAN – The widest dimension of a culvert, regardless of its shape.

CURVE LAYOUT – The technique or method of laying out a road curve on the ground before a road is constructed. Curves may be broad enough such that little

or no layout is necessary. Switchbacks and sharp curves, especially those on moderate or steep slopes, often require the use of surveying techniques to ensure the best, most functional design (See center stake method).

CUT-AND-FILL – A method of road construction in which a road is built by cutting into the hillside (usually using a bulldozer) and spreading the spoil materials in low spots and as sidecast along the route. “Cut-and-fill” is often a synonym for “cut-and-sidecast” (See balanced benching, top-down road construction).

CUT SLOPE (CUTBANK) – The artificial face or slope cut into soils or rock along the inside of a road.

DEBRIS – Rocks, sediment, and organic material (logs, branches, brush, wood, leaves, etc.), that are carried or transported in surface runoff, ditch flows or flood flows in stream channels that often cause plugging of drainage structures. Floating debris and transported sediment are the main causes of culvert plugging and stream crossing failure.

DEBRIS CONTROL STRUCTURES – Structures built in a stream channel to screen or deflect floating woody debris before it reaches, and can plug, the culvert inlet. They include debris screens, debris racks, and debris deflectors.

DEBRIS DEFLECTOR – A debris control structure installed in front of a culvert inlet to deflect floating organic debris away from the culvert inlet, or to realign it to float through the culvert, so as to prevent plugging.

DEBRIS FLOW – A rapidly moving, saturated mass of rock fragments, soil and mud, with more than half of the particles being larger than sand size. Debris flows may originate as streamside or headwater debris slides that incorporate water, sediment and woody debris as they move down a channel during storms or floods. Debris flows generally travel down small, steep stream channels and result in scouring of streambed over distances from several hundred feet to several miles.

DEBRIS RACK (DEBRIS SCREEN, TRASH RACK) – A structure constructed upstream of a culvert inlet to screen out floating debris that could otherwise plug the culvert inlet. Debris screens should be designed

to allow small debris to pass and float through the culvert, while retaining larger debris (larger than the culvert diameter) that could block the pipe entrance.

DEBRIS SLIDE – A slow to rapid slide, involving downslope translation of relatively dry and predominantly unconsolidated materials, with more than half of the particles being larger than sand size.

DEBRIS TORRENT – See debris flow.

DECKING – The traveling surface (usually wood planks or steel sheets) of railroad flatcar and steel I-beam bridges used on forest, ranch and rural roads. Decking is usually bolted in place and can be replaced when it is worn out.

DECOMMISSIONING – See road decommissioning.

DECOMPACTION – See ripping.

DESIGN FLOW (100-YEAR RECURRENCE (CA)) – The design flow for a stream crossing culvert typically ranges between a 20 and 100 year recurrence interval, depending on the sensitivity of the road, the crossing and downstream resources. Increasingly, stream crossings are designed to accommodate the 100-year peak flow; a flood flow that statistically has a 1-percent chance of occurring in any given year. This flow can be estimated by empirical relationships between precipitation, watershed characteristics and runoff, and then may be modified by direct channel cross section measurements and other evidence. However, sizing culverts for a 100-year flood flow alone does not ensure adequate capacity for wood and sediment.

DITCH (ROADSIDE DITCH) – A dug ditch or small channel, usually at the base of the cutbank and along the inside edge of a road used to collect water from the road and emerging from the cutbank, and to carry it away to a safe disposal area. There may be a ditch on both sides of through cut and crowned roads.

DITCH RELIEF CULVERT – A drainage structure or facility (usually a culvert pipe) which will move water from an inside road ditch to an outside area, beyond the outer edge of the road fill.

DIVERSION POTENTIAL (DP) – A stream crossing has a diversion potential if, when the culvert plugs, the stream would back up and flow down the road or ditch, rather than directly over the fill crossing and back into the natural drainage channel.

DOWNSPOUT – A pipe, flume or trough attached (bolted) to a culvert outlet and used to convey water from the culvert outlet down over and beyond the road fill so as to prevent erosion. The downspout on a stream crossing culvert should be a full-round pipe that is attached to the culvert where it emerges from the fill using an elbow. On steep slopes, downspouts may need to be anchored to the fill slope. Culverts that are placed and discharged at the base of the road fill discharge directly into the natural channel or hill-slope and usually do not require a downspout.

DRAINAGE BASIN – See watershed.

DRAINAGE BLANKET – Also called aggregate filter blankets, these fabric encased aggregate layers are designed and placed at localized wet areas beneath cut-and-fill and backcast constructed roads, or at the base of wet cutbanks to remove groundwater beneath the roadbed and to keep the subgrade dry. A well-drained subgrade can support up to 50% more weight than poorly drained, well graded soils.

DRAINAGE STRUCTURE – A structure installed to control, divert or to cross over water, including but not limited to culverts, bridges, ditch drains, fords, waterbars, outsloping and rolling dips.

DROP INLET – A vertical riser on a culvert inlet, usually of the same diameter as the culvert, and often slotted to allow water to flow into the culvert as streamflow rises around the outside. Drop inlets are often used on ditch relief culverts where cutbank ravel would plug the inlet to a horizontal culvert. Drop inlets are sometimes fitted with a cap or top to protect them from cutbank ravel, and are slotted or cut away at the ditch level to allow flow to enter from the ditch (See riser, snorkel).

DRY SEEDING – A method of spreading seed on the ground surface. Dry seeding can be accomplished

by drilling (actually placing seed in the ground and covering it) or by broadcasting (where seed is aerially spread over the surface of the ground).

EARTHFLOW – A mass-movement landform and slow-to-rapid mass movement process characterized by downslope translation or “flow” of soil and weathered rock over a discrete shear zone at the base, with most of the particles being smaller than sand.

EASEMENT (RIGHT-OF-WAY AGREEMENT) –

An agreement which defines the conditions under which one party may use a road or roads owned by someone else. An easement is usually longer lived than an agreement, which may apply to a limited period of use.

EMBANKMENT – Excavated soil materials, placed and compacted, used to construct and raise the road subgrade. Cut-and-fill roads have an outside fill that is called an embankment fill.

EMBEDDED CULVERT – An embedded culvert is one that has been embedded, or partially sunk, into the bed of a stream channel. “Embedment Depth” is the depth the culvert is embedded from the invert of the culvert barrel to the top of the embedding material. It is usually expressed as the percentage of the culvert diameter that is embedded (e.g., 30% embedded).

EMERGENCY OVERFLOW CULVERT – A secondary culvert, installed higher in the fill than the primary culvert, designed to transmit streamflow through the stream crossing fill if the main culvert plugs or its capacity is exceeded during a flood event. They are designed to reduce the risk of overtopping and failure. Emergency overflow culverts are installed in stream crossings where the main culvert is prone to plugging, it is undersized and cannot be replaced, or where the fill is very deep or very large and failure would cause severe downstream ecological damage or safety concerns. Emergency overflow culverts are sometimes installed in place of a critical dip or dipped fill where those treatments are not feasible.

EMERGENCY ROAD MAINTENANCE

– See storm maintenance.

ENDHAULING – The removal and transportation of excavated material to prevent sidecast, and the storage of the material in a stable location where it cannot enter stream channels. Endhauling is usually accomplished using dump trucks, but on larger jobs may be performed by mobile scrapers.

ENERGY DISSIPATOR – A device or material used to reduce the energy of flowing water. Energy dissipators are typically used at and below culvert outlets and other drainage structures to prevent erosion.

ENVIRONMENTAL IMPACT – The positive or negative effect of any action, or group of actions, upon a given area or resource.

EPHEMERAL STREAMS – Streams that contain running water only sporadically, such as during and immediately following storm events.

EQUIPMENT LIMITATION, EQUIPMENT EXCLUSION – The terms are used when the use of heavy equipment is to be limited or prohibited, respectively, for the protection of water quality, the beneficial uses of water, and/or other wildland or forest resources.

ERODIBLE SOILS – Soils which are relatively prone to erosion by raindrop impact and surface runoff. Granular, non-cohesive soils (such as soils derived sand dunes or from decomposed granite) are known to be especially erodible.

EROSION – The dislodgement of soil particles caused by wind, raindrop impact or by water flowing across the land surface. Erosion usually refers to processes of surface erosion (raindrop erosion, rilling, gullyng and ravel) and not to mass soil movement (landsliding).

EROSION CONTROL – The act of controlling on-going erosion caused by raindrop impact, rilling, gullyng, raveling and other surface processes.

EROSION HAZARD RATING (EHR) – A calculated measure of the susceptibility of soils to erosion by raindrop impact and surface runoff. According to the California Forest Practice Rules, EHR is calculated using a defined field methodology, and the resulting rating

(low, moderate, high, extreme) influence subsequent land management practices which can be employed.

EROSION PREVENTION – Preventing erosion before it has occurred. Erosion prevention is typically less expensive and more effective than controlling erosion once it has started. Erosion prevention is intended to protect a road, including its drainage structures, cut and fill slopes, road bed and other disturbed areas from damage, and to protect water quality.

EROSION-PROOF – The act of performing erosion control and erosion prevention activities which will protect a road, including its drainage structures and fills, from serious erosion during a large storm and flood.

EXCESS MATERIAL – See spoil.

FALL LINE (FALL LINE ROAD) – The fall line of a slope is the direction perpendicular to the slope's contour; that is; it is the line straight up or down a hillslope. A fall line road is a road, or road reach, that goes straight up or down a hillside. Fall line roads can be steep or gentle, depending on the slope gradient of the hill.

FAVORABLE GROUND – Terrain which is favorable for road construction, usually consisting of gentle and stable slopes, benches and ridges.

FISH PASSAGE – The unimpeded movement of anadromous or resident fish up or down a stream channel in all their freshwater life stages. It is often discussed with respect to stream crossings, where roads cross stream channels that are used by fish and/or other aquatic organisms. If passage is blocked to one or more life stages of a fish, when the fish would otherwise be passing through the stream reach, the obstruction is considered a barrier.

FILL – The material that is placed in low areas, compacted and built up to form the roadbed or landing surface.

FILL SLOPE – That part of a road fill between the outside edge of the road and the base of the fill, where it meets the natural ground surface.

FILL SLOPE EXCAVATION – Excavation and removal of unstable or potentially unstable soil and organic debris from the outside fill slope of a road, turnout or landing. Fill slope excavations are performed as a preventive measure to guard against landsliding of unstable material into downslope stream channels. They may be performed on active landings, or as a part of road and landing decommissioning.

FILTER FABRIC – See geotextile.

FILTER STRIP – See buffer.

FILTER WINDROW – A row of slash and woody debris laid and pressed down along the base of a road fill or sidecast slope to contain soil eroded from the fill slope. Filter windrows are often used to contain erosion from fill slopes and sidecast areas where a road approaches and crosses a stream channel.

FISH-BEARING – A stream which supports fish during some part of the year.

FLARED INLET – A culvert inlet which is flared or widened to increase its capacity and reduce the chance of inlet plugging and damage. Flared inlets are culvert attachments that are bolted or secured to the culvert inlet with banks. They are available for most culvert materials and shapes (See improved culvert inlet).

FLATCAR BRIDGE – A portable bridge constructed from a railroad flatcar. Single flatcar bridges can span channels top widths up to about 80 feet wide.

FLOW TRANSFERENCE – A method of estimating the peak flows for an ungaged stream by using flow data from a hydrologically similar, nearby watershed that has a long term gaging record. In general, local stream-flow data are more likely to represent drainage-basin characteristics that determine peak flows than regional regression equations or other analytical relationships.

FORD – A shallow place with good footing where a river or stream may be crossed in a vehicle. A ford is mostly a natural phenomenon, in contrast to a low water crossing, which is an artificial bridge that allows crossing a river

or stream when water is low. Fords may be unimproved (crossing on the natural streambed that is rocky or on bedrock) or improved (usually by artificial hardening of the streambed). A hardened ford is a ford strengthened by rock, concrete or other hardened materials built across the bed and banks of a live or dry stream which allows vehicle passage during low flow periods. A ford is normally only suitable for very minor, low traffic roads and becomes impassable during periods of moderate streamflow.

FRENCH DRAIN (UNDERDRAIN; PIPE UNDERDRAIN) – A buried trench, filled with coarse aggregate, which acts to drain subsurface water from a wet area and discharge it in a safe and stable location. French drains should be lined with filter fabric to keep soil from plugging the drain rock. They are often used beneath roadside ditches where the cut slope is wet and water would otherwise saturate the adjacent road bed. The standard underdrain is the pipe underdrain. A pipe underdrain consists of a perforated pipe near the bottom of a narrow trench lined with filter fabric and backfilled with permeable material. The pipe underdrain provides for much faster removal and discharge of intercepted groundwater.

FULL BENCH ROAD – Road construction technique in which the bench cut width is the same as the road width, and no fill is used in construction. Endhauling is needed to remove the excavated spoil material.

FULL FILL ROAD – Road construction technique in which no bench cut is made into the hillslope and the road prism is made entirely from imported fill. The ground surface must still be prepared (grubbed and bared) for the fill to bind to the underlying substrate. Full fill roads are most commonly built when crossing wet soils and valley bottoms (where the road has been slightly elevated), and wherever a road crosses an incised stream channel.

GEOMORPHIC – Pertaining to the form or shape of the earth's surface, and to those processes that affect and shape the land's surface. Geomorphic processes include all forms of soil erosion and mass soil movement, as well as other processes.

GEOTEXTILE (FILTER FABRIC) – Permeable textile made from synthetic, plastic fibers used to separate, filter,

reinforce, protect, and/or drain rock, soil and other related materials. Geotextiles are synthetic fabrics manufactured and designed for use in subsurface and surface drainage applications. They are especially useful in maintaining a separation between coarse road aggregate and finer native soil particles beneath, as well as in erosion control applications. It comes in a number of different types (with different specifications and uses) and is used in a number of different road building settings. Manufacturer's specifications should always be consulted before using a fabric for drainage or other engineering applications.

GPS – The Global Positioning System is a global navigational system based on earth orbiting satellites that provides precise 2-dimensional information (longitude and latitude) of location. Handheld GPS units are useful for mapping road location or tracking potential road alignments. GPS accuracy can be affected by dense forest canopy, lack of satellite coverage, or atmospheric conditions.

GRADE BREAK – The location of a reversal in the slope (grade) of the road from climbing to falling, or from falling to climbing. Grade breaks occur where a road contours the landscape and rises and falls over short distances, or where rolling dips have been built into the road to drain the road surface.

GRADE CONTROL – The term grade control can be applied to any alteration in the watershed which provides stability to the streambed. The most common method of establishing grade control is the construction of in-channel grade control structures designed to provide hard points in the streambed or gully capable of resisting erosive forces of flowing water. Grade control structures must adhere to specific design criteria to be effective.

GRADING – the act of excavating and moving soil along the road alignment to an established grade-line during road construction or reconstruction. Grading is one of the tasks of road construction, and is preceded by grubbing and followed by surfacing. Grading also refers to the mechanical smoothing of the roadbed to maintain a free-draining, smooth travelling surface.

GROUNDWATER – The standing body of water beneath the surface of the ground, consisting largely of surface water that has seeped down into the earth.

GRUBBING – The act of scarifying the surface of the ground along a proposed road alignment prior to placing fill or sidecast on top. Grubbing is one of the tasks of road construction, and is preceded by clearing and followed by grading.

GULLY (GULLIED) – An erosion channel formed by concentrated surface runoff which is generally larger than 1 ft² in cross sectional area (1' deep by 1' wide). Gullies often form where road surface or ditch runoff is directed onto unprotected slopes, or where a stream has been diverted into a ditch or onto an unprotected slope.

HABITAT – The place where a plant or animal (including aquatic life and fish) naturally or normally lives and grows.

HARDENED FORD – See ford.

HEADWALL – A vertical or sloping (beveled) wall that encompasses the culvert inlet and provides a transition between the stream channel and the inlet. Headwalls can be constructed of various materials, with rock, masonry and concrete being the most common. Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, and providing embankment protection against erosion (See wingwalls).

HEADWATER SWALE – The swale or dip in the natural topography that is upslope from a stream, at its headwaters. There may or may not be any evidence of overland or surface flow of water in the headwater swale.

HINGE LINE – The intersection between the approaching roadbed and the full fill of a culverted stream crossing. Typically, roads go from a cut-and-fill or full bench cross section on a hillside to a full fill cross section where fill material has been used to "fill" the stream crossing during road construction. There are two hinge lines on a stream crossing fill; one on the left and one on the right.

HORIZONTAL CURVE – The horizontal arc of a circle whose radius is that of the curve of the road.

HYDROLOGIC CONNECTIVITY (HYDROLOGICALLY CONNECTED ROAD) – Hydrologic connectivity refers to the length or proportion of a road or road network that drains runoff directly to streams or other water bodies. Any road segment that has a continuous surface flow path to a natural stream channel during a ‘design’ runoff event is termed a hydrologically connected road or road reach. Connectivity usually occurs through road ditches, road surfaces, gullies, rolling dips, waterbars or other drainage structures or disturbed surfaces associated with roads.

HYDROSEEDING (HYDRAULIC SEEDING) – A technique for applying a slurry of seed, fertilizer and mulch by hydraulically spraying the mixture on the bare ground surface. Hydroseeding is typically performed on slopes that are too steep for dry seeding.

IMPROVED CULVERT INLET (BEVEL EDGED, SIDE TAPERED AND SLOPE TAPERED) – Compared to a projecting culvert with square edges, an improved inlet will increase flow capacity. Improved inlets include a beveled or rounded inlet edge (5 to 20% flow increase), a side tapered inlet (25-40% flow increase), or a slope tapered inlet (up to 100% flow increase). The inlet edge causes contractions of the flow at the culvert inlet. A beveled inlet edge decreases flow contraction at the entrance, thereby increasing flow capacity. A side tapered inlet has an enlarged face area within the culvert inlet throat accomplished by tapering the sidewalls out in a funnel shape. The slope-tapered inlet combines an efficient throat section with additional head as the flow drops into the throat (See flared inlet).

INACTIVE ROAD – A road needed only infrequently, for fire control, tree thinning or other intermittent forest or ranch activities. These roads remain largely unused for most of the year, or for several years in succession, but have drainage structures intact and require regular inspection and maintenance.

INBOARD DITCH – The ditch on the inside of the road, usually at the foot of the cutbank.

INFILTRATION – The movement of water through the soil surface into the soil.

INNER GORGE – A stream reach bounded by steep valley walls that terminate upslope into a more gentle topography. Inner gorge slopes are usually developed by mass wasting processes in areas of rapid stream down-cutting or uplift and may display signs of instability.

INSLOPED ROAD – Road surface that is sloped in toward the cutbank. Insloped roads usually have an inboard ditch that collects runoff from the road surface and cutbank.

INTERMITTENT STREAM – Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. Intermittent streams flow in response to rainfall, and then for some period after the cessation of rainfall (being fed by groundwater discharge).

INTERVISIBLE – The ability to see from one feature to the next. Turnouts which are inter-visible can be seen from one another.

LANDING – Any place on or adjacent to a logging site (usually on a road) where logs are collected and assembled for further transport.

LANDING EXCAVATION – See fill slope excavation.

LANDSLIDE – The gravitational downslope movement of a mass of rock, debris, or earth. Landslides are classified by material type (e.g., rock, debris, and earth) and process type (e.g., slide, flow, fall, topple, and spread). Includes but is not limited to debris slides, debris flows (torrents), rock falls and topples, debris avalanches, and earth flows. It does not, however, include dry ravel or surface erosion by running water. It may be caused by natural erosional processes, by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

LEAD-OUT DITCH (LEAD OFF DITCH, BERM BREAKS, DITCH CUTOUTS OR DITCH TURNOUTS) – Excavations through a roadside berm or low through cut that are designed to divert water out of the ditch or off the roadway (at a point where this doesn’t occur naturally). The lead-out ditch is usually a gash or sweeping cut from the side of the road and onto the

adjacent natural slope, made at a grade slightly steeper than the ditch or road they are intended to drain.

LOG CROSSING – A drainage structure made out of logs laid in and parallel to a stream channel and then covered with soil. Before the mid-1980's log crossings were frequently used as "permanent stream crossings" instead of culverts or bridges in forested areas of the Pacific Northwest. Log crossings are highly susceptible to plugging and washout during storm flows. Log crossings are used today only for temporary stream crossings that are to be removed prior to the wet weather season.

LOGGING ROAD – A road other than a public road used by trucks going to and from landings to transport logs and other forest products.

LOW-VOLUME ROAD – A transportation system or road typically constructed to manage, extract resources or otherwise develop rural or wildland areas. They are typically designed for low traffic levels (average <400 vehicles per day) but may also be designed to accommodate commercial loads.

LOW WATER CROSSING – See ford.

MAINTAINED ROAD – A road which is regularly inspected and whose cut slopes, road surface, drainage structures and fill slopes are maintained to prevent erosion and deterioration.

MAN-MADE WATERCOURSE – A watercourse which is constructed and maintained to facilitate man's use of water. They include but are not limited to ditches and canals used for domestic, hydropower, irrigation and other beneficial uses. According to California forestry regulations, man-made watercourses technically do not include road-side drainage ditches.

MASS SOIL MOVEMENT – Downslope movement of a soil mass under the force of gravity. Often used synonymously with "landslide," common types of mass soil movement include rock falls, slumps, earthflows, debris avalanches, debris slides and debris torrents (See landslide).

MITERED INLET – A sloping inlet that is cut or installed usually at the upstream end of a culvert, parallel and against or close to the embankment slope. Mitering the inlet reveals a larger opening at the culvert entrance, and thereby increases the hydraulic efficiency and potential flow volume compared to a projecting inlet. A mitered inlet with a sloping headwall further increases the hydraulic efficiency of the inlet. Mitered inlets on metal culverts are usually made with a cutting torch, while mitered inlets on plastic culverts are usually cut with a saw (See improved culvert inlet).

MULCH (MULCHING) – Material placed or spread on the surface of the ground to protect it from raindrop, rill and surface erosion. Mulches include wood chips, rock, straw, wood fiber, hydromulch and a variety of other natural and synthetic materials. Mulching is the process of spreading mulch.

MULTI-BENCHING – A road building method used on moderate or steeply sloping land in which two or more benches are excavated into the native hillslope and fill is then compacted on the benches to provide a stable road bench.

OBSTACLE – Locations along a proposed road alignment that need to be avoided. Obstacles include rock outcrops, landslides, extremely steep slopes, unsuitable stream crossing locations, wet areas, lakes, etc.

OUTLET (CULVERT OUTLET) – The downstream opening in a drainage structure or pipe where the water leaves the structure.

OUTSLOPED ROAD – Road surface that is sloped out away from the cutbank toward the road's fill slope. Outsloped roads may or may not have an inboard ditch.

OUTSLOPING – The act of converting an insloped road to an outsloped road. Outsloping can also refer to the act of excavating the fill along the outside of the road and placing and grading it against the cutbank, thereby creating an outsloped surface where the roadbed once existed. In road decommissioning, partial or full outsloping (recontouring) are two methods for providing permanent drainage dispersal from the former road bed.

PARTIAL BENCH – A partial bench road is one in which the roadbed is part bench and part fill, somewhere between a full bench and a full fill road (See cut-and-fill).

PEAK FLOW (FLOOD FLOW) – The highest amount of stream or river flow occurring in a year or from a single storm event. For design purposes, roads and drainage structures are typically built to withstand a peak flow event of a given recurrence interval, such as the 100-year flow event.

PERENNIAL STREAM – A stream that typically has running water on a year-round basis.

PERMANENT ROAD – A road which is planned and constructed to be part of a permanent all-season transportation system. These roads have a surface which is suitable for hauling of forest and ranch products, and for the passage of normal vehicle traffic throughout the entire winter period and have drainage structures, if any, at watercourse crossings which will accommodate the design (100-year) flood flow. Permanent roads receive regular and storm-period inspection and maintenance.

PERMANENT WATERCOURSE CROSSING – A watercourse crossing that will be constructed to accommodate the estimated 100-year flood flow, including woody debris and sediment, and will remain in place and continue to be maintained until they are upgraded or removed.

PERMEABLE FILL – See drainage blanket.

PIPE JACKING/ RAMMING – See trenchless technologies.

PLATE ARCH – See bottomless arch.

PROJECTING INLET – An inlet configuration where the culvert pipe projects from the roadway fill into the streambed, without mitering, beveling or headwall construction.

PUT-TO-BED – “Put-to-bed” is a colloquial name for the process of pro-actively abandoning (decommissioning or closing) a road by eliminating the risk of sediment production until the road is again needed in future years. “Putting-to-bed” or road closure involves completely removing stream crossing fills and associated drainage

structures and eliminating the risk of sediment production from roads and landings (See road decommissioning).

QUALIFIED PROFESSIONAL – An experienced, often licensed, professional who interprets complex physical or biological processes and/or designs roads and road structures. They may include engineers, geologists, biologists and other resource or construction specialists.

QUARRY – A site where rock, riprap, aggregate, and other construction materials are extracted, usually from a large rock outcrop or rock face. Quarry materials are usually extracted by ripping or blasting, and often need to be processed by crushing or screening to produce the desired gradation of rock sizes.

RANCH ROAD – A road other than a public road used by ranch and farm vehicles in the conduct of ranching operations. Ranch roads are sometimes used for hauling forest products and thereby are also classified as, and subject to, the same regulations as logging roads.

RANGE FINDER – A hand-held field instrument used to measure distances less than about 1000 feet.

RATIO (SLOPE) – A way of expressing slope gradient as a ratio of horizontal distance to vertical rise, such as 3:1 (3 feet horizontal for every 1 foot vertical rise of fall).

RATIONAL FORMULA (METHOD) – An empirical method for estimating peak flows from a small watershed. The rational formula is often used to estimate flows and to select appropriate culvert sizes for small, ungaged stream channels crossed by a road.

RAVEL (DRY RAVEL) – Soil particles dislodging and rolling down a slope under the influence of gravity. Ravel occurs most rapidly when a cohesionless soil on a steep slope dries out. Raveling is dramatically increased when frost acts on the exposed soil. Ravel on some steep, bare cutbanks can quickly fill ditches and supply sediment that is then eroded and moved to nearby ditch relief culverts or streams by concentrated ditch flow.

RECONSTRUCTION (ROAD) – The upgrading or rebuilding of a road that is abandoned or substandard in one or more elements of its design (See road reconstruction).

RETAINING STRUCTURE (RETAINING WALL) – An engineered structure designed to resist the lateral displacement of soil, especially along the base of a cutbank, the base of a road fill or as a part of a newly constructed road embankment. It is commonly used to support a roadway or to add road width on steep terrain or where there has been a fill slope failure that narrowed the road. They are often constructed of gabions, reinforced concrete, timber cribs, or mechanically stabilized earth.

RILL – An erosion channel, varying in size from a rivulet up to about 1 ft² in cross sectional area, that typically forms where rainfall and surface runoff is concentrated on fill slopes, cutbanks and ditches. If the channel is larger than 1 ft² in size, it is called a gully.

RIPARIAN – The banks and other adjacent terrestrial environs of lakes, watercourses, estuaries and wet areas, where transported surface and subsurface freshwater provides soil moisture to support mesic vegetation.

RIPPING (ROAD) – The process of breaking up or loosening compacted soil (e.g., skid trails, spur roads or landings) to better assure penetration of roots of young tree seedlings and to increase infiltration. It is also termed decompaction (See scarified).

RIPRAP – Large, durable rock, or other suitable material, used to protect the underlying soil from erosion, usually by flowing water. Riprap is used to armor shorelines, streambeds, bridge abutments, pilings and other structures against scour, water or ice erosion. Riprap is usually angular (not platy or round) and sized to resist scour or movement from the expected flows. Riprap, or riprap sized rock, is also used to buttress fills and cuts that might otherwise be unstable and prone to failure.

RIVER RUN ROCK – Aggregate (gravel) that is excavated from a river bed. River run rock is usually well rounded and, unless it is screened, also contains sand.

ROAD ABANDONMENT – Road abandonment was once synonymous with blocking the road and letting it grow over with vegetation. Today, proper road abandonment involves a series of proactive steps and activities which essentially stormproof (decommission) a road so that further maintenance will not be needed and significant erosion will not occur. Road abandonment is a term sometimes used in California forestry that is comparable to road decommissioning (See road decommissioning).

ROAD CLOSURE – A term sometimes used to signify the seasonal closing of a road to traffic, usually by installation of a gate or barrier. However, proper and effective long term road closure is not accomplished by simply blocking a road to traffic and walking away from it to let “nature reclaim the road” (abandoning the road) or by temporarily “storing” the road (road storage) for future use but not treating all the potential sources of erosion and sediment delivery (See road decommissioning).

ROAD DECOMMISSIONING – To remove those elements of a road that unnaturally reroute hillslope drainage or present slope stability and/or erosion and sediment delivery hazards. Road decommissioning treatments include complete removal and restoration of all stream crossing fills, excavation or stabilization of all existing and potential road fill instabilities that could deliver sediment to stream channels, decompacting and permanently dispersing road surface drainage, and treating all other existing or potential road-related sediment sources. Depending on the nature and magnitude of existing and potential threats posed by a road, the required decommissioning treatments could range from minor drainage improvements to major earth moving activities.

Terminology describing road decommissioning practices is varied and often contradictory. While other terms (e.g., road closure, road abandonment, road storage, put-to-bed and road vacating) have been used to describe various road decommissioning techniques, the activities must include those that are necessary to eliminate or greatly reduce the impacts of roads (similar to those described above), or they are likely to be only partially effective and leave some watershed and environmental threats in place.

ROAD FAILURE – Damage to the roadbed (usually caused by a roadbed slump, fill failure, stream crossing washout or major gully) which prevents vehicular passage, but does not usually mean minor cutbank or fill sloughing incidental to road settling.

ROAD OR LANDING FILL EXCAVATION – Excavation and removal of unstable or potentially unstable fill and/or sidecast spoil from the outer edge a road prism. Road fill excavations are performed as a preventive measure to guard against failure of unstable fill materials into downslope stream channels.

ROAD GRADE – The slope of a road along its alignment.

ROAD MAINTENANCE – The actions taken to prevent erosion and/or the deterioration of a road, including the cutbank, the road surface, the fill slope and all drainage structures. Road maintenance activities include such tasks as grading, ditch cleaning, brushing and culvert cleaning.

ROAD NETWORK – The pattern of all the roads in an ownership, watershed, hillside or other defined area. The road network typically includes main trunk roads, secondary roads and spur roads.

ROAD RECONSTRUCTION – Repair or upgrading of those pre-existing roads that are to be restored or improved to make them useable for hauling forest products, for ranching operations or for rural residential traffic.

ROAD RUNOFF – Surface runoff that collects on and is drained from the road surface, usually as a direct response to rainfall. Road runoff usually travels down the road surface or in a roadside ditch.

ROAD STORAGE – A road “in storage” is a maintenance classification where a road may be closed to use for a long period of time with the expectation that it will be used again in the future. A minimum level of erosion prevention is usually conducted to reduce the potential impact of road failure, but many potential sediment sources may remain untreated. For example, stream crossings may be dipped but are usually left in place (See road closure, road decommissioning).

ROAD STORM-PROOFING – See storm-proofing.

ROAD UPGRADING – Measures taken to bring a road up to current design standards, including road cuts and fills, road surface drainage, stream crossings, and other road elements. Road upgrading is considered one type of road storm-proofing (road decommissioning is the other) in which the road is made as resilient to storms and floods as is possible, while also reducing hydrologic connectivity between roads and streams to the maximum extent feasible (See storm-proofing).

ROCK ARMOR – Course rock that is placed to protect a soil surface, usually from erosion caused by flowing or falling water. Rock armor is one type of material used for energy dissipation at culvert outfalls (See riprap).

ROCK PIT – A large outcrop of bedrock that has been developed for aggregate uses, such as road surfacing material and/or larger rock armor. A borrow pit is an excavation from which various materials are removed for use in another location (See borrow site).

ROLLING DIP (BROAD BASED DIP) – Shallow, rounded dip in the road where road grade reverses for a short distance and surface runoff is directed in the dip or trough to the outside or inside of the road. Rolling dips are drainage structures used primarily on gravel surfaced, outsloped roads designed to drain the road surface and constructed to remain effective while allowing passage of motor vehicles at normal or slightly reduced road speed.

ROTATIONAL SLIDE – A landslide that has an arcuate, concave-up failure plain, and whose movement is rotational rather than translational.

RUNOFF – Rainfall or snowmelt which flows overland across the surface of hillslopes and along roads and trails.

RURAL ROADS – Low traffic roads located in forested and rangeland settings that serve residential, recreational and resource management uses. Rural roads may be owned and/or managed by governmental or private parties, and they may be gravel surfaced or paved. Rural roads are the backbone of the transportation system in many rural counties in California and elsewhere.

SCARIFIED (SCARIFICATION) – A soil surface whose organic material is removed and whose surface is mechanically broken up or decompacted (See ripping).

SEASONAL ROAD – A road which is planned and constructed as part of a permanent transportation system where most hauling and heavy vehicle use may be discontinued during the wet season, or whenever roads are wet, and whose use is restricted to periods when the surface is dry. Most seasonal roads are not surfaced for wet weather use, but have a surface adequate for hauling of forest and ranch products in the dry season, and in the extended dry periods or hard frozen conditions occurring during the winter period. Seasonal roads have drainage structures at watercourse crossings which will accommodate the 100-year design flood flow.

SEDIMENT CONTROL – Controlling the path and disposition of eroded sediment.

SEDIMENT DELIVERY – Material (usually referring to sediment) which is delivered to a stream channel. Sediment delivery often refers to the percent of material eroded from a site which actually gets delivered to a stream channel (as opposed to that which is stored on the hillslope).

SEDIMENT RETENTION BASIN – A natural or dug basin or depositional area used to receive or spread runoff, infiltrate water and settle sediment before it can be delivered to a stream.

SEDIMENT YIELD – The quantity of soil, rock particles, organic matter, or other dissolved or suspended debris that is transported through a cross-section of stream in a given period. Technically, yield consists of dissolved load, suspended load, and bed load.

SIDECAST – The excess earthen material pushed or dumped over the side of roads or landings.

SIDE TAPERED INLET – See improved culvert inlet.

SILT FENCE – A constructed barrier used to contain soil eroded from a construction site. The barrier is made from geotextile filter fabric stretched between fence posts placed on contour along a slope or in a ditch, or it may be

composed of a straw bale or other permeable barrier, or non-permeable barrier, used to trap or cause deposition of sediment-laden runoff (See sediment retention basin).

SLIPLINING – See trenchless technologies.

SLIVER FILL – A thin fill lying parallel to the underlying hillslope, rather than as a wedge used in normal cut and fill construction. The use of sliver fills is not recommended, and endhauling of spoils is highly preferred to sliver fill construction. Sliverfills cannot be compacted on slopes exceeding about 35%. As they thicken, sliver fills become more susceptible to failure. Sliver fills are only appropriate where it is impossible to dispose of the material elsewhere and where the fill is composed entirely of coarse rock. Sliverfills are “placed” and are never constructed by uncontrolled sidecasting.

SLOPE RATIO – See ratio.

SLOPE STABILITY – The resistance of a natural or artificial slope or other inclined surface to failure by mass soil movement (landsliding).

SLOPE TAPERED INLET – See improved culvert inlet.

SLUMP – An episodic, fast to very slow mass movement process involving rotation of a block of hillslope or road along a broadly concave slip surface, often referred to as a rotational slide (See rotational slide).

SMARA – California’s Surface Mining and Reclamation Act (SMARA) was passed and adopted in 1975 and updated in 2007. SMARA provides a comprehensive surface mining and reclamation policy in California designed to minimize adverse environmental impacts and to assure mined lands are reclaimed to a usable condition.

SOIL BIOENGINEERING – Soil bioengineering techniques rely on the use of live plant cuttings to provide basic structural stabilization to slopes and streambanks, to reinforce soil substrate, and to reduce soil erosion. Techniques include brush layering, fascines (wattles), branch packing, live staking, wattle fencing and live pole drains, among others (See biotechnical engineering).

SOIL EROSION – See erosion.

SOIL SERIES – A group of soils developed from a particular type of parent material having naturally developed horizons that, except for texture of the surface layer, are similar in differentiating characteristics and in arrangement of the soil profile.

SOIL TEXTURE – The relative proportion of sand, silt and clay in a soil; grouped into standard classes and subclasses in the Soil Survey Manual of the U.S. Department of Agriculture.

SOIL WATER – Water in the soil, including groundwater and water in the unsaturated zone above the groundwater table.

SPOIL (SPOIL MATERIALS) – Material (soil and organic debris) that is not used or needed as a functional part of the road or a landing. Spoil material is generated during road construction, reconstruction and maintenance activities.

SPOIL DISPOSAL SITE – The location where spoil material (woody debris and excavated soils) can be placed without the threat of accelerated erosion or of initiating slope instability. Stable spoil disposal sites include the cut portion of closed roads, the inside portion of landings and turnouts, and flat or low gradient natural benches.

SPUR ROAD – A side road off a main trunk road or a secondary road. Most spur roads are dead-end and may terminate at a logging site, a barn site or a rural residential site. Depending on their use, spur roads may be permanent, seasonal or temporary.

STORED ROAD – See road storage, road decommissioning.

STORM MAINTENANCE (EMERGENCY ROAD MAINTENANCE) – Road inspection and maintenance that is performed during and immediately after periods of high rainfall and runoff when drainage structures are most likely to plug, malfunction or fail.

STORM-PROOFING; STORM-PROOFED ROAD – A storm-proofed road is one where measures have been

taken to either upgrade or decommission the road so as to minimize the risk and potential magnitude of future erosion and sediment delivery. It generally consists of reducing hydrologic connectivity; identifying and treating potential road failures (mostly fill slope failures) that could fail and deliver sediment to streams; and reducing the risk of stream crossing failures and stream diversion (See Figure 204, Characteristics of Storm-proofed Roads).

STREAM CROSSING – The location where a road crosses a stream channel. Drainage structures used in stream crossings include bridges, fords, armored fills, arches, culverts and a variety of temporary crossings.

STREAM CROSSING EXCAVATION (DECOMMISSIONING) – The excavation of the fill material that was used to build (fill) a stream crossing, specifically a culverted crossing, an arch, a log crossing or a temporary crossing. A stable stream crossing excavation must be dug down to the level of the original stream bed, with side slopes graded (excavated) back to a stable angle (usually 2:1 (50% gradient) or less, depending on soil characteristics).

STREAM DIVERSION – A stream that has been diverted out of its natural channel and down a road, across a hillslope or into another stream channel is considered to be diverted. Most stream diversions occur at road crossings, where a stream crossing culvert plugs and streamflow travels down the road or ditch rather than back over the fill and back into its natural channel. Diversions can be man-made or natural, and they occur wherever flow has been obstructed. At road crossings, streams are considered diverted if streamflow leaves its natural channel and travels beyond the stream crossing fill, even if that distance is only a few hundred feet. Diverted streams may quickly flow back into their natural channel, or flow down the road some distance before entering another stream channel or flowing down an unchanneled hillslope.

SUB-BASE – The lowest layer of a road's structural section, placed on the subgrade (native materials) and underlying the base or surface course. It normally consists of a well graded coarse material (pit run gravel, natural gravel or gravel/sand/silt mixtures) that has lower strength and durability than road base materials, but which can still provide structural support to overlying loads.

SUBDRAINAGE (SUBSURFACE DRAINAGE) – The flow of water beneath the surface of the ground (through the soil). Along roads, specific construction techniques can be used to make sure subsurface drainage is not impeded by the roadbed or road fill, and that poor subsurface drainage does not result in slope instability, or persistent saturation or damage to roadbed materials.

SUBGRADE – Consists of the native material beneath the constructed road, and is typically a thoroughly compacted portion of natural embankment material directly beneath the imported base materials or road foundation. In some cases, the term can also refer to imported material that has been used to build an embankment.

SURFACE EROSION – The detachment and transport of soil particles by wind, water or gravity. Surface erosion can occur as the loss of soil in a uniform layer (sheet erosion), in many rills, gullies, or by dry ravel.

SURFACING (SURFACE COURSE) – The top layer of the road surface, also called the wearing course. Rock aggregate and paving are two types of surfacing used to weather-proof the road for wet season use.

SWALE – A channel-like linear depression or low spot on a hillslope which rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface runoff under the present climatic conditions (See headwater swale).

SWITCHBACK – The location along a road where the route turns and reverses direction, usually over a short distance, where the road is climbing or descending a hillside.

TEMPORARY ROAD – A road that is to be used only during short-lived ranch, timber or mining operations. These roads have a surface adequate for seasonal hauling use and have drainage structures, if any, adequate to carry the anticipated flow of water during the period of use. These drainage structures must be removed prior to the beginning of the winter period (if they are constructed for the design storm flow event) (See temporary stream crossing).

TEMPORARY STREAM CROSSING – A stream crossing that is to be excavated and removed, usually on a

temporary road. If a temporary stream crossing is to remain in place over one winter, it should be designed to the same standards as a permanent watercourse crossing.

THROUGH CUT – A road cut through a hillslope or ridge, or down the fall line of a hillside or ridge, in which there is at least a small cut on both sides of the road. Through cuts that are more than about 2 feet deep are very difficult to drain and are prone to gully and high maintenance costs (See fall line road).

THROUGH FILL – A road which is entirely composed of fill material; the opposite of a through cut. Sometimes through fills have a berm along one or both sides of the road, thereby intentionally containing road surface runoff on the road and directing it to a single discharge point. Through fills are typically found at stream crossings where the fill may be bermed on one or both sides of the road to hydrologically disconnect runoff from the stream and discharge it slightly down road from the crossing (See full fill road).

TOP-DOWN ROAD CONSTRUCTION – Road construction techniques which involve excavating a road bench on the hillside and sidecasting the spoil material on the slopes below. Top-down road construction techniques should only be employed on gently or moderately sloping hillslopes where sidecast material cannot fail or be eroded and transported to local stream channels.

TRASH RACK – See debris control structures, debris rack.

TRENCHLESS TECHNOLOGIES – The use of construction methods to install or repair underground infrastructure (culverts) without digging a trench or opening an excavation cut. Trenchless technologies for culvert repair or replacement include culvert liners, sliplining and pipe jacking or ramming, among others.

TRUNK ROAD – A main, through-going road which typically forms the core of a road network that also contains secondary and spur roads.

TURNOUT – A planned wide spot along a single lane road that is used to allow vehicles to safely pass. Turnouts on single lane roads should be intervisible for safety.

UNDERDRAIN (PIPE UNDERDRAIN) – See French drain.

UNSTABLE AREAS – Areas characterized by mass movement features or unstable soils, or by some or all of the following: hummocky topography consisting of rolling bumpy ground, frequent benches, and depressions; short irregular surface drainages which begin and end on the slope; visible tension cracks and head wall scarps; irregular slopes which may be slightly concave in upper half and convex in lower half as a result of previous slope failure; evidence of impaired ground water movement resulting in local zones of saturation including sag ponds with standing water, springs, or patches of wet ground; hydrophilic (wet site) vegetation; leaning, jackstrawed or split trees; and pistol-butted trees with excessive sweep in areas of hummocky topography.

UNSTABLE SOILS – Are indicated by the following characteristics:

- (1) Unconsolidated, non-cohesive soils (coarser textured than loam) and colluvial debris including sands and gravels, rock fragments, or weathered granitics. Such soils are usually associated with a risk of shallow-seated landslides on slopes of 65% or more, having non-cohesive soils less than 5 feet deep in an area where precipitation exceeds 4 inches in 24 hours in a 5-year recurrence interval.
- (2) Soils that increase and decrease in volume as moisture content changes. During dry weather, these materials become hard and rock-like exhibiting a network of polygonal shrinkage cracks and a blocky structure resulting from desiccation. Some cracks may be greater than 5 feet in depth. When wet, these materials are very sticky, dingy, shiny, and easily molded.

UPGRADING – See road upgrading, road reconstruction, storm-proofing.

VENTED FORD – A stream crossing structure, usually used on a perennial, low gradient stream or small river, designed to allow low water flow in the stream channel to pass through the structure (e.g., culverts) below a hardened (usually concrete) roadway. During

periods of high water or flooding, streamflow passes over the roadway and the crossing is closed to traffic.

VERTICAL CURVE – The vertical arc of a circle whose radius is that of the road as it rises and falls (over a hill), or falls and rises (across a swale or dip) through a change in grade.

WASHBOARDING – A series of regular bumps consisting of closely spaced ridges and depressions across the road caused by vehicle traffic over unsurfaced and gravel surfaced roads with low surface cohesion. They are most often seen in hot, dry areas and on sandy, dirt or gravel roads. Washboards develop when vehicles exceed a critical speed, or where they accelerate and repeatedly kick-up loose materials. They worsen with excessive vehicle speeds and high traffic volumes.

WASHED OUT STREAM CROSSING – A stream crossing fill that has been partially or completely eroded and “washed” downstream. Washouts usually occur when a culvert plugs and streamflow backs up and flows over the roadbed during flood events.

WATERBAR (WATERBREAK) – Shallow, drivable ditch excavated at an angle across a road or trail to drain surface runoff. Waterbars are usually built on seasonal or temporary roads which are to receive little or no traffic during the winter period.

WATERCOURSE – Any well-defined channel with distinguishable bed and bank showing evidence of having contained flowing water indicated by erosion or deposit of rock, sand or gravel. Watercourse also includes man-made watercourses (See also Class I, II, III and IV watercourse - California).

WATERCOURSE AND LAKE PROTECTION ZONE (WLPZ - CALIFORNIA) – A strip of land, along both

sides of a watercourse or around the circumference of a lake or spring, where additional practices (or restrictions) may be required for protection of the quality and beneficial uses of water, fish and riparian wildlife habitat, other wildland resources, and for controlling erosion.

WATER QUALITY – The chemical, physical and biological characteristics of water.

WATERSHED – The area or drainage basin contributing water, organic matter, dissolved nutrients and sediments to a stream or lake. An area bounded mostly by ridges and drained, at its outlet, by a single trunk stream.

WATTLES (FASCINE, LIVE FASCINE, STRAW WATTLES) – Long bundles of brush or branch cuttings, bound together into sausage shaped structures, which are partially buried and staked on contour along a slope, preferably to sprout, and form a sediment trap or break up sheet flow on the slope. If the materials are composed of sprouting species, they are called live fascines. Wattles made out of straw encased in a tube-shaped plastic netting are called straw wattles.

WEARING COURSE – See surfacing, surface course.

WET AREA – An area defined by poorly drained, wet soils that are typically caused by emerging springs and seeps and support aquatic vegetation, grasses and forbs as their principal vegetative cover.

WETLANDS – Areas that are inundated by surface water or ground water with a frequency sufficient to support, and under normal circumstances do or would support, a prevalence of vegetative or aquatic life that require saturated or seasonally saturated soil conditions for growth and reproduction. Wetlands generally include, but are not limited to, swamps, marshes, bogs and similar areas that are characterized by seasonally or perennially wet soils and wetland vegetation.

WHEEL GUARDS – Slightly elevated safety rails along both sides of the running surface of a bridge, designed to warn drivers and to help keep vehicles on the bridge.

WINDROW – See filter windrow.

WINGWALLS AND APRONS – Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable, or where the culvert is skewed to the normal channel flow. They orient flow, protect the fill face and reduce culvert plugging potential.

An apron is a hardened floor between the wingwalls, usually made of concrete, which reduces inlet velocities, turbulence and plugging potential (See headwall).

WINTERIZE – To perform erosion prevention and erosion control work on a road in preparation for winter rains and flood flows. Winterizing activities include waterbarring, ditch cleaning, culvert cleaning, removal of berms, road re-shaping, resurfacing, etc.

WINTER OPERATING PERIOD – In California, the period between November 15 to April 1, except for purposes of installing waterbreaks and rolling dips, in which case the extended period is October 15 to April 1 (for forestry operations).

WINTER OPERATING PLAN – A functional plan developed to describe how land use operations will be conducted during the winter period. Winter operating plans usually contain detailed information on erosion control and erosion prevention actions that are to be followed to protect the site from rainfall and storm runoff.

WINTER OPERATIONS (WET WEATHER OPERATIONS) – Generally refers to logging and associated forest road operations conducted during the wet weather operating period (generally from November 15 to April 1 in California). A wet weather operating plan is required by the California Department of Forestry and Fire Protection for wet season (winter) operations. Other jurisdictions may have similar ordinances and seasonal restrictions.

APPENDIX A:**Culvert Sizing procedures for the 100-Year Peak Flow****A. INTRODUCTION**

Several methods have been developed for estimating the peak flood discharge that can be expected from small ungaged, wildland watersheds. These procedures are useful for determining the size (diameter) of culvert that should be installed in a stream crossing that is to be constructed or upgraded.

Determining the proper size (diameter) culvert requires: 1) estimating the peak discharge of streamflow which would occur at each stream crossing during the 100-year flood, and then 2) determining the size of culvert which would handle that flow using the Federal Highway Administration (FHWA) culvert capacity nomograph (FHWA, 1965).

A summary of selected methods, with example calculations for flood flow estimating is available from the California Department of Forestry and Fire Protection (CAL FIRE) in an “in-house” document called “Designing Watercourse Crossings for Passage of 100-year Flood Flows, Wood, and Sediment” (Cafferata et al., 2004). The document covers such techniques as the Rational Method, the USGS Magnitude and Frequency Method, and the Flow Transference Method. Each method has its strengths and weaknesses, and relies on field or map measurements, published climatic data, and subjective evaluations of watershed conditions.

Several of the methods require precipitation intensity data which are typically available from the National Oceanic and Atmospheric Administration (NOAA) website: <http://dipper.nws.noaa.gov/hdsc/pfds/>, or your state’s water resource or forestry departments. Rainfall depth-duration frequency data are also available in published map atlases online, or in good public and college libraries. Ask for assistance

from the state forest professional with jurisdiction for your area, as foresters are routinely required to perform these calculations.

A description of methodology and an example are provided for the three techniques to estimate the 100-year flood flow (Rational Method, USGS Magnitude and Frequency Method, and Flow Transference Method). It is recommended that two or three different methods be used in an area to compare and verify the results. Field experience can also be used as a check. Just remember, most of us have not been around for a 100-year flood and we naturally tend to underestimate the amount of water that is carried by streams during these extreme events.

B. CULVERT SIZING METHODS (EXAMPLES)**METHOD 1. THE RATIONAL METHOD OF ESTIMATING 100-YEAR FLOOD DISCHARGE**

The most commonly used technique for estimating 100-year flood discharges from small ungaged forested watersheds is the Rational Method.

This method is based on the equation:

$$Q_{100} = CIA$$

Where: Q_{100} = predicted peak runoff from a 100-year runoff event (in cubic feet second)

C = runoff coefficient (percent of rainfall that becomes runoff)

I = uniform rate of rainfall intensity (inches/hour)

A = drainage area (in acres)

Assumptions:

1. The 100-year design storm covers the entire basin with uniform constant rainfall intensity until the design discharge at the crossing is achieved.
2. The design watershed characteristics are homogenous.
3. Overland flow. This method is less accurate or predictable as the percent impervious surface area in the watershed decreases.
4. The runoff coefficient (C) is constant across the watershed.
5. The 100-year storm event produces the 100-year flood flow.

Advantages:

1. Frequently used and flexible enough to take into account local conditions.

2. Easy to use if local rainfall data is available.

Disadvantages:

1. Flexibility may lead to misuse, or misinterpretation of local conditions.
2. Precipitation factor " I " may be difficult to obtain in remote areas.
3. Less accurate for watersheds greater than 200 acres

Information needed:

A = area of watershed (acres)

C = runoff coefficient from [Table A-1](#)

H = elevation difference between highest point in watershed and the crossing point (feet)

L = length of channel from the head of the watershed to the crossing point (miles)

I = uniform rate of rainfall intensity. Obtained from precipitation frequency-duration data for local rain gages as shown in [Table A-2](#).

TABLE A-1. Values for Rational Method runoff coefficient (C) values

Soils	Land use or type	C value
Sandy and gravelly soils	Cultivated	0.20
	Pasture	0.15
	Woodland	0.10
Loams and similar soils without impeded horizons	Cultivated	0.40
	Pasture	0.35
	Woodland	0.30
Heavy clay soil or those with a shallow impeding horizon; shallow over bedrock	Cultivated	0.50
	Pasture	0.45
	Woodland	0.40

TABLE A-2. Example of Rainfall Depth Duration Frequency Data for Eureka, California National Weather Service Station (NWS)

Design storm (Return Period)	Maximum precipitation for indicated rainfall duration										
	5 Min	10 Min	15 Min	30 Min	1 Hr	2 Hr	3 Hr	6 Hr	12 Hr	24 Hr	C-Yr
RP 2	0.17	0.25	0.31	0.41	0.55	0.77	0.95	1.34	1.88	2.51	37.88
RP 5	0.23	0.34	0.41	0.55	0.74	1.04	1.28	1.81	2.54	3.38	47.93
RP 10	0.27	0.39	0.48	0.64	0.86	1.21	1.49	2.10	2.95	3.93	53.51
RP 25	0.32	0.46	0.56	0.75	1.00	1.42	1.74	2.45	3.44	4.59	59.83
RP 50	0.35	0.51	0.62	0.82	1.10	1.56	1.92	2.70	3.79	5.06	63.88
RP 100	0.38	0.55	0.67	0.90	1.20	1.70	2.09	2.95	4.13	5.51	67.71
RP 200	0.41	0.59	0.72	0.97	1.30	1.84	2.25	3.18	4.46	5.95	71.30
RP 500	0.45	0.65	0.79	1.06	1.41	2.00	2.46	3.47	4.86	6.49	76.06
RP 1000	0.48	0.69	0.84	1.13	1.51	2.14	2.63	3.70	5.20	6.93	78.94
RP 10000	0.58	0.83	1.01	1.35	1.80	2.55	3.13	4.42	6.21	8.28	88.75

Steps:

1. Select runoff coefficient (C) values:
 Several different publications give a range of "C" values for the rational formula, however, the values given in **Table A-1** by Rantz (1971) appear to be the most appropriate for the woodlands and forests around Eureka, California.

the crossing point (in feet) (where the culvert is going to be installed).

(Note: if the value of T_c is calculated as less than 10 minutes, studies suggest you should use a default value of 10 minutes)

2. Select a rainfall intensity (I) value:
 In selecting an "I" value, two factors are considered: a) the travel time or time of concentration (T_c) for the runoff to reach the crossing, and b) the precipitation conditions for the particular watershed in question.

b. Uniform rate of rainfall intensity.

Once the time of concentration has been determined, then that value is used to determine which rainfall duration to use (i.e., if $T_c = 1$ hour, then use 100-year, 1 hour precipitation duration; if $T_c = 4$ hours, then use 100-year, 4-hour duration). Rainfall depth duration tables similar to **Table A-2** are available for precipitation stations throughout each state. For example, rainfall depth duration frequency data can be obtained from the California Department of Water Resources on-line at <ftp://ftp.water.ca.gov/users/dfmhydro/Rainfall%20Dept-Duration-Frequency/>. Contact your state's water resources department (or its equivalent) to obtain rainfall depth duration frequency data for your area.

a. Time of concentration (T_c) can be calculated using the formula:

$$T_c = \left[\frac{11.9L^3}{H} \right]^{0.385}$$

Where: T_c = time of concentration (in hours)

L = length of channel in miles from the head of the watershed to the crossing point

H = elevation difference between highest point in the watershed and

Example: Rational Method used to calculate 100-year design storm

1. Area of example stream crossing watershed (A) = 100 acres.
2. Runoff coefficient (C) = 0.30 (loam woodland soil, from **Table A-1**)
3. Calculate the time of concentration (T_c)

$$T_c = \left[\frac{11.9L^3}{H} \right]^{0.385}$$

Where,

$$L = 1.8 \text{ mi.}, H = 200 \text{ ft.}$$

$$T_c = \left[\frac{11.9(1.8)^3}{200} \right]^{0.385}$$

$$= 0.67 \text{ hr or 40 min}$$

Using **Table A-2**, interpolate the rainfall depth value for a 40 minute duration between the 30 minute and 1 hour duration of a 100-year return period storm event (e.g., 0.90 in/30 min and 1.20 in/60 min, therefore = 1.0 in/40 min).

4. Calculate the rainfall intensity (I)

$$I = \left(\frac{1.0 \text{ in}}{40 \text{ min}} \right) = \left(\frac{1.5 \text{ in}}{60 \text{ min}} \right) = 1.5 \text{ in/hr}$$

5. Calculate Q_{100}

$$Q_{100} = CIA$$

$$Q_{100} = (0.3) \times (1.5) \times (100)$$

$$= 45 \text{ cubic feet per second (cfs)}$$

METHOD 2. THE USGS MAGNITUDE AND FREQUENCY METHOD FOR ESTIMATING 100-YEAR FLOOD DISCHARGE

The USGS Magnitude and Frequency Method is based on a set empirical equations derived for six regions in the state of California for the 2-, 5-, 10-, 25-, 50-, and 100-year design flood flows. These equations were developed from the precipitation and runoff data collected

from more than 700 stream gaging stations in California (USGS, 2012). For the purposes of this handbook, only the set of equations for the 100-year design flood flow are shown below:

$$\text{North Coast } Q_{100} = 48.5A^{0.866}p^{0.556}$$

$$\text{Sierra } Q_{100} = 20.6A^{0.874}p^{1.24}H^{-0.25}$$

$$\text{Desert Region } Q_{100} = 1,350A^{0.506}$$

$$\text{Central Coast } Q_{100} = 11.0A^{0.84}p^{0.994}$$

$$\text{South Coast } Q_{100} = 3.28A^{0.891}p^{1.59}$$

$$\text{Lahontan } Q_{100} = 0.713A^{0.731}p^{1.56}$$

Where: Q_{100} = predicted peak runoff from a 100-year storm (cubic feet second)
 A = drainage area (square miles)
 H = Mean basin elevation (feet)
 P = mean annual precipitation (inches/year)

Assumptions:

1. The 100-year design storm uniformly covers large geographic areas.
2. The design watershed characteristics are homogenous.
3. The 100-year storm event produces the 100-year flood flow.

Advantages:

1. Equations are based on a large set of widely distributed gaging locations, including rain on snow events.
2. Easy to use.
3. Mean basin elevation is easy to determine from USGS topographic maps.

4. Mean annual precipitation data are readily available
5. Equations were updated in 2012.

Disadvantages:

1. Generalizes vast geographic areas and can result in over estimation and under-estimation at the local watershed level.
2. Less accurate for watersheds less than 100 acres. The regression equations were based on data for larger watershed areas (>100 acres), and therefore using the regression equations for smaller watersheds would result in extrapolating the Q_{100} estimate below the range of data used to develop the regression equation.

Information needed:

1. A = area of watershed (acres)
2. P = mean annual precipitation (in/year)
3. H = Mean basin elevation (feet).

Example: USGS Magnitude and Frequency Method used to calculate 100-year design storm

1. Geographic area = Sierra Nevada Region (e.g., Mohawk Ravine in Nevada County, California)
2. Area of example stream crossing watershed (A) = 445 acres or 0.7 square miles.
3. Mean annual precipitation (P) = 65 in/year
4. Mean basin elevation (H) = 4,112 feet

5. Calculate Q_{100} for the Sierra Region:

$$Q_{100} = 20.6A^{0.874}P^{1.24}H^{-0.25}$$

$$Q_{100} = 20.6(0.7)^{0.874}65^{1.24}4,112^{-0.25}$$

$$Q_{100} = 334 \text{ cubic feet per second (cfs)}$$

METHOD 3. FLOW TRANSFERENCE METHOD FOR ESTIMATING 100-YEAR FLOOD DISCHARGE

The 100-year design flood flow can also be calculated for proposed stream crossings that are located in or nearby a hydrologically similar watershed that has a long-term gaging station. The 100-yr discharge is calculated by adjusting for the difference in drainage area between the gaged station and the ungaged site using the following equation:

$$Q_{100u} = Q_{100g} \left(\frac{A_u}{A_g} \right)^b$$

Where: Q_{100u} = peak runoff from a 100-year storm at ungaged site (cubic feet per second)
 Q_{100g} = peak runoff from a 100-year storm at gaged site (cubic feet per second)
 A_u = drainage area at ungaged site (square miles)
 A_g = drainage area at gaged site (square miles)
 b = exponent for drainage area from appropriate USGS Magnitude and Frequency equation—for example, the exponent (b) = 0.87 for the North Coast USGS Magnitude and Frequency Method equation (see Method 2 above)

Assumptions:

1. Ungaged and gaged stream sites have the same geomorphic and hydrologic characteristics.

2. Long-term stream gaging data at gaged site.

Advantages:

1. More accurate than other methods if the stream gaging station is nearby and the available stream gaging peak discharge records are accurate (Cafferata et al., 2004)
2. Easy to use.
3. Local data are more likely to reflect the proposed stream crossing site's drainage basin characteristics (e.g., slopes, geology, soils, and climate).

Disadvantages:

1. Less accurate if gaging data record is less than 20 years.
2. Less accurate if used with gaged and ungaged watersheds that are in different locations or have different watershed conditions and characteristics.

Information needed:

1. A_u = drainage area at ungaged site (square miles)
2. A_g = drainage area at gaged site (square miles)
3. b = exponent for drainage area from appropriate USGS Magnitude and Frequency Method equation

Example: Flow Transference Method used to calculate 100-year design storm

1. Geographic area = North Coast (e.g., unnamed tributary in North Coast)

$$2. Q_{100u} = 14,000 \text{ cfs}$$

3. Area of example gaged stream crossing watershed (A_g) = 54,000 acres or 84.4 square miles.

4. Area of example ungaged stream crossing watershed (A_u) = 300 acres or 0.47 square miles.

5. $b = 0.87$ – area exponent from the North Coast USGS Magnitude and Frequency equation

6. Calculate Q_{100} :

$$Q_{100} = Q_{100g} \left(\frac{A_u}{A_g} \right)^b$$

$$Q_{100} = 14,000 \text{ cfs} \left(\frac{0.47 \text{ sq mi}}{84.4 \text{ sq mi}} \right)^{0.87}$$

$$Q_{100} = 153 \text{ cubic feet per second (cfs)}$$

C. SIZING CULVERTS USING THE FEDERAL HIGHWAY ADMINISTRATION CULVERT CAPACITY NOMOGRAPH

The Federal Highway Administration (FHWA) Culvert Capacity Nomograph is commonly used throughout the U.S. as a tool to determine the recommended culvert diameter based on calculated design stream flow and headwater depth (headwall/diameter) ratio (**Figure A-1**).

Once the 100-year design flood flow is determined using one or more of the methods stated previously, the steps to determine the adequate culvert size are very straight forward:

1. Determine the culvert “entrance type” from the three types illustrated in **Figure A-1**. Typically, most rural roads have culverts with “projecting” (barrel shaped) inlets. Other

choices include mitered or beveled inlets and culverts with headwalls.

culvert with Headwater Depth ratio = 1 would require a 72 in diameter pipe.

2. Determine the "Headwater Depth Ratio" for the proposed stream crossing. The "Headwater Depth Ratio" is the ratio HD/D where HD is the headwall depth from the height of the fill where water would begin to spill out of the crossing (this could be the low point in the fill or an adjacent road ditch) to the bottom of the culvert invert (culvert bottom), and D is the diameter or rise of the culvert inlet. It is not recommended to design a stream crossing culvert with a HW/D ratio greater than 1, even though the fill may be considerably higher and a large pond could be physically accommodated.¹
3. To size a projecting inlet culvert, place a straight edge connecting the "Headwater Depth" ratio of 1 on the "Projecting Inlet" scale at (far right scale of the nomograph) through the 100-year design flood discharge calculated for the proposed stream crossing site (see middle scale on diagram for "Discharge (Q) in cfs.")
4. Read off the needed culvert diameter on the left scale of the nomograph.
5. For example, a stream with $Q_{100} = 200$ cfs, designed with a projecting inlet

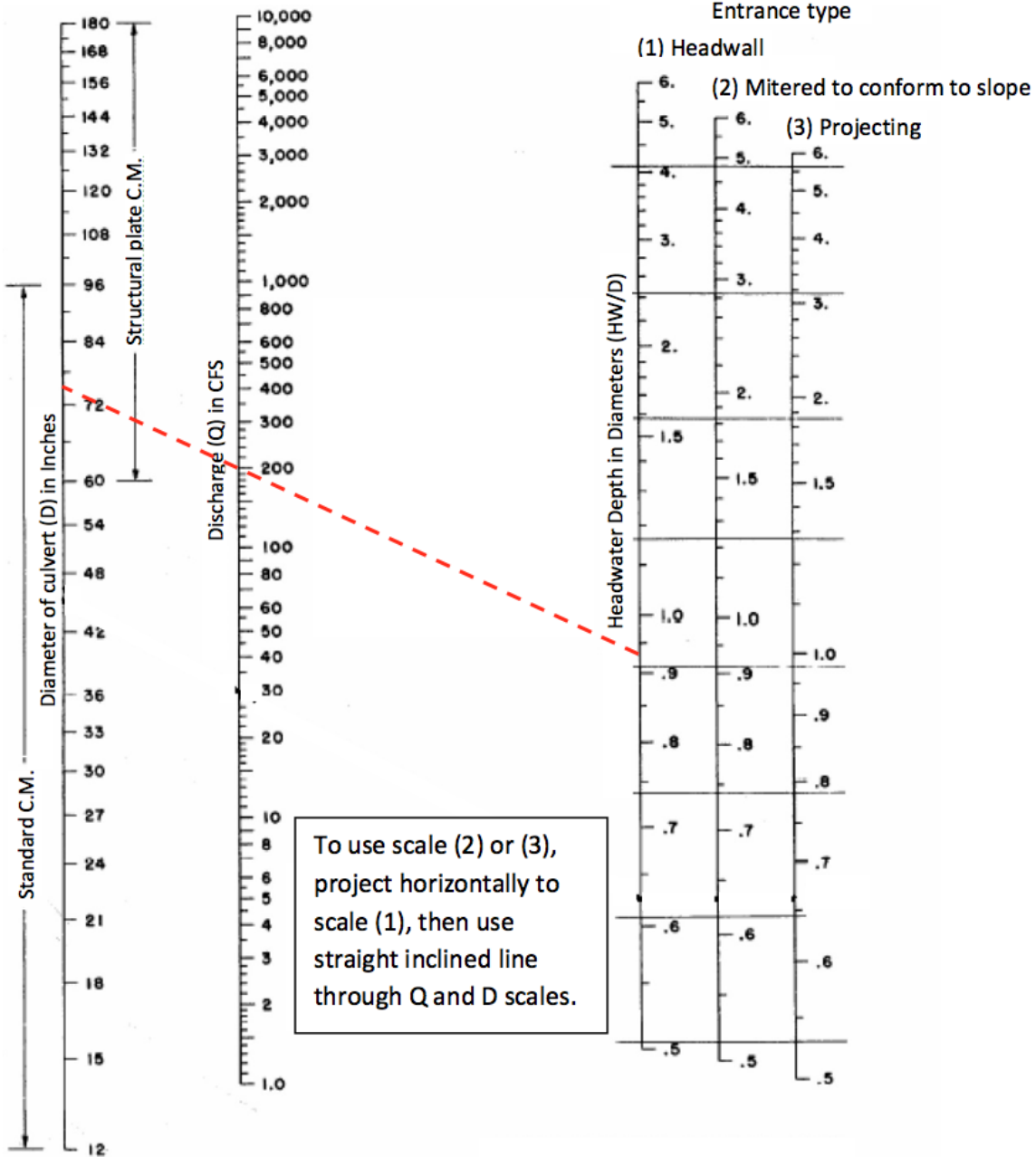
D. SIZING CULVERTS TO ACCOMMODATE THE 100-YEAR DESIGN FLOOD FLOW, WOODY DEBRIS AND SEDIMENT

Typically culverts are sized to only accommodate the 100-year design flood flow. Some landowners and land managers desire to design stream crossing culverts to accommodate expected sediment and organic debris in transport in addition to meeting the requirements for passing 100-year peak flows. This is especially important in unconfined and confined stream channels that transport a lot of woody debris and sediment during flood flows.

One proposed methodology for accomplishing this includes designing culvert size based on 0.67 headwall-to-culvert diameter ratio (HW/D), instead of the 1.0 HW/D that is typically applied (Cafferata et al., 2004). This often results in culverts that are 12 in. diameter larger than would be required to pass the 100-year peak flood flow. Another method to reduce the potential for culvert plugging by sediment and organic debris is to size culverts based on bankfull channel width, either by using oval or arch culverts, or by employing oversized round culverts that match or exceed mean bankfull channel width (Flanagan and Furniss, 2003). This is often employed when designing embedded culverts for fish passage (NMFS, 2001). A third method to account for plugging potential (and which PWA generally employs) is to apply secondary treatments, such as flared inlets or trash barriers, at culverted stream crossings judged to have a higher than normal likelihood of culvert plugging.

¹ Current recommended design standards are for culverts to accommodate a "Headwater Depth" ratio of 1, where the culvert is assumed to be over capacity if the water depth rises above the top of the culvert inlet ($HW/D = 1$). This is a conservative and protective design recommendation. Technically, most stream crossing fills have room for standing water higher, sometimes a lot higher, than the top of the culvert, but relying on high headwalls to accommodate peak flows and standing water is a risky proposition that can lead to increased risk of overtopping and crossing failure. Because most culvert plugging and exceedance is attributable to culvert plugging with woody debris and sediment, proposed HW/D design ratios are now proposed to be less than 1 (See Section "D" below for "Headwater Depth" suggestions for accommodating or accounting for woody debris and sediment).

FIGURE A-1.
 FHWA Culvert
 Capacity
 Inlet Control
 Nomograph.



E. REFERENCES

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- USGS, 2012, Methods for Determining Magnitude and Frequency of Floods in California, Based on Data Through Water Year 2006, US Geological Survey Scientific Investigations Report 2012-5113, 38 p. Available at: <http://pubs.usgs.gov/sir/2012/5113/>

APPENDIX B:**General Overview of Required Permits for Construction Work within or Adjacent to Streams, Wetlands, and Other Waterbodies**

Construction activities in or adjacent to streams, wetlands, and water bodies may be under the jurisdiction and regulatory authority of federal, state, and local agencies. The planning, design, and implementation of road construction projects requires specific permits, agreements, or other authorizations, as well as follow federal and state guidelines developed to protect fish, wildlife, native vegetation, and water quality. Make sure to contact your local regulatory agencies to determine what permits are required for construction activities within sensitive areas, such as streams, riparian zones and wetlands. It is also important to understand the consequences if the required permits are not procured prior to construction activities. The fines for not complying with the federal, state, and local permitting processes can be substantial and in some cases be greater than the total project cost.

This appendix provides the state of California's necessary notification requirement for any construction activity that will:

- substantially divert or obstruct the natural flow of any river, stream or lake;
- substantially change or use any material from the bed, channel, or bank of, any river, stream, or lake; or
- deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it may pass into any river, stream, or lake.

The 1602: Lake and Streambed Alteration Program is an agreement that is regulated through the California Department of Fish and Wildlife (CDFW) in order to protect California's fish, wildlife, and native plant resources. The 1602 notification process applies to

all perennial, intermittent, and ephemeral rivers, streams, and lakes in the state.

Section 1602 of the part of the Fish and Game Code § 1600-1616, states:

1602. (a) An entity may not substantially divert or obstruct the natural flow of, or substantially change or use any material from the bed, channel, or bank of, any river, stream, or lake, or deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it may pass into any river, stream, or lake, unless all of the following occur:

(1) The department receives written notification regarding the activity in the manner prescribed by the department. The notification shall include, but is not limited to, all of the following:

(A) A detailed description of the project's location and a map.

(B) The name, if any, of the river, stream, or lake affected.

(C) A detailed project description, including, but not limited to, construction plans and drawings, if applicable.

(D) A copy of any document prepared pursuant to Division 13 (commencing with Section 21000) of the Public Resources Code.

(E) A copy of any other applicable local, state, or federal permit or agreement already issued.

(F) Any other information required by the department.

(2) The department determines the notification is complete in accordance with Chapter 4.5 (commencing with Section 65920) of Division 1 of Title 7 of the Government Code, irrespective of whether the activity constitutes a development project for the purposes of that chapter.

(3) The entity pays the applicable fees, pursuant to Section 1609.

(4) One of the following occurs:

(A) (i) The department informs the entity, in writing, that the activity will not substantially adversely affect an existing fish or wildlife resource, and that the entity may commence the activity without an agreement, if the entity conducts the activity as described in the notification, including any measures in the notification that are intended to protect fish and wildlife resources.

(ii) Each region of the department shall log the notifications of activities where no agreement is required. The log shall list the date the notification was received by the department, a brief description of the proposed activity, and the location of the activity. Each item shall remain on the log for one year. Upon written request by any person, a regional office shall send the log to that person monthly for one year. A request made pursuant to this clause may be renewed annually.

(B) The department determines that the activity may substantially adversely affect an existing fish or wildlife resource and issues a final agreement to the entity that includes reasonable measures necessary to protect the resource, and the entity conducts the activity in accordance with the agreement.

(C) A panel of arbitrators issues a final agreement to the entity in accordance with subdivision (b) of Section 1603, and the entity conducts the activity in accordance with the agreement.

(D) The department does not issue a draft agreement to the entity within 60 days from the date notification is complete, and the entity conducts the activity as described in the notification, including any measures in the notification that are intended to protect fish and wildlife resources.

(b)(1) If an activity involves the routine maintenance and operation of water supply, drainage, flood control, or waste treatment and disposal facilities, notice to and agreement with the department shall not be required after the initial notification

and agreement, unless the department determines either of the following:

(A) The work described in the agreement has substantially changed.

(B) Conditions affecting fish and wildlife resources have substantially changed, and those resources are adversely affected by the activity conducted under the agreement.

(2) This subdivision applies only if notice to, and agreement with, the department was attained prior to January 1, 1977, and the department has been provided a copy of the agreement or other proof of the existence of the agreement that satisfies the department, if requested.

(c) It is unlawful for any person to violate this chapter.

The 1602 notification package is provided on the CDFW website: <http://www.dfg.ca.gov/habcon/1600/forms.html>. The document provides the (1) notification process and instructions, (2) notification submittal form, (3) attachments for specific activities, including gravel/sand/rock extraction, timber harvesting, water diversion, and routine maintenance, (4) notification fee schedule, and (5) frequently asked questions and answers.

After the notification is filed, CDFW will determine within 30 days whether the notification package is complete and whether you will need a Lake or Streambed Alteration Agreement for the proposed activity. An agreement will be required if the activity could substantially adversely affect an existing fish and wildlife resource. If so, CDFW may conduct an onsite inspection and then submit a draft agreement to the applicant. The draft agreement will include measures to protect fish and wildlife resources while conducting the project. After you receive

the final agreement, you may begin the project the agreement covers, provided you have obtained any other necessary local, state, and federal authorizations. Most states and other regulatory entities have a permitting process similar to California's 1602 notification process for work in and around streams and lakes.

A. OTHER PERMITS

Depending on the project activities being proposed, the applicant might need to obtain other permits, agreements, or other authorizations from one or more governmental agencies. You should first contact the planning departments of the city or county where the project will take place to determine whether any local permits are required for the project.

The state and federal agencies listed below, or others in your area, might also have permitting authority over the project. You should contact these agencies if you are not familiar with their permitting requirements.

B. STATE AGENCIES

- Coastal Commission
- Department of Conservation
- Department of Forestry and Fire Protection
- Department of Water Resources
- Reclamation Board/District
- Regional Water Quality Control Boards
- State Lands Commission
- State Water Resources Control Board

C. FEDERAL AGENCIES

- National Marine Fisheries Service; NOAA Fisheries
- U.S. Army Corp of Engineers
- U.S. Fish and Wildlife Service
- U.S. Forest Service (joint roads)
- U.S. Bureau of Land Management (joint roads)

D. CALIFORNIA ENVIRONMENTAL QUALITY ACT

State agencies must comply with the California Environmental Quality Act (CEQA) before they may issue final permits or agreements. Issuance of a final agreement occurs when the state agency receives the signed draft agreement from you and the state agency signs it. When more than one state agency is involved, the applicant must provide a signed agreement to all applicable state agencies before the lead agency has fully complied with CEQA. In those instances, the state agency must wait for the lead agency to fully comply with CEQA before it may sign the draft agreement, thereby making it final.

Under CEQA, the “lead agency” is the local or State governmental agency that has the principal responsibility for carrying out or approving the project. All other local or State agencies with discretionary approval authority are “responsible agencies.” The lead agency must determine first whether the project is exempt from CEQA. If the project is not exempt, the lead agency must prepare an environmental document, which will be a negative declaration, a mitigated negative declaration, or an environmental impact report. A lead agency is entitled to recover all of its CEQA-related costs from you. If the Department acts as the

lead agency for the project your draft agreement covers, it will instruct you to submit an initial deposit to cover its initial CEQA-related costs. The deposit and any further CEQA-related costs will be in addition to the notification fee.

If the Department is a responsible agency, you must submit, with the notification form, a copy of any document prepared by the lead agency pursuant to CEQA, if one already has been prepared. You must also identify the lead agency on the notification form (box 14.D). A final agreement cannot be signed by the Department until a copy of the Notice of Determination has been submitted to and reviewed by the Department.

Pursuant to FGC §711.4, you must pay a filing fee to the lead agency if the project is subject to CEQA, unless one of the exceptions specified in FGC §711.4(c) (2) or (3) or (d) (1) or (2) applies.

Current CEQA fees are found in FGC §711.4, available at www.leginfo.ca.gov/calaw.html. The filing fee is in addition to the notification fee.

For a detailed explanation of CEQA, please consult the statute itself (PRC §21000, et seq.), the CEQA Guidelines (CCR, title 14, §15000 et seq.) that implement CEQA, and CEQA handbooks and guides. CEQA and the CEQA Guidelines are available at <http://www.ceres.ca.gov/planning>

APPENDIX C:

California Board of Forestry and Fire Protection 2013 Road Rules and Technical Addendum No. 5: Guidance on hydrologic disconnection, road drainage, minimization of diversion potential and high risk crossings

The California Board of Forestry and Fire Protection (CAL FIRE) is responsible for the development of forest practice standards and enforcement of the California Forest Practice Rules (CFPR), under Title 14, Chapter 4 of the California Code of Regulations, and includes regulations for timber harvesting and road construction, maintenance, and decommissioning activities on privately owned lands. The CFPR are intended to ensure that logging and forest management is done in a manner that protects public resources, including fisheries, wildlife, forests, and streams. The rules pertaining to logging roads, landings, and logging road watercourses are organized into the “Road Rules” package of the CFPR and were recently updated in 2013.

In addition to the Road Rules package, CAL Fire developed “Technical Addendum No. 5: Guidance on hydrologic disconnection, road drainage, minimization of diversion potential, and high risk crossings,” a document that provides guidance for Registered Professional Foresters, Licensed Timber Operators, timberland owners, and agency personnel for proper logging road drainage and hydrologic disconnection. The document provides (1) an explanation of hydrologic connectivity and disconnection; (2) guidance on the proper location of drainage facilities and structures, energy dissipaters, road surface outsloping, and rolling dip placement; (3) a description of diversion potential and correct critical dip placement; and (4) potential approaches for handling high risk crossings.

The *Handbook for Forest, Ranch, and Rural Roads* is consistent with the CAL FIRE road rules and guidance objectives stated in Technical Addendum No. 5. The handbook is

also consistent with CFPR terminology, with the exception of the term “abandonment.” According to CFPR, road abandonment refers to what the handbook terms as road decommissioning. The handbook also differs slightly from the CFPR where the CFPR has generalized language regarding road construction, decommissioning, and maintenance. In these cases, the Handbook provides more detailed guidelines and specific recommendations consistent with the goals of the Z’berg-Nejedly Forest Practice Act and the CFPR.

A. C-I. 2013 ROAD RULES

14 CCR § 895.1. DEFINITIONS.

Abandoned Road means a logging road on which proactive measures have been applied to effectively remove it from the permanent road network.

Abandonment means implementing measures to effectively remove an existing logging road, landing, or logging road watercourse crossing from the permanent road network.

Appurtenant Road means a logging road under the ownership or control of the timber owner, timberland owner, timber operator, or plan submitter that will be used for log hauling.

Berm means a curb, dike, or linear mound of earth that is constructed to control water and direct roadway runoff waters or that has developed through road grading activities.

Connected Headwall Swale means a geomorphic feature consisting of a concave depression with convergent slopes, typically of 65 percent or greater steepness that is connected to a watercourse or lake by way of a continuous linear depression and that has been sculpted over geologic time by shallow landslide events. The slope profile is typically smooth and unbroken by benches, but may be interrupted by recent landslide deposits or scars. Emergent groundwater and wet areas may exist at the base of the swale. Soil and colluvium depth is typically greatest at the axis of the swale, thinning to either side.

Critical Dip means a constructed dip or low point across a logging road surface down grade from, or over, a logging road watercourse crossing that functions to prevent crossing overflow from draining down the road and minimizes fill erosion.

Crowning means creating a road surface with a convex cross sectional profile that drains runoff toward both sides of the road.

Deactivated Road means a logging road that is part of the permanent road network where measures have been implemented to prevent active use by logging trucks and standard production four-wheel drive highway vehicles.

Deactivation means implementing measures necessary to prevent the active use of an existing logging road, landing, or logging road watercourse crossing.

Excess Material means excavated material that is not used as a functional part of the road or a landing. Excess material is synonymous with spoils.

Extended Wet Weather Period means the period from October 15 to May 1.

Fill means material that is mechanically placed and built up in compacted lifts to form a roadbed or landing surface. Fill includes the material placed around culverts and related drainage structures at logging road watercourse crossings.

Ford means a logging road watercourse crossing where the road grade dips through the watercourse channel.

Harvest Area means the area where trees are felled and removed.

Hydrologic Disconnection means the removal of direct routes of drainage or overland flow of road runoff to a watercourse or lake.

Insloping means shaping the logging road or landing surface to drain toward a cutbank or inside ditch.

Outsloping means shaping the road surface to drain toward the outside edge of the logging road or landing.

Permanent Road means a logging road that is part of the permanent road network and is designed for year-round use. These roads have a surface that is suitable for maintaining a stable operating surface throughout the year.

Permanent Road Network means the permanent, seasonal, and temporary, and deactivated roads, including appurtenant roads, that provide the infrastructure necessary for timber operations and forest management. Abandoned roads are not part of the permanent road network.

Permanent Watercourse Crossing means a watercourse crossing that will remain in place when timber operations have been completed.

Prescribed Maintenance Period means the time period, beginning with filing of the work completion report, provided that the report is subsequently approved, during which erosion controls that are required and constructed as part of timber operations must be maintained in a functional condition.

Public Road means a road open to the general public which is: (a) in the State or County road system, or (b) a road on which a public agency has deeded, unlimited easement.

Reconstructed Roads means those existing roads that are to be restored or improved to make useable for hauling forest products; “reconstructed” does not include road maintenance or rehabilitation that does not require substantial change in the original prism of the road.

Road Approach means the portion of the logging road surface that drains overland water flow to the watercourse crossing.

Road Maintenance means activities that do not require substantial change to the logging road prism to maintain stable operating surfaces, functioning logging road drainage facilities and structures, and stable cutbanks and fill slopes. Examples of road maintenance may include rocking a road surface; localized shaping or outslipping; installation and maintenance of rolling and critical dips; restoring functional capacity of inboard ditches, cross drains, or culverts; and repairing water bars.

Road Prism means all parts of a road including cut banks, ditches, road surfaces, road shoulders, and road fills.

Seasonal Road means a logging road that is part of the permanent road network that is not designed for year-round use. These roads have a surface that is suitable for maintaining a stable operating surface during the period of use.

Sidecast means excess earthen material pushed or dumped over the side of a roads or landing.

Significant Sediment Discharge means soil erosion that is currently, or may be in the future, discharged to watercourses or lakes in quantities that violate Water Quality Requirements or result in significant individual or cumulative adverse impacts to the beneficial uses of water. One indicator of a Significant Sediment Discharge is a visible increase in turbidity to receiving Class I, II, III, or IV waters.

Significant Existing or Potential Erosion Site means a location where soil erosion is currently, or may be in the future, discharged to watercourses or lakes in quantities that violate Water Quality Requirements or result in significant individual or cumulative adverse impacts to the beneficial uses of water.

Temporary Road means a logging road that is to be used only during timber operations and that will be deactivated or abandoned upon completion of use.

Through Cut means a section of road that lies below the adjacent ground level on both sides of the road.

14 CCR § 914.7 [934.7, 954.7]. TIMBER OPERATIONS, WINTER PERIOD.

During the winter period:

(a) Mechanical site preparation and timber harvesting, shall not be conducted unless a winter period operating plan is incorporated in the timber harvesting plan and is followed, or unless the requirements of subsection (c) are met. Cable, helicopter and balloon yarding methods are exempted.

(b) The winter period operating plan shall include the specific measures to be taken in the winter operating period to avoid or substantially lessen erosion, soil movement into watercourses and soil compaction from timber operations. A winter period operating plan shall address the following subjects:

- (1)** Erosion hazard rating.
- (2)** Mechanical site preparation methods.
- (3)** Yarding system (constructed skid trails and tractor road watercourse crossings).
- (4)** Operating Period.
- (5)** Erosion control facilities timing.
- (6)** Consideration of form of precipitation-rain or snow.
- (7)** Ground conditions (soil moisture condition, frozen).
- (8)** Silvicultural system-ground cover.
- (9)** Operations within the WLPZ.
- (10)** Equipment use limitations.
- (11)** Known unstable areas.
- (12)** Logging roads and landings.

(c) In lieu of a winter period operating plan, the RPF can specify the following measures in the THP:

- (1)** Tractor yarding or the use of tractors for constructing logging roads, landings, watercourse crossings, layouts, fire-breaks or other tractor roads shall be done only during dry, rainless periods and shall not be conducted on saturated soils conditions that may produce significant sediment discharge.

§ 914.8 [934.8, 954.8] TRACTOR ROAD WATERCOURSE CROSSING

(d) Tractor road watercourse crossing facilities shall be removed and stabilized before the beginning of the winter period to the standards of 14 CCR § 923.9 [943.9, 963.9], subsections (p)(1)–(4), or as specified in the winter period operating plan. The RPF may propose an exception if explained and justified in the plan, and found by the Director to be in conformance with this article.

CCR § 915.1 [935.1, 955.1]. USE OF HEAVY EQUIPMENT FOR SITE PREPARATION.

- (a)** Use of heavy equipment for site preparation shall comply with the provisions set forth in 14 CCR 914.2 [934.2, 954.2].
- (b)** Heavy equipment shall not be used for site preparation under saturated soil conditions that may produce significant sediment discharge; or when it cannot operate under its own power due to wet conditions.

§ 916.3 [936.3, 956.3].
**GENERAL LIMITATIONS
 NEAR WATERCOURSES,
 LAKES, MARSHES, MEADOWS
 AND OTHER WET AREAS**

(c) The timber operator shall not construct or use tractor roads in Class I, II, III or IV watercourses, in the WLPZ, marshes, wet meadows, and other wet areas unless when explained and justified in the plan by the RPF, and approved by the Director, except as follows:

- (1) At prepared tractor road crossings as described in 14 CCR § 914.8(b) [934.8(b), 954.8(b)].
- (2) Crossings of Class III watercourses that are dry at the time of use.
- (3) At new and existing tractor and road crossings approved as part of the Fish and Game Code process (F&GC 1600 et seq.).

916.4 [936.4, 956.4].
**WATERCOURSE AND
 LAKE PROTECTION.**

(a) The RPF or supervised designee shall conduct a field examination and map all lakes and Class I, II, III, and IV watercourses.

- (1) As part of this field examination, the RPF or supervised designee shall evaluate areas near, and areas with the potential to directly impact, watercourses and lakes for sensitive conditions including, but not limited to, existing and proposed roads, skid trails and landings, unstable and erodible watercourse banks, unstable upslope areas, debris, jam potential, inadequate flow capacity, migrating channels, overflow channels, flood prone areas,

and riparian zones wherein the values set forth in 14 CCR §§ 916.4 [936.4, 956.4, subsection(b) are impaired.

§ 916.9 [936.9, 956.9].
**PROTECTION AND
 RESTORATION OF THE
 BENEFICIAL FUNCTIONS
 OF THE RIPARIAN ZONE IN
 WATERSHEDS WITH LISTED
 ANADROMOUS SALMONIDS.**

In addition to all other district Forest Practice Rules, the following requirements shall apply in any watershed with listed anadromous salmonids. Requirements of 14 CCR § 916.9 [936.9, 956.9] precede other sections of the FPRs.

Geographic scope—Requirements for watersheds with listed anadromous salmonids differ depending on the geographic location of the watershed and geomorphic characteristics of the watercourse. Unique requirements for watersheds with listed anadromous salmonids are set forth for 1) watercourses in the coastal anadromy zone with confined channels, 2) watercourses with flood prone areas or channel migration zones, and 3) watercourses with confined channels located outside the coastal anadromy zone.

Watersheds which do not meet the definition of “watersheds with listed anadromous salmonids” are not subject to this section except as follows: The provisions of 14 CCR 916.9 [936.9, 956.9], subsections (k)–(q), also apply to planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids for purposes of reducing significant adverse impacts from transported fine sediment. Projects in other watersheds further upstream that flow into watersheds with listed anadromous salmonids, not otherwise designated above, may be subject to these provisions based on an assessment consistent with cumulative impacts assessment

requirements in 14 CCR §§ 898 and 912.9 [932.9, 952.9] and Technical Rule Addendum No. 2, Cumulative Impacts Assessment. These requirements do not apply to upstream watersheds where permanent dams attenuate the transport of fine sediment to downstream watercourses with listed anadromous salmonids.

(f) Class I watercourses—

(1) For Class I watercourses, where fish are always or seasonally present or where fish habitat is restorable, any plan involving timber operations within the WLPZ shall contain the following information:

(A) Clear and enforceable specifications of timber operations within the Class I WLPZ, including a description of how any disturbance, or log or tree cutting and removal shall be carried out to conform with 14 CCR §§ 916.2 [936.2, 956.2], subsection (a) and 916.9 [936.9, 956.9], subsection (a).

(B) Documentation of how proposed harvesting in the WLPZ contributes to the objectives of each zone stated in 14 CCR § 916.9 [936.9, 956.9], subsection (c) and other goals in 14 CCR § 916.9 [936.9, 956.9], subsection (a) (1)–(8). Documentation shall include the examinations, analysis, and other requirements listed in 14 CCR § 916.4 [936.4, 956.4], subsection (a).

(3) Class I watercourses with flood prone areas or channel migration zones:

(E) Preferred Management Practices in the Inner Zone A and B of Flood Prone Areas

4. Avoid Slash concentration and site preparation: or pile burning.

5. Delineate Zone on the Ground: Locations of all WLPZ zones and CMZs shall be designated on the ground.

6. Avoid Use of Water Drafting Sites: or stream alteration permits.

7. Avoid Disturbance to Critical Flood Prone Area Habitat: and down large woody debris.

(F) Outer Zone:

(k) Year-round tractor road use limitations.

(1) Tractor roads shall not be used when operations may result in significant sediment discharge.

(l) Extended Wet Weather Period—No timber operations shall take place unless the approved plan incorporates a complete winter period operating plan pursuant to 14 CCR § 914.7 [934.7, 954.7], subsection (b).

(1) Unless the winter period operating plan proposes operations during an extended wet weather period with low antecedent soil wetness, no tractor roads shall be constructed, reconstructed, or used on slopes that are over 40 percent and within 200 feet of a Class I, II, or III watercourse, as measured from the watercourse or lake transition line.

(n) Treatments to stabilize soils—Within the WLPZ, and within any ELZ

or EEZ designated for watercourse or lake protection, treatments to stabilize soils, minimize soil erosion, and prevent significant sediment discharge, shall be described in the plan as follows.

(1)

(C) Any other area of disturbed soil that threatens to discharge sediment into waters in amounts that would result in a significant sediment discharge.

(2) Soil stabilization treatment measures may include, but need not be limited to, removal, armoring with rip-rap, replanting, mulching, installing commercial erosion control devices to manufacturer's specifications, or chemical soil stabilizers.

§ 923 [943,963]. INTENT FOR LOGGING ROADS, LANDINGS, AND LOGGING ROAD WATERCOURSE CROSSINGS.

(a) All logging roads, landings, and logging road watercourse crossings in the logging area shall be planned, constructed, reconstructed, used, maintained, removed, abandoned, and deactivated in a manner that:

(1) Is consistent with long-term enhancement and maintenance of the forest resource.

(2) Accommodates appropriate yarding systems.

(3) Is economically feasible.

(b) Such planning, construction, reconstruction, use, maintenance, removal, abandonment, and deactivation shall occur in a manner that considers safety and

avoids or substantially lessens significant adverse impacts to, among other things:

(1) Fish and wildlife habitat and listed species of fish and wildlife.

(2) Water quality and the beneficial uses of water.

(3) Soil resources.

(4) Significant archeological and historical sites.

(5) Air quality.

(6) Visual resources.

(7) Fire hazard.

(c) The RPF may propose exceptions to the rules of this Article if explained and justified in the plan and found by the Director not to result in a significant adverse impact on the environment.

(d) Exceptions may also be provided through application of Fish and Game Code Sections 1600 et seq. and shall be made an enforceable part of the plan in accordance with 14 CCR §§ 1039, 1040, 1090.14, 1092.26, or 1092.27, as appropriate.

(e) For watersheds with listed anadromous salmonids and for planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids all logging roads, landings, and logging road watercourse crossings shall be planned, designed, constructed and reconstructed, used, maintained, abandoned, deactivated, and removed in accordance with 14 CCR § 916.9 (a) and (c) [936.9 (a) and (c), 956.9 (a) and (c)].

(f) The provisions of Articles 12 [Article 11 for Northern District] that apply in watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids shall not apply to a plan that is subject to:

- (1)** A valid incidental take permit issued by CDFW pursuant to Section 2081(b) of the Fish and Game Code that addresses anadromous salmonid protection; or
- (2)** A federal incidental take statement or incidental take permit that addresses anadromous salmonid protection, for which a consistency determination has been made pursuant to Section 2080.1 of the Fish and Game Code; or
- (3)** A valid natural community conservation plan that addresses anadromous salmonid protection approved by CDFW under section 2835 of the Fish and Game Code; or
- (4)** A valid Habitat Conservation Plan (HCP) that addresses anadromous salmonid protection, approved under Section 10 of the federal Endangered Species Act of 1973; or
- (5)** Project revisions, guidelines, or take avoidance measures pursuant to a memorandum of understanding or a planning agreement entered into between the plan submitter and CDFW in preparation of obtaining a natural community conservation plan that addresses anadromous salmonid protection.

§ 923.1[943.1, 963.1]. PLANNING FOR LOGGING ROADS AND LANDINGS.

Logging roads and landings shall be planned and located within the context of a systematic layout pattern that considers 14 CCR § 923(b), uses existing logging roads and landings where feasible and appropriate, and provides access for fire and resource protection activities.

(a) Logging roads and landings shall be planned and located to minimize the following:

- (1)** Duplicative roads and total road mileage.
- (2)** The number of logging road watercourse crossings.
- (3)** Construction and reconstruction near watercourses, lakes, marshes, wet meadows, and other wet areas.
- (4)** Construction and reconstruction across steep areas that lead without flattening to Class I, II, III, or IV watercourses and lakes.
- (5)** Construction and reconstruction on unstable areas or in connected headwall swales.
- (6)** Construction and reconstruction near nesting sites of rare, threatened, or endangered bird species.
- (7)** Construction and reconstruction near populations of rare, threatened, or endangered plants.
- (8)** Ground disturbance and the size of cuts and fills.

(9) The potential for affecting surface hydrology, including but not limited to, concentrating or diverting runoff or draining the logging road or landing surface directly into a watercourse or lake.

(10) Maintenance needs while being compatible with the logging road classification and long-term road usage.

(b) No logging roads or landings shall be planned for construction (i) within 150 feet of the Class I watercourse transition line, (ii) within 100 feet of the Class II watercourse transition line on slopes greater than 30%, (iii) within Class I, II, III, or IV watercourses or lakes, (iv) within a WLPZ, or (v) in marshes, wet meadows, and other wet areas, except as follows:

(1) At existing logging road watercourse crossings.

(2) At logging road watercourse crossings to be constructed or reconstructed that are approved as part of the Fish and Game Code process (F&GC 1600 et seq.)

(3) At logging road watercourse crossings of Class III watercourses that are dry at the time of use.

(c) No logging roads or landings shall be planned for reconstruction (i) within Class I, II, III, or IV watercourses or lakes, (ii) within a WLPZ, or (iii) in marshes, wet meadows, and other wet areas, except as follows:

(1) At existing logging road watercourse crossings.

(2) At logging road watercourse crossings to be constructed or reconstructed that are approved as

part of the Fish and Game Code process (F&GC 1600 et seq.)

(3) At logging road watercourse crossings of Class III watercourses that are dry at the time of use.

(d) Logging roads and landings shall be planned and located to avoid unstable areas and connected headwall swales. The Director may approve an exception if those areas are unavoidable and site-specific measures to minimize slope instability due to logging road or landing construction or reconstruction are described and justified in the plan.

(e) As part of the planning and use of logging roads, landings, and watercourse crossings in the logging area, the RPF or supervised designee shall: (i) locate and map significant existing and potential erosion sites and (ii) specify feasible treatments to mitigate significant adverse impacts from the road or landing.

(1) The RPF shall evaluate all logging roads and landings in the logging area, including appurtenant roads, for evidence of significant existing and potential erosion sites.

(2) For significant existing and potential erosion sites identified per 14 CCR § 923.1 [943.1, 963.1] subsection (e) (1), the RPF shall consider the following key factors as part of developing necessary treatments:

(A) Type of road (permanent, seasonal, or temporary road), road location, expected log truck haul routes, and traffic use (e.g. volume and season) of each road segment during the life of the plan.

- (B)** Age of road and the history of sediment delivery from existing roads.
- (C)** Beneficial uses of the watercourse or lake and sensitive conditions potentially affected by the road including, but not limited to, watercourse classification and presence of listed anadromous salmonids.
- (D)** The hillslope grade, road grade of crossing approaches and the gradient of the stream channel.
- (E)** The erodibility of hillslope material exposed by the road.
- (F)** The length of hydrologic connectivity of a road segment, the physical properties of the connected segment and the presence or absence of an effective sediment filter strip.
- (G)** Site-specific information regarding the condition of and location of all existing or potential sediment sources including, but not limited to: watercourse crossings, road approaches, ditch relief culverts, road surfaces, road cuts, road fills, inboard ditches, through-cuts, and landings.
- (3)** The RPF shall submit a list of the significant existing and potential erosion sites identified per 14 CCR § 923.1 [943.1, 963.1], subsection (e) (1) which have feasible treatments with the plan. This list shall include the following information:
- (A)** A map showing the location(s) of significant existing and potential erosion site(s) with a unique identifier for each site.
- (B)** Brief description of present condition of the mapped significant existing or potential erosion site.
- (C)** Brief description of proposed treatments for the mapped significant existing or potential erosion site.
- (D)** Items (B) and (C) above can be provided in tabular form as part of the plan.
- (4)** The RPF shall disclose and map the significant existing and potential erosion sites identified per 14 CCR § 923.1 [943.1, 963.1], subsection (e) (1), for which no feasible treatment measures exist.
- (5)** Where feasible treatments for significant existing or potential erosion site are proposed, the RPF shall describe in the plan a logical order of treatment.
- (f)** When selecting feasible alternatives (see 14 CCR §§ 897 and 898) during the planning phase of logging roads and landings, the RPF shall consider the location and planned use of logging roads and landings and whether such logging roads and landings will be abandoned or deactivated.
- (g)** In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, where logging road or landing construction or reconstruction is proposed, the plan shall identify:

(1) How the proposed operations will fit into the systematic layout pattern.

(2) What, if any, offsetting mitigation measures, including but not limited to, abandonment of logging roads and landings, are needed to minimize potential adverse impacts to watersheds from the road system.

(h) In watersheds with listed anadromous salmonids no logging roads or landings shall be planned for construction or reconstruction in the CMZ or Core Zone of a Class I watercourse except those listed in 14 CCR § 916.9(e)(1)(A)–(E) [936.9(e)(1)(A)–(E), 956.9(e)(1)(A)–(E)] or pursuant to 14 CCR § 916.9(v) [936.9(v), 956.9(v)], or within 150 feet of a Class I watercourse transition line.

(i) In watersheds with listed anadromous salmonids within the Inner Zone A and B of flood prone areas of Class I watercourses the following Preferred Management Practices should be considered for inclusion in the plan by the RPF and by the Director:

(1) Constructed and reconstructed logging roads and landings should not be planned for location within these zones.

(2) When feasible, planned use of existing logging roads and landings should be minimized in the flood prone area.

(3) Exceptions include the use of roads and landings to accomplish actions to improve salmonid habitat conditions stated in 14 CCR § 916.9(f) (3) (E) (1) [936.9(f) (3) (E) (1), 956.9(f) (3) (E) (1)].

§ 923.2 [943.2, 963.2]. DESIGN AND LOCATION FOR LOGGING ROADS AND LANDINGS

Constructed and reconstructed logging roads and landings shall be designed and located in accordance with their proposed use, maintenance requirements, and the approved plan:

(a) All logging roads and landings shall:

(1) Avoid or mitigate potential impacts to public safety.

(2) Avoid unstable areas and connected headwall swales to the extent feasible and minimize activities that adversely affect them.

(3) Minimize the size of cuts and fills to the extent feasible.

(4) Be outsloped where feasible and drained with waterbreaks and/or rolling dips in conformance with other applicable Forest Practice Rules.

(5) Be hydrologically disconnected from watercourses and lakes to the extent feasible to minimize sediment delivery from road runoff to a watercourse, and reduce the potential for hydrologic changes that alter the magnitude and frequency of runoff delivery to a watercourse. Guidance on methods for hydrologic disconnection may be found in the Board's Technical Rule Addendum Number 5.

(6) Include adequate drainage structures and facilities necessary to avoid concentrating and diverting runoff, to minimize erosion of roadbeds, landing surfaces, drainage ditches, sidecast and fills, to minimize the potential for soil erosion and sediment transport,

and to prevent significant sediment discharge. Guidance on methods for conformance with this rule section may be found in the Board's Technical Rule Addendum Number 5.

(7) Avoid crossing, or locations on, 100 feet or more of lineal distance over any slopes greater than 65 percent or within 100 feet of the boundary of a WLPZ on slopes greater than 50 percent that drain toward the zoned watercourse or lake. Where logging road or landing construction or reconstruction is proposed in these areas, specific measures to minimize movement of soil and the discharge of concentrated surface runoff shall be incorporated in the plan. The Director may waive inclusion of such measures where the RPF can show that slope depressions, drainage ways, and other natural retention and detention features are sufficient to control overland transport of eroded material.

(b) The Director may require removal of deposits of excess material if the deposits are in a position to adversely affect the beneficial uses of water.

(c) Excess material excavated during logging road and landing construction shall not be transported to locations where it may result in significant sediment discharge.

(d) In addition to the requirements of subsection (a) above, all logging roads to be constructed or to be reconstructed shall:

(1) Be no wider than a single-lane compatible with the largest type of equipment specified for use on the logging road, with adequate turnouts provided as required for safety, except where

wider road dimensions are required by existing contracts with a federal agency.

(2) Avoid grades greater than 20% or grades greater than 15% that extend greater than 500 continuous feet. Exceptions may be approved where there is no other feasible access for harvesting of timber or where use of a gradient greater than 20% will serve to reduce soil disturbance.

(e) In addition to the requirements of subsection (a) above, all landings to be constructed or to be reconstructed shall:

(1) Be consistent with the yarding and loading system to be used.

(2) Be no larger than one-half acre.

(3) Avoid construction on slopes greater than 40 percent where the landing will exceed one-quarter acre in size.

§ 923.3 [943.3, 963.3]. MAPPING AND IDENTIFICATION FOR LOGGING ROADS AND LANDINGS.

The following mapping and identification standards shall apply to logging roads and landings:

(a) For logging road- and landing-related mapping requirements refer to 14 CCR §§ 1034(x)(4)(A)–(E) and (5)(A)–(G), 1090.5(w)(4)(A)–(E) and (5)–(6), 1090.5(gg), 1090.7(n)(4)–(6), and 1092.09(l)(5)(A)1.–5. and (6)(A)–(G).

(b) The RPF shall identify in the field, for use by the LTO, all logging roads and landings to be constructed or to be reconstructed:

(1) Across slopes greater than 65 percent for 100 lineal feet or more.

(2) Across slopes greater than 50 percent for 100 lineal feet or more within 100 feet of the boundary of a WLPZ that drains toward the zoned watercourse or lake.

(c) The location of all logging roads to be constructed or to be reconstructed shall be flagged or otherwise identified on the ground prior to the pre-harvest inspection. Exceptions may be explained and justified in the plan and agreed to by the Director if flagging is unnecessary as a substantial aid to examining: (1) compatibility between logging road location and yarding and silvicultural systems, or (2) possible significant adverse effects of logging road location on the factors listed under 14 CCR § 923(b) [943(b), 963(b)].

§ 923.4 [943.4, 963.4]. CONSTRUCTION AND RECONSTRUCTION FOR LOGGING ROADS AND LANDINGS

Logging roads and landings shall be constructed or reconstructed in accordance with the approved plan and the following requirements. If a change in designation of logging road classification is made after the plan is approved, the change shall be reported in accordance with 14 CCR §§ 1039, 1040, 1090.14, 1092.26 or 1092.27, as appropriate.

(a) Logging roads and landings shall be hydrologically disconnected from watercourses and lakes to the extent feasible to minimize sediment delivery from road runoff to a watercourse, and reduce the potential for hydrologic changes that alter the magnitude and frequency of runoff delivery to a watercourse. Guidance on methods for hydrologic disconnection may be found in the Board's Technical Rule Addendum Number 5.

(b) No logging roads or landings shall be constructed (i) within 150 feet of the Class I watercourse transition line, (ii) within 100 feet of the Class II watercourse transition line on slopes greater than 30%, (iii) within Class I, II, III, or IV watercourses or lakes, (iv) within a WLPZ, or (v) in marshes, wet meadows, and other wet areas, except as follows:

(1) At existing logging road watercourse crossings.

(2) At logging road watercourse crossings to be constructed or reconstructed that are approved as part of the Fish and Game Code process (F&GC 1600 et seq.)

(3) At logging road watercourse crossings of Class III watercourses that are dry at the time of use.

(c) No logging roads or landings shall be reconstructed (i) within Class I, II, III, or IV watercourses or lakes, (ii) within a WLPZ, or (iii) in marshes, wet meadows, and other wet areas, except as follows:

(1) At existing logging road watercourse crossings.

(2) At logging road watercourse crossings to be constructed or reconstructed that are approved as part of the Fish and Game Code process (F&GC 1600 et seq.)

(3) At logging road watercourse crossings of Class III watercourses that are dry at the time of use.

(d) Logging roads and landings shall not be constructed or reconstructed across unstable areas or connected headwall swales except as specified in the Plan.

- (e)** Logging roads and landings shall not be constructed with overhanging banks.
- (f)** Any tree over 12 inches dbh with more than 25 percent of the root surface exposed by logging road or landing construction shall be felled concurrently with the timber operations.
- (g)** On slopes greater than 40 percent, the organic layer of the soil shall be removed prior to fill placement.
- (h)** Waste organic material, such as uprooted stumps, cull logs, accumulations of limbs and branches, and unmerchantable trees, shall not be buried in logging road or landing fills. Wood debris or cull logs and chunks may be placed and stabilized at the toe of fill to restrain excavated soil from moving downslope.
- (i)** Slash and other debris from road construction shall not be bunched against residual trees, which are required for silvicultural or wildlife purposes, nor shall it be placed in locations where it could be discharged into Class I or II watercourses or lakes.
- (j)** Where constructed fills will exceed three feet in vertical thickness, fill slopes shall be inclined no greater than 65 percent.
- (k)** Logging roads or landings shall not be constructed or reconstructed under saturated soil conditions that may produce significant sediment discharge, except that construction may occur on isolated wet spots arising from localized ground water such as springs, provided measures are taken to prevent significant sediment discharge.
- (l)** Construction or reconstruction of logging roads or landings shall not take place during the winter period unless the approved plan incorporates a complete winter period operating plan pursuant to 14 § CCR 914.7 [934.7, 954.7] that specifically addresses such logging road or landing construction or reconstruction.
- (m)** On slopes greater than 50 percent for greater than 100 lineal feet, fills greater than four feet in vertical height at the outside shoulder of the logging road or landing shall be:
- (1)** Constructed on a bench that is excavated at the proposed toe of the fill and is wide enough to compact the first lift.
 - (2)** Compacted in approximately one-foot lifts from the toe to the finished grade or retained by an engineered structure.
- (n)** Logging roads and landings approved for construction or reconstruction across 100 feet or more of lineal distance on any slope greater than 65 percent or within 100 feet of the boundary of a WLPZ on slopes greater than 50 percent that drain toward the zoned watercourse or lake shall be constructed to the specific construction techniques or measures as described in the plan.
- (o)** Fills shall not be constructed on slopes greater than 65 percent.
- (p)** On slopes greater than 65 percent, sidecast from logging road and landing construction shall be minimized to the degree feasible.
- (q)** Excess material transported from logging road or landing construction or reconstruction shall be deposited and stabilized in a manner and in areas that avoid potential adverse impacts to locations that could deliver significant sediment discharge.

(r) In watersheds with listed anadromous salmonids, no logging roads or landings shall be constructed or reconstructed within the CMZ or Core Zone of a Class I watercourse except for those listed in 14 CCR § 916.9 [936.9, 956.9], subsections (e)(1)(A)–(F) or pursuant to 14 CCR § 916.9 [936.9, 956.9], subsection (v).

(s) In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, the following shall apply:

(1) On slopes greater than 50 percent that have access to a watercourse or lake:

(A) Specific provisions for the protection of salmonid habitat shall be identified and described for all logging road construction.

(B) Where cutbank stability is not an issue, logging roads may be constructed as a full-benched cut (no fill). Spoils not utilized in logging road construction shall be disposed of in stable areas with less than 30 percent slope outside of any WLPZ, EEZ, or ELZ designated for watercourse or lake protection. The Director, with concurrence from other responsible agencies, may waive inclusion of these measures where the RPF can show that slope depressions and other natural retention and detention features are sufficient to control overland transport of eroded material.

(C) Logging roads may be constructed with balanced cuts and fills:

(i) If properly engineered, or,

(ii) If fills are removed and the slopes recontoured prior to the winter period.

(2) During the extended wet weather period, no timber operations shall take place unless the approved plan incorporates a complete winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)]. The winter period operating plan shall specifically address, where applicable, proposed logging road and landing construction, and reconstruction.

§ 923.5 [943.5,963.5]. EROSION CONTROL FOR LOGGING ROADS AND LANDINGS.

The following erosion control standards shall apply to logging roads and landings:

(a) All logging road and landing surfaces shall be adequately drained through the use of logging road and landing surface shaping in combination with the installation of drainage structures or facilities and shall be hydrologically disconnected from watercourses and lakes to the extent feasible.

Guidance on methods for hydrologic disconnection may be found in the Board's Technical Rule Addendum Number 5.

(b) Drainage facilities and structures shall be installed along all logging roads and all landings that are used for timber operations in sufficient number to minimize soil erosion and sediment transport and to prevent significant sediment discharge.

(c) Ditch drains, associated necessary protective structures, and other features associated with the ditch drain shall:

(1) Be adequately sized to convey runoff.

(2) Minimize erosion of logging road and landing surfaces.

(3) Avoid discharge onto unprotected fill.

(4) Discharge to erosion resistant material.

(5) Minimize potential adverse impacts to slope stability.

(d) Waterbreaks and rolling dips installed across logging roads and landings shall be of sufficient size and number and be located to avoid collecting and discharging concentrated runoff onto fills, erodible soils, unstable areas, and connected headwall swales.

(e) Where logging roads or landings do not have permanent and adequate drainage, and where waterbreaks are to be used to control surface runoff, the waterbreaks shall be cut diagonally a minimum of six inches into the firm roadbed and shall have a continuous firm embankment of at least six inches in height immediately adjacent to the lower edge of the waterbreak cut. On logging roads that have firmly compacted surfaces, waterbreaks may be installed by hand methods and need not provide the additional six-inch embankment provided the waterbreak ditch is constructed so that it is at least six inches deep and six inches wide on the bottom and provided there is ample

evidence based on slope, material, amount of rainfall, and period of use that the waterbreaks so constructed will be effective in diverting water flow from the logging road surface without the embankment.

(f) Distances between waterbreaks shall not exceed the following standards and consider erosion hazard rating and road gradient:

(g) Where outsloping and rolling dips are used to control surface runoff, the dip in the logging road grade shall be sufficient to capture runoff from the logging road surface. The steepness of cross-slope gradient in conjunction with the logging road or landing gradient and the estimated soil erosion hazard rating shall be used to determine the rolling dip spacing in order to minimize soil erosion and sediment transport and to prevent significant sediment discharge. Guidance on rolling dip spacing may be found in the Board's Technical Rule Addendum Number 5.

(h) Drainage facilities and structures shall discharge into vegetation, woody debris, or rock wherever possible. Where erosion-resistant material is not present, slash, rock, or other energy dissipating material shall be installed below the drainage facility or drainage structure outlet as necessary to minimize soil erosion and sediment transport and to prevent significant sediment discharge. Guidance on energy dissipaters

MAXIMUM DISTANCE BETWEEN WATERBREAKS

Estimated Hazard Rating	Logging Road 10 or less	Gradient in Percent 11–25	>25
	Feet	Feet	Feet
Extreme	100	75	50
High	150	100	75
Moderate	200	150	100
Low	300	200	150

for drainage structures may be found in the Board's Technical Rule Addendum Number 5.

(i) Where logging road and landing surfaces, road approaches, inside ditches and drainage structures cannot be hydrologically disconnected, and where there is existing or the potential for significant sediment discharge, necessary and feasible treatments to prevent the discharge shall be described in the plan.

(j) All logging roads and landings used for timber operations shall have adequate drainage upon completion of use for the year or by October 15, whichever is earlier. An exception is that drainage facilities and drainage structures do not need to be constructed on logging roads and landings in use during the extended wet weather period provided that all such drainage facilities and drainage structures are installed prior to the start of rain that generates overland flow.

(k) Where logging road or landing construction or reconstruction takes place during the extended wet weather period, drainage facilities and drainage structures shall be installed concurrent with construction or reconstruction operations.

(l) Bare soil on logging road or landing cuts, fills, transported spoils, or sidecast that is created or exposed by timber operations shall be stabilized to the extent necessary to minimize soil erosion and sediment transport and to prevent significant sediment discharge. Sites to be stabilized include, but are not limited to:

(1) Sidecast or fill exceeding 20 feet in slope distance from the outside edge of a logging road or a landing that has access to a watercourse or lake.

(2) Cut and fills associated with approaches to logging road watercourse crossings of Class I or II waters or Class III waters where an ELZ, EEZ, or a WLPZ is required.

(3) Bare areas exceeding 800 continuous square feet within a WLPZ.

(m) Soil stabilization measures shall be described in the plan pursuant to 14 CCR 923.5(l) [943.5(l),963.5(l)], and may include, but are not limited to, removal, armoring with rip-rap, replanting, mulching, seeding, installing commercial erosion control devices to manufacturer's specifications, or chemical stabilizers.

(n) Where the natural ability of ground cover within a WLPZ is inadequate to protect the beneficial uses of water by minimizing soil erosion or by filtering sediments, the plan shall specify protection measures to retain and improve the natural ability of the ground cover to filter sediment and minimize soil erosion.

(o) Soil stabilization treatments shall be in place upon completion of operations for the year of use or prior to the extended wet weather period, whichever comes first. An exception is that bare areas created during the extended wet weather period shall be treated prior to the start of rain that generates overland flow, or within 10 days, whichever is sooner, or as agreed to by the Director.

(p) Overhanging or unstable concentrations of slash, woody debris or soil along the downslope edge or face of landings shall be removed or stabilized when it is located on slopes greater than 65 percent, within 100 feet of the boundary of a WLPZ on slopes greater than 50 percent that drain toward the zoned watercourse or

lake, or when it may result in significant sediment discharge. Removed materials shall not be placed at disposal sites that could result in a significant sediment discharge.

(q) In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, the following shall apply:

(1) Constructed and reconstructed logging roads shall be outsloped where feasible and drained with waterbreaks or rolling dips.

(2) In addition to the provisions listed under 14 CCR § 923.2(d)(2) [943.2(d)(2), 963.2(d)(2)], all permanent and seasonal logging roads with a grade of 15 percent or greater that extend 500 continuous feet or more shall have specific erosion control measures stated in the plan.

(3) Within the WLPZ, and within any ELZ or EEZ designated for watercourse or lake protection, treatments to stabilize soils, minimize soil erosion, and prevent significant sediment discharge shall be described in the plan as follows:

(A) In addition to the requirements of subsections (l)–(o), soil stabilization is required for the following areas:

(i) Areas exceeding 100 continuous square feet where timber operations have exposed bare soil, and

(ii) Disturbed logging road and landing cut banks and fills, and

(iii) Any other area of disturbed soil that threatens to cause significant sediment discharge.

(B) Where straw mulch is used, the minimum straw coverage shall be 90 percent, and any treated area that has been reused or has less than 90 percent surface cover shall be treated again by the end of timber operations.

(C) Where slash mulch is applied, a minimum of 75% of the area shall be covered by slash in contact with the ground.

(D) For areas disturbed outside of the extended wet weather period, treatment shall be completed prior to the start of any rain that causes overland flow across or along the disturbed surface that could result in significant sediment discharge.

(E) For areas disturbed during the extended wet weather period, treatment shall be completed prior to any day for which a chance of rain of 30 percent or greater is forecast by the National Weather Service or within 10 days of disturbance, whichever is earlier.

(F) Where the natural ability of ground cover is inadequate to protect the beneficial uses of water by minimizing soil erosion or by filtering sediments within any ELZ or EEZ designated for watercourse or lake protection, the plan shall specify protection measures to retain and improve the natural ability of the ground cover to filter sediment and minimize soil erosion.

§ 923.6 [943.6, 963.6]. USE OF LOGGING ROADS AND LANDINGS

The following use standards shall apply to logging roads and landings:

(a) Logging roads and landings shall be used in a manner that is consistent with their design and construction specifications.

(b) Logging roads and landings shall not be used during any time of the year when operations may result in significant sediment discharge to watercourse or lakes, except in emergencies to protect the road, to reduce erosion, to protect water quality, or in response to public safety needs.

(c) During the extended wet weather period, Log hauling or other heavy equipment uses shall be limited to logging roads and landings that exhibit a stable operating surface in conformance with (b) above. Routine use of logging roads and landings shall not occur when equipment cannot operate under its own power.

(d) When burning permits are required pursuant to PRC § 4423, logging roads and landings that are in use shall be kept in passable condition for fire trucks.

(e) Roadside berms that impede logging road drainage, concentrate logging road surface flow, or lead to hydrologic connection shall be removed or breached before the beginning of the winter period, with the exception of berms needed for erosion control.

(f) Temporary roads shall be blocked or otherwise closed to standard production four-wheel drive highway vehicles prior to the winter period, or upon completion of use as specified in an approved

winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)].

(g) Logging roads and landings used for log hauling or other heavy equipment uses during the winter period shall occur on a stable operating surface and, where necessary, be surfaced with rock to a depth and quantity sufficient to maintain such a surface. Use is prohibited on roads that are not hydrologically disconnected and exhibit saturated soil conditions. Exceptions may be proposed by the RPF, when locations are disclosed and justified in the THP, consistent with 14 CCR 923 (c), and approved by the Director.

(h) In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, the following shall apply:

(1) Existing logging roads or landings shall not be used within the CMZ of a Class I watercourse except as listed in 14 CCR § 916.9 916.9 [936.9, 956.9] subsection (e) (1) (A)–(F) or pursuant to 14 CCR § 916.9(v) [936.9(v), 956.9(v)].

(2) When feasible, minimize use of existing logging roads and landings located within Inner Zones A and B of flood prone areas. Exceptions include the use of roads and landings to accomplish actions to improve salmonid habitat conditions stated in 14 CCR § 916.9 916.9(f) (3) (E) (1.) [936.9(f) (3) (E) (1.), 956.9(f) (3) (E) (1.)]

(3) Log hauling on logging roads and landings shall be limited to those which are hydrologically disconnected from watercourses to the extent feasible, and exhibit a stable operating surface in conformance with (b) above. Exceptions

may be proposed by the RPF, when locations are disclosed and justified in the THP, consistent with 14 CCR 923 (c), and approved by the Director.

(4) Concurrent with use for log hauling, all road approaches to logging road watercourse crossings shall be treated for erosion control as needed to minimize soil erosion and sediment transport and to prevent significant sediment discharge to watercourses or lakes.

(5) Concurrent with use for log hauling, all traveled surfaces of logging roads in a WLPZ, and ELZ or EEZ designated for watercourse or lake protection, shall be treated for erosion control as needed to minimize soil erosion and sediment transport and to prevent significant sediment discharge to watercourses or lakes.

(6) No timber operations shall take place during the extended wet weather period unless the approved plan incorporates a complete winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)] that specifically addresses, where applicable, proposed logging road or landing use.

§ 923.7, 943.7, 963.7 MAINTENANCE AND MONITORING FOR LOGGING ROADS AND LANDINGS

The following maintenance and monitoring standards shall apply to logging roads and landings:

(a) Logging road and landing surfaces shall be monitored and maintained during timber operations and throughout the prescribed maintenance period to ensure hydrologic disconnection from watercourses

and lakes to the extent feasible, minimize soil erosion and sediment transport, and to prevent significant sediment discharge.

(b) Logging roads that are used in connection with stocking activities shall be maintained throughout such use, even if this extends beyond the prescribed maintenance period.

(c) During timber operations, road running surfaces in the logging area shall be treated as necessary to prevent excessive loss of road surface materials by methods including , but not limited to, rocking, watering, paving, chemically treating, or installing commercial erosion control devices to manufacturer's specifications.

(d) Grading of logging roads or landings to obtain a drier running surface more than one time before reincorporation of any resulting berms back into the road surface is prohibited.

(e) Drainage facilities and drainage structures, including associated necessary protective structures, shall be maintained to allow free flow of water, and minimize soil erosion and slope instability. Drainage facilities and structures shall be repaired, replaced, or installed as needed to protect the quality and beneficial uses of water.

(f) Soil stabilization treatments on logging road or landing cuts, fills, and sidecast shall be maintained as needed to reduce the potential for slope instability, minimize soil erosion and sediment transport, and to prevent significant sediment discharge.

(g) Heavy equipment shall not be used in a WLPZ for maintenance during wet weather, except in emergencies to protect the road, to reduce erosion, to protect water quality, or in response to public safety needs.

- (h)** Where there is evidence of significant sediment discharge along a logging road or landing used for timber operations, additional measures shall be implemented to minimize soil erosion and sediment transport, and to prevent significant sediment discharge.
- (i)** The prescribed maintenance period for erosion controls on logging roads and associated landings and drainage structures, including appurtenant, abandoned, and deactivated logging roads and landings, shall be at least one year. The Director may prescribe a maintenance period extending up to three years in accordance with 14 CCR § 1050.
- (j)** In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, the prescribed maintenance period for deactivated or abandoned roads shall be one year unless otherwise prescribed by the Director pursuant to 14 CCR § 1050. The prescribed maintenance period for logging roads and associated landings, including appurtenant roads, shall be three years.
- (k)** All logging roads, including abandoned, deactivated, and appurtenant roads, landings, and associated drainage structures used for timber operations shall be monitored as needed to comply with 14 CCR § 1050. Monitoring inspections shall be conducted, when access is feasible during the prescribed maintenance period, a sufficient number of times during the extended wet weather period, particularly after large winter storm events and at least once annually, to evaluate the function of drainage facilities and structures. The Department shall also conduct monitoring inspections at least once during the

prescribed maintenance period to assess logging road and landing conditions.

- (1)** Inspections shall include checking drainage facilities and structures for evidence of downcutting, plugging, overtopping, loss of function, and sediment delivery to Class I, II, or III watercourses and lakes. If evidence of sediment delivery or potential sediment delivery is present, and the implementation of feasible corrective measures could reduce the potential for significant sediment discharge, such additional measures shall be implemented when feasible.
- (2)** Inspections conducted pursuant to California Regional Water Quality Control Board requirements may be used to satisfy the inspection requirements of this section.
- (l)** In watersheds with listed anadromous salmonids, water drafting for timber operations shall:
- (1)** Comply with Fish and Game Code Section 1600, et seq. Timber operations conducted under a Fish and Game Code Section 1600 Master Agreement for Timber Operations that includes water drafting may provide proof of such coverage for compliance with 14 CCR 923.7(l).
- (2)** Describe the water drafting site conditions and proposed water drafting activity in the plan, including:
- (A)** A general description of the conditions and proposed water drafting;
- (B)** The watercourse classification;

- (C)** The drafting parameters including the months the site is proposed for use; estimated total volume needed per day; estimated maximum instantaneous drafting rate and filling time; and disclosure of other water drafting activities in the same watershed;
- (D)** The estimated drainage area (acres) above the point of diversion;
- (E)** The estimated unimpeded streamflow, pumping rate, and drafting duration,
- (F)** a discussion of the effects on aquatic habitat downstream from the drafting site(s) of single pumping operations, or multiple pumping operations at the same location, and at other locations in the same watershed;
- (G)** A discussion of proposed alternatives and measures to prevent adverse effects to fish and wildlife resources, such as reducing hose diameter; using gravity-fed tanks instead of truck pumping; reducing the instantaneous or daily intake at one location; describing allowances for recharge time; using other dust palliatives; and drafting water at alternative sites;
- (H)** The methods that will be used to measure source streamflow prior to the water drafting operation and the conditions that will trigger streamflow to be measured during the operation.

(3) All water drafting for timber operations are subject to each requirement below unless the Department of

Fish and Game modifies the requirement in the Lake or Streambed Alteration agreement that authorized the drafting operation, or unless otherwise specified below:

- (A)** All intakes shall be screened to prevent impingement of juvenile fish against the screen. The following requirements apply to screens and water drafting on Class I waters:
 - (i)** Openings in perforated plate or woven wire mesh screens shall not exceed 3/32 inches (2.38 millimeters). Slot openings in wedge wire screens shall not exceed 1/16 inches (1.75 millimeters).
 - (ii)** The screen surface shall have at least 2.5 square feet of openings submerged in water.
 - (iii)** The drafting operator shall regularly inspect, clean, and maintain screens to ensure proper operation whenever water is drafted.
 - (iv)** The approach velocity (water moving through the screen) shall not exceed 0.3 feet/second.
 - (v)** The diversion rate shall not exceed 350 gallons per minute.
- (B)** Approaches and associated drainage features to drafting locations within a WLPZ or channel zone shall be surfaced with rock or other suitable material to minimize generation of sediment.

(C) Barriers to sediment transport, such as straw wattles, logs, straw bales or sediment fences, shall be installed outside the normal high water mark to prevent sediment delivery to the watercourse and limit truck encroachment.

(D) Water drafting trucks parked on streambeds, floodplains, or within a WLPZ shall use drip pans or other devices such as adsorbent or absorbent blankets, sheet barriers or other materials as needed to prevent soil and water contamination from motor oil or hydraulic fluid leaks.

(E) Bypass flows for Class I watercourses shall be provided in volume sufficient to avoid dewatering the watercourse and maintain aquatic life downstream, and shall conform to the following standard:

(i) Bypass flows in the source stream during drafting shall be at least 2 cubic feet per second.

(ii) Diversion rate shall not exceed 10 percent of the surface flow.

(iii) Pool volume reduction shall not exceed 10 percent.

(F) The drafting operator shall keep a log that records for each time water is drafted, the date, total pumping time, pump rate, starting time, ending time, and volume diverted. Logs shall be filed with the Department of Forestry and Fire Protection at the end of seasonal operations and maintained with the plan record. This requirement may be modified in the approved plan that covers the water drafting,

but only with concurrence from the Department of Fish and Game.

(G) Before commencing any water drafting operation, the RPF and the drafting operator shall conduct a pre-operations field review to discuss the water drafting measures in the plan and/or Lake or Streambed Alteration Agreement.

§ 923.8[943.8, 963.8]. ABANDONMENT AND DEACTIVATION OF LOGGING ROADS AND LANDINGS.

All logging roads and landings that are proposed to be removed from the permanent road network shall be abandoned. All temporary logging roads and landings that are to remain a part of the permanent road network shall be deactivated annually prior to the winter period or upon completion of timber operations as specified in an approved winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)]. Other logging roads and landings proposed to be deactivated shall comply with the standards specified in this section. Where abandonment or deactivation is required or proposed, specific measures to prevent significant sediment discharge that apply the following general requirements shall be described in the plan:

(a) All abandoned and deactivated logging roads and landings shall be left in a condition that provides for long-term, maintenance-free function of drainage and erosion controls.

(b) Soil exposed by abandonment or deactivation operations shall be removed or stabilized as needed to minimize soil erosion and sediment transport.

(c) Logging road watercourse crossings, other drainage structures, and associated fills shall be removed and stabilized in accordance with 14 CCR § 923.9 [943.9, 963.9], subsections (p)(1)–(4).

(d) Logging roads to be abandoned or deactivated shall be blocked prior to the winter period, or upon completion of timber operations as specified in an approved winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)], so that standard production four wheel-drive highway vehicles cannot pass the point of closure at the time of abandonment or deactivation. If the logging road is to be abandoned, then the blockage design shall be described in the plan.

§ 923.9 [943.9, 963.9]. WATERCOURSE CROSSINGS [ALL DISTRICTS]

Watercourse crossing drainage structures on logging roads shall be planned, constructed, reconstructed, and maintained or removed according to the standards provided in this rule section.

(a) The planning for and use of logging road watercourse crossings shall include the evaluation and documentation of significant existing and potential erosion sites consistent with 14 CCR § 923.1(e) [943.1(e), 963.1(e)].

(b) The number of crossings shall be kept to a feasible minimum. Existing logging road watercourse crossing locations shall be utilized where feasible and appropriate.

(c) All new drainage structures and facilities on watercourses that support fish or listed aquatic species shall allow for unrestricted passage of all life stages that may be present, and allow for the natural

movement of bedload to form a continuous bed through the crossing. Such structures and facilities shall be fully described in the plan in sufficient clarity and detail to allow evaluation by the review team and the public, provide direction to the LTO for implementation, and provide enforceable standards for the inspector.

(d) In watersheds with listed anadromous salmonids, a description of all existing permanent Class I watercourse crossings shall be provided, where fish are always or seasonally present or where fish passage is restorable. Where it is determined that current crossing conditions may be adversely affecting fish passage at any life stage, the RPF shall disclose such conditions in the plan and propose measures, if feasible, to address these conditions subject to the Director's review and determination.

(e) The location of all new permanent constructed and reconstructed, and temporary logging road watercourse crossings, including those crossings to be abandoned or deactivated, shall be shown on a map. If the structure is a culvert intended for permanent use, the minimum diameter of the culvert and the method(s) used to determine the culvert diameter shall be specified in the plan.

(1) The location of all logging road watercourse crossings to be constructed or reconstructed shall be flagged or otherwise identified on the ground prior to the pre-harvest inspection, if necessary, or prior to logging road watercourse crossing construction or reconstruction. Exceptions may be explained and justified in the plan and agreed to by the Director if flagging is unnecessary as a substantial aid to examining possible significant adverse effects of the

crossing location on the factors listed under 14 CCR § 923(b) [943(b), 963(b)].

(f) All permanent watercourse crossings that are constructed or reconstructed shall accommodate the estimated 100-year flood flow, including debris and sediment loads.

(g) All culverts used for new and replacement logging road watercourse crossings shall be installed at or as close as practical and feasible to the natural watercourse grade. Culverts shall be installed in alignment with the watercourse channel to the extent feasible, and of the appropriate length to prevent fill erosion.

(h) Logging road watercourse crossings shall not discharge water onto erodible fill or other erodible material without the installation of energy dissipaters and other necessary protective structures.

(i) Fills for constructed and reconstructed logging road watercourse crossings shall be thoroughly compacted in approximately one-foot lifts during installation. The face of crossing fills shall be no greater than 65 percent (1.5:1, horizontal to vertical). Excavated material and cut banks resulting from construction or reconstruction which has access to a watercourse shall be sloped back from the channel to prevent slumping, to minimize soil erosion, and to prevent significant sediment discharge.

(j) Critical dips shall be incorporated into the construction or reconstruction of logging road watercourse crossings utilizing culverts, except where diversion of overflow is addressed by other methods stated in the plan.

(k) Watercourse crossings and associated fills and approaches shall be constructed and maintained to prevent diversion of

stream overflow down the road, and to minimize fill erosion should the drainage structure become obstructed. Methods to mitigate or address diversion of stream overflow at logging road watercourse crossings shall be stated in the plan.

(l) Any necessary protective structures associated with logging road watercourse crossings such as wing walls, rock armored headwalls, and downspouts shall be adequately sized to transmit runoff, minimize erosion of crossing fills, and prevent significant sediment discharge. Rock used to stabilize the outlets of crossings shall be adequately sized to resist mobilization, with the range of required rock dimensions described in the plan.

(m) The following drainage standards shall apply to logging road watercourse crossings:

(1) Adequate surface drainage at logging road watercourse crossings shall be provided through the use of logging road surface shaping in combination with the installation of drainage facilities, ditch drains, or other necessary protective structures to hydrologically disconnect the road from the crossing to the extent feasible.

(2) Consistent with 14 CCR § 923.5(a)–(i) [943.5(a)–(i), 963.5(a)–(i)], drainage facilities and ditch drains shall be installed adjacent to logging road watercourse crossings, as needed, to hydrologically disconnect to the extent feasible the logging road approach from the crossing, to minimize soil erosion and sediment transport, and to prevent significant sediment discharge during and upon completion of timber operations. Guidance on hydrologic disconnection may be found in the Board’s Technical Rule Addendum Number 5.

(3) Drainage structures and facilities installed adjacent to logging road watercourse crossings shall be located to avoid discharging concentrated runoff onto fills, erodible soils, unstable areas, and connected headwall swales to the extent feasible.

(n) Where a significant volume of sediment is stored upstream from a logging road watercourse crossing that is proposed to be reconstructed or removed, the stored sediment shall be removed or stabilized, to the extent feasible, as described in the plan and in conformance with the conditions of required CDFW 1600 agreements, where applicable.

(o) Where crossing fills over culverts are large, or where logging road watercourse crossing drainage structures and erosion control features historically have a high failure rate, such drainage structures and erosion control features shall be oversized, designed for low maintenance, reinforced, or removed before the completion of timber operations or as specified in the plan. Guidance on reducing the potential for failure at high risk watercourse crossings may be found in the Board's Technical Rule Addendum Number 5.

(p) All logging road watercourse crossings that are proposed by the plan submitter to be removed, including temporary crossings and those along abandoned or deactivated roads, shall be removed as described in the plan and shall apply the following standards:

(1) Fills shall be excavated to form a channel that is as close as feasible to the natural watercourse grade and orientation, and that is wider than the natural channel as observed upstream and downstream of the logging road watercourse crossing to be removed.

(2) The excavated material and any resulting cut bank shall be no greater than 65 percent (1.5:1, horizontal to vertical) from the outside edge of the constructed channel to prevent slumping, and to minimize soil erosion and sediment transport, and to prevent significant sediment discharge. Exposed soil located between the watercourse crossing and the nearest adjacent drainage facility or hydrologic divide, whichever is closer, including cut banks and excavated material, shall be stabilized by seeding, mulching, rock armoring, replanting, or other suitable treatment to prevent soil erosion and significant sediment discharge.

(3) Where it is not feasible to remove a logging road watercourse crossing or its associated fill to the above standards, the plan shall identify how soil erosion and significant sediment discharge will be prevented.

(4) All logging road watercourse crossings proposed for removal shall be removed upon completion of use, prior to the winter period or as specified in the applicable CDFW 1600 agreement, whichever is earlier, or as otherwise specified in the plan.

(q) Logging road watercourse crossings shall not be constructed or reconstructed under saturated soil conditions or when such activities could result in significant sediment discharge.

(r) Temporary logging road watercourse crossings shall be removed and stabilized prior to the winter period or as specified in the plan.

(s) In watersheds with listed anadromous salmonids and in planning watersheds

immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, where construction or reconstruction is proposed during the extended wet weather period, no timber operations shall take place unless the approved plan incorporates a complete winter period operating plan pursuant to 14 CCR § 914.7(b) [934.7(b), 954.7(b)] that specifically addresses such construction or reconstruction.

(t) The following stabilization standards shall apply to logging road watercourse crossings:

(1) Soil stabilization measures shall be described in the plan and may include, but are not limited to, removal, armoring with rip-rap, replanting, mulching, seeding, installing commercial erosion control devices to manufacturer's specifications, or chemical stabilizers.

(2) Bare soil on fills or sidecast associated with logging road watercourse crossings that are created or exposed by timber operations shall be stabilized to the extent necessary to minimize soil erosion and sediment transport and to prevent significant sediment discharge. Erosion control measures for the traveled surface of roads and landing surfaces are specified in 14 CCR §§ 923.5 [943.5, 963.5] and 923.7 [943.7, 963.7]. Sites to be stabilized include, but are not limited to, sidecast or fill exceeding 20 feet in slope distance from the outside edge of the road surface at the logging road watercourse crossing.

(3) Soil stabilization treatments shall be in place upon completion of operations for the year of use or prior to the extended wet weather period,

whichever comes first. An exception is that bare areas created during the extended wet weather period shall be treated prior to the start of rain that generates overland flow, or within 10 days, whichever is sooner, or as agreed to by the Director.

(4) In watersheds with listed anadromous salmonids and in planning watersheds immediately upstream of, and contiguous to, any watershed with listed anadromous salmonids, treatments to stabilize soils, minimize soil erosion, and prevent significant sediment discharge within the WLPZ and within any ELZ or EEZ designated for watercourse or lake protection, shall be described in the plan as follows:

(A) In addition to the requirements of 14 CCR § 923.9(p) (1)–(3) [943.9(p) (1)–(3), 963.9(p) (1)–(3)], soil stabilization is required for the following:

(i) Areas exceeding 100 continuous square feet where timber operations have exposed bare soil.

(ii) Disturbed logging road watercourse crossing cut banks and fills, and

(iii) Any other area of disturbed soil that threatens to cause significant sediment discharge.

(B) Where straw mulch is used, the minimum straw coverage shall be 90 percent, and any treated area that has been reused or has less than 90 percent surface cover shall be treated again by the end of timber operations.

(C) Where slash mulch is applied, slash coverage in contact with the ground surface shall be a minimum of 75 percent.

(D) For areas disturbed outside the extended wet weather period, treatment shall be completed prior to the start of any rain that causes overland flow across or along the disturbed surface that could result in significant sediment discharge.

(E) For areas disturbed during the extended wet weather period, treatment shall be completed prior to any day for which a chance of rain of 30 percent or greater is forecast by the National Weather Service or within 10 days of disturbance, whichever is earlier.

(u) Logging road watercourse crossings shall be monitored and maintained during timber operations and throughout the prescribed maintenance period as needed, to comply with 14 CCR § 1050. The prescribed maintenance period is specified in 14 CCR § 923.7(i)–(j) [943.7(i)–(j), 963.7(i)–(j)]. Monitoring inspections shall be conducted, when access is feasible during the prescribed maintenance period, a sufficient number of times during the extended wet weather period, particularly after large winter storm events and at least once annually, to evaluate watercourse crossing function. The Department shall also conduct monitoring inspections at least once during the prescribed maintenance period to assess watercourse crossing conditions.

(1) Inspections shall include checking watercourse crossings for evidence of downcutting, plugging, overtopping, loss of function, and sediment delivery to Class I, II, or III watercourses and lakes. If evidence

of sediment delivery or potential sediment delivery is present, and the implementation of feasible corrective measures could reduce the potential for significant sediment discharge, such additional measures shall be implemented when feasible.

(2) Inspections conducted pursuant to California Regional Water Quality Control Board requirements may be used to satisfy the inspection requirements of this section.

(v) Logging road watercourse crossings shall be maintained as designed, constructed, and reconstructed during timber operations and throughout the prescribed maintenance period. Crossings used in connection with stocking activities shall be maintained throughout such use, even if this extends beyond the prescribed maintenance period.

B. BOARD OF FORESTRY TECHNICAL RULE ADDENDUM NO. 5

GUIDANCE ON HYDROLOGIC DISCONNECTION, ROAD DRAINAGE, MINIMIZATION OF DIVERSION POTENTIAL, AND HIGH RISK CROSSINGS

Purpose

The purpose of this technical rule addendum is to provide guidance to Registered Professional Foresters (RPFs), Licensed Timber Operators (LTOs), Timberland Owners, and agency personnel on hydrologic disconnection of road segments and logging road drainage, as required by the Forest Practice Rules pursuant to 14 CCR § 923 et seq. [943 et seq., 963 et seq.]. Logging roads cannot be completely disconnected from watercourses in all locations. This addendum provides assistance in understanding where disconnection is necessary and where site-specific field observations indicate that key areas and problem indicators combine to result in significant existing or potential erosion sites. The information contained herein is designed to be integrated with site-specific evaluation of logging road conditions in the field.

Part I of this addendum presents an introduction to the concept of hydrologic disconnection, a method to evaluate existing hydrologic connectivity, and treatment measures available to achieve hydrologic disconnection. Part II contains guidance on the appropriate location of drainage facilities and structures, installation of energy dissipators, road surface outsloping, and placement of rolling dips. Part III describes diversion potential at watercourse crossings and the importance of critical dip installation. Part IV describes crossings with higher risk of failure and potential approaches that can be used to reduce the risk of catastrophic failure. Part V concludes

with a table and several figures that illustrate the concepts discussed in the text of the addendum.

I. Hydrologic Disconnection

As defined in 14 CCR § 895.1, hydrologic disconnection means the removal of direct routes of drainage or overland flow of road runoff to a watercourse or lake. The goal of hydrologic disconnection is to minimize sediment delivery and hydrologic change derived from road runoff being routed to a watercourse (Refer to **Figure 1**). Hydrologic disconnection is achieved by creating a road surface and drainage configuration that directs water to discharge from the road in a location where it is unlikely to directly flow into a watercourse. Hydrologic disconnection can be accomplished by directing road runoff onto effective filter strips. Filter strips should have high infiltration capacity and dense vegetation and/or obstructions (e.g., woody debris, slash) to dissipate energy, facilitate percolation, and resist or prevent erosion and channelization. Hydrologic connectivity increases the potential for the road segment to deliver road-derived sediment and road chemicals, including spills, to a watercourse. When roads are connected to watercourses, this effectively increases the drainage density of the watershed, producing hydrologic changes that can alter the magnitude and frequency of runoff delivery to watercourses. The proportion of road prisms that are hydrologically connected is strongly controlled by road location, road design, road maintenance, local topography, geology, and factors that control the amount of road runoff (e.g., the amount of annual precipitation).

Hydrologically connected roads can deliver water and sediment via inside ditches that drain to a watercourse crossing; by a connected road drainage structure or facility (i.e., ditch drain culvert, rolling dip, waterbreak, or lead-off inside ditch that delivers runoff to a watercourse channel); or by direct runoff from the road running surface to a watercourse

at road crossings (Refer to **Figure 1**). **In the western U.S., road-watercourse crossings account for the majority of the connected road length**, followed by gullies formed by concentrated runoff at drainage structure or facility outlets. Evidence of connection below a road drainage structure or facility is provided by: (1) indication of surface flow between the drainage structure outlet and a defined channel or a flood prone area; (2) a channel that extends from a road drainage structure outlet to the high water line of a defined channel or a flood prone area; (3) a sediment deposit that reaches the high water line of a defined channel or a flood prone area; (4) observation of turbid water reaching the watercourse during runoff events; or (5) indications of channel widening and/or incision below a drainage structure resulting from increases in flow.

Primary mechanisms for decreasing hydrologic connectivity are: (1) installation of a “disconnecting” drainage facility or structure close to the watercourse crossing; (2) increasing the frequency of ditch drain (relief) culvert spacing for roads with inside ditches; (3) converting crowned, or insloped roads with inside ditches, to outsloped roads with rolling dips; (4) removing or breaching outside berms on crowned or outsloped roads to facilitate effective drainage; (5) applying treatments to dissipate energy, disperse flows, and minimize erosion at road drainage outlets not connected to watercourses; and (6) avoiding concentration of flows onto unstable areas. In particular, the distance between a watercourse crossing and the first upslope adequately functioning and sized road drainage facility or structure is of high importance because this distance has a large influence on the volume of water and sediment delivered to a watercourse.

Not all road segments are hydrologically connected and complete hydrologic disconnection is not possible for most roads. For example, insloped road segments with an inside ditch

will generally include a segment that is connected between the watercourse and first road drainage facility or structure located up-grade from the watercourse crossing (Refer to **Figure 2**). The likelihood of connectivity generally decreases rapidly as the distance between the road and the watercourse increases. Low delivery potential roads also include road segments on flat terrain that do not intersect watercourse channels. For all existing road segments where hydrologic connection may be present, 14 CCR § 923.1(e) [943.1(e), 963.1(e)] requires that an evaluation be conducted to identify which segments need to be disconnected and how the disconnection will occur.

A. Key Areas to Evaluate for Hydrologic Connectivity

When evaluating the hydrologic connectivity of logging roads, particular attention should be devoted to identifying road segments with a high number of watercourse crossings and those located close to watercourses (e.g., <200 feet). Key areas to consider in this context include, but are not limited to:

- Road segments with road drainage structure or facility outlets near watercourses.
- Insloped or crowned road segments with inside ditches.
- Crowned or outsloped road segments with outside berms.
- Steep road or ditch grades (e.g., > 7 percent).
- Roads on steep hillslope gradients (e.g., > 40 percent).
- Roads located on lower hillslope positions (as opposed to mid-slope and upper hillslope positions).

- Throughcut and incised road segments that are difficult to adequately drain.
- Areas with relatively high hillslope instability (e.g., Franciscan mélange terrain).
- Areas with high precipitation amounts and intensity, and/or high levels of snowmelt runoff (e.g., transient and seasonal rain-on-snow zone).
- Road segments with surfaces prone to erosion (e.g., non-cohesive soils such as decomposed granitic soils) and/or significant rutting from intensive use.
- Road segments with wet weather use.
- Areas with little surface roughness or vegetative cover (e.g., areas recently burned), or compacted soils with low infiltration capacities.
- Unsurfaced roads that are graded on a regular basis.
- Inside ditches that are graded on a regular basis.
- Roads with high traffic volumes (e.g., primary roads in a road network, as opposed to secondary, low-use roads).
- Roads with maintenance issues (e.g., road segments with damaged or plugged drainage structures) and/or limitations regarding ownership or control (e.g., public roads, private non-appurtenant roads, roads with unauthorized use).
- Evidence of direct sediment entry into a watercourse or a flood prone area from road surfaces or drainage structures and facilities (e.g., ponded sediment, sediment deposits, delivery of turbid runoff from drainage structures during rainfall events).
- Ditch scour or downcutting resulting from excessively long undrained ditches with infrequent ditch drain (relief) culverts or other outlet structures or facilities. This condition can also result from design inadequacies (e.g., spacing not altered for steep ditch gradient), inadequate erosion prevention practices (e.g., lack of armoring), or ditches located in areas of erodible soils.
- Gullies or other evidence of erosion on road surfaces or below the outlets of road drainage facilities or structures, including ditch drain (relief) culverts, with transport or a high likelihood of transport to a watercourse.

Additionally, if a road and/or ditch runoff is hydrologically connected to a watercourse, the following factors elevate the risk of sediment delivery to a watercourse:

- Existing or high potential for cutbank sloughing or erosion into inside ditches.
- Native surfaced road exhibiting erosion.
- Native-surfaced road composed of erodible soil types (e.g., granitic soils).
- Rilled, gullied, or rutted road approaches to crossings.
- Existing ditch drain (relief) culverts or other road drainage structures with significant plugging from sediment and/or small woody debris.

- Existing ditch drain (relief) culverts or other road drainage structures with

B. Indicators of Significant Existing or Potential Problems

Indicators of significant existing or potential problems with the existing road drainage conditions include, but are not limited to:

decreased capacity due to damage or impairment (e.g., crushed or bent inlets, flattened dips due to road grading).

- Decreased structural integrity of ditch drain (relief) culverts, waterbreaks, or other road drainage structures (e.g., excessive pipe corrosion, breached waterbreaks, or rutted road segments).

C. Design and Treatment Measures to Achieve Hydrologic Disconnection

Treatment measures for existing logging roads are necessary where site-specific field observations indicate that key areas and problem indicators combine to result in significant existing or potential erosion sites. Proposed and reconstructed roads should be designed to achieve hydrologic disconnection to the extent feasible. Additional restrictions and requirements specified under 14 CCR § 923.4(a) [943.4(a), 963.4(a)] apply for new or reconstructed roads, while 14 CCR § 923.5(a) [943.5(a), 963.5(a)], and 923.6(g) and (h)(3) [943.6(g) and (h)(3), 963.6(g) and (h)(3)] apply to existing roads.

Measures to hydrologically disconnect logging road segments include, but are not limited to:

- Installation of a road drainage facility or structure as close as possible to the watercourse crossing. Typically, this distance is 30 to 100 feet above the crossing (Refer to [Figure 2](#)), but may be up to 200 feet or more based on road drainage design and site-specific conditions. For example, the distance from the watercourse crossing to the road drainage facility or structure might be based on the location of where the buffering capacity of the filter strip is the greatest (i.e., densest vegetation and ground cover). Note that this spacing may be closer than the maximum distance specified under 14 CCR § 923.5(f) [943.5(f), 963.5(f)], or as needed for conformance with 14 CCR § 923.5(g) [943.5(g),

963.5(g)]. Depending on the road drainage design, the road drainage facility or structure can be a ditch drain (relief) culvert, rolling dip, waterbreak, or other effective facility or structure. Surface drainage designs or facilities that concentrate runoff (e.g., crowned or insloped road surfaces) require more buffering distance between the drainage outlet and the watercourse than those that disperse runoff (e.g., outsloped road surfaces).

- Installation of additional road drainage facilities or structures above (upgrade of) the closest road drainage facility or structure to the watercourse crossing that are appropriately sized and located in conformance with 14 CCR § 923.5(b) and (c) [943.5(b) and (c), 963.5(b) and (c)]. Maximum waterbreak spacing for roads is specified under 14 CCR § 923.5(f) [943.5(f), 963.5(f)]. Appropriate spacing for rolling dips is considered in Section II.C. of this Technical Rule Addendum.
- Installation of ditch drains that are sufficiently spaced to minimize: ditch scour, prevent exceedance of ditch drain hydraulic capacity, and erosion at drain outlets. Local experience, knowledge and site specific conditions (e.g., hydrology, soil and geologic material present) should be considered by the RPF in the location and spacing of ditch drains. Spacing of ditch drains should be adjusted in response to: (1) poor filtering capacity or potentially unstable areas at the outlet (additional factors are listed in the following section), and (2) proximity to a watercourse. Near a watercourse, the ditch drain spacing should be closer so that smaller amounts of flow are routed down the ditch line, thus providing an added factor of safety for high flow conditions and potential failure of drainage facilities. An example of ditch drain (relief) spacing guidelines is displayed in [Table 1](#) (see Section IV of this addendum). In the preparation of THPs, NTMPs, and PTHPs, RPFs may develop and use other spacing

guidelines that better match the field conditions where their plans are proposed. For example, the RPF can observe the length of road necessary to initiate significant rill erosion and use these observations to adjust spacing guidelines to local conditions.

- In general, if ditch drain (relief) culverts are used, they are recommended to be at least 18 inches in diameter to lower the potential for plugging from soil and small woody debris.
- Elevation of the crossing slightly above the road grade to insure that the crossing (e.g., bridges or relatively flat road approaches) does not serve as the low point for road surface runoff (Refer to **Figures 2 and 7**). Where applicable, this does not alleviate the necessity for installation of a critical dip to mitigate diversion potential.
- Installation of outside berms to decrease hydrologic connectivity where they direct flow to a more suitable discharge area.

Many road segments will have a small portion of their length still connected, even following implementation of 14 CCR §§ 923.2(a)(5) [943.2(a)(5), 963.2(a)(5)], 923.5(a) [943.5(a), 963.5(a)], and 923.6(g) and (h)(3) [943.6(g) and (h)(3), 963.6(g) and (h)(3)]. Additionally, treatment of road approaches for connected road segments next to watercourses may be necessary pursuant to 14 CCR § 923.5(i) [943.5(i), 963.5(i)].

II. Road Drainage, Energy Dissipation, Outsloping and Rolling Dips

A. Location of Drainage Facilities and Structures

In addition to drainage structures and facilities being located: (1) to disconnect road drainage upslope of watercourses, and (2) at a sufficient

interval (spacing) to avoid volume concentrations and associated erosion, as discussed above, there are additional factors that should be considered prior to placing drainage structures and facilities in the field. To assist in identifying sites best suited for a drainage structure or facility, the following criteria should be considered. These criteria should be evaluated and appropriately weighted based on site-specific conditions, so that the effectiveness of the drainage structure or facility is maximized and potential problems are avoided or minimized. RPFs should maintain or restore natural drainage patterns as much as possible, while considering the factors listed below. Drainage structures and facilities should be placed:

- To avoid the concentration of flow onto unstable or potentially unstable areas, such as known active landslides, hummocky ground, concave headwalls, or steep fill slopes.
- To discharge onto divergent (convex) to planar slopes where possible, to allow for better dispersion and infiltration (Refer to **Figure 3**).
- Before hydrologic divides to prevent water from one hydrologic basin mixing with, and potentially impacting, another hydrologic basin not conditioned to receiving the additional flows.
- Above breaks in the road grade that transition from low-gradient to high-gradient to remove the water off of the road before it gains velocity and erosive power on the downslope steep road segment.
- To drain localized or emergent groundwater, springs, and wet areas present in the road prism.

B. Installation of Energy Dissipators for Drainage Structures and Facilities

Where the natural topography, soil surface texture, and vegetation is inadequate to dissipate the energy of flowing water, energy dissipators (e.g., slash, rock armor, flow diverters, downspouts, etc.) should be placed at outfalls of drainage structures and facilities to disperse flows and promote infiltration, consistent with the requirements stated in 14 CCR § 923.5(h) [943.5(h), 963.5(h)]. The use and selection of an appropriate energy dissipator should be based on field conditions and is a function of flow, erosion characteristics of the soils, slope gradient, slope roughness and cover, and distance to a receiving watercourse. Effective energy dissipators commonly used in the forest setting, include, but are not limited to:

- Dense vegetative ground cover.
- Wood slash that is “packed” into place with heavy equipment (ideally) or by hand.
- Pit-run rock. Generally composed of competent local rock that has a range of rock sizes and is of sufficient size to resist movement from road runoff.
- Properly located, sized, and maintained stilling basins.

C. Logging Road Outsloping and Installation of Rolling Dips

Outsloped roads are built with a slight angle of the road surface towards the outside edge (Refer to [Figure 4](#)). This configuration allows road surface runoff to drain in a dispersed manner over the fill slope onto undisturbed forest soils. As defined in 14 CCR § 895.1, outsloping means shaping the road surface to drain toward the outside edge of the logging road or landing.

Rolling dips are typically constructed on outsloped roads to ensure adequate drainage of the road surface. As defined in 14 CCR § 895.1, a rolling dip means a drainage facility that is constructed to remain effective while allowing passage of motor vehicles at reduced road speeds.

An outsloped road’s running surface is considered hydrologically disconnected as long as runoff is effectively transported across rather than down the road surface, outside berms do not restrict runoff, and the road prism does not encroach upon the watercourse. Rolling dips should be installed on outsloped roads to ensure that surface flow is routed off the road surface in situations where outsloping alone may not be effective to prevent concentrating flow or eroding the fill (Refer to [Figure 5](#)). Outsloped roads with rolling dips are typically not appropriate for roads with a gradient in excess of ten percent (10%) because of the steepness of the dip approach grades that would be required and the added difficulty to effectively drain the road surface. The maximum amount of outsloping achievable depends on the type of traffic that will use the road (e.g., lowboys, log trucks, pickup trucks), and the road surfacing. Outsloped roads are not appropriate in all situations due to safety concerns, timing of use, or expected traffic (e.g., winter use in snow zones).

The spacing of rolling dips must be in conformance with 14 CCR § 923.5(g) [943.5(g), 963.5(g)]. As with ditch drain (relief) culvert location, the location of rolling dips is to be modified based on the site buffering capacity at proposed installation locations and avoidance of concentrated flow onto unstable areas. Spacing of rolling dips is a function of: (1) road grade, soil erodibility, and road surface area draining to the dip, and (2) proximity to a watercourse. Near a watercourse, the rolling dip spacing should be closer so that smaller amounts of flow are routed towards each dip, thus providing an added factor of safety for high flow

conditions and potential failure of drainage facilities. Local experience and knowledge of soil and geologic material present should be considered by the RPF in the location and spacing of rolling dips. An example of general rolling dip spacing guidelines is displayed in **Table 1**. In the preparation of THPs, NTMPs, and PTHPs, RPFs may develop and use other spacing guidelines that better match the field conditions where their plans are proposed.

III. Diversion Potential at Watercourse Crossings and Critical Dip Installation

Diversion potential at watercourse crossings is typically associated with large storm events, and can be a significant source of erosion and sediment. Watercourse crossings have diversion potential if overflow at a plugged culvert inlet diverts the watercourse down the road rather than over the crossing and back into the natural watercourse channel. Diverted flows can create excessive erosion where the flows erode non-channeled surfaces and where they exceed the channel capacity of non-original channels. Diversion potential exists on roads that have a continuous climbing grade across the crossing or where the road slopes downward away from the crossing in at least one direction (Refer to **Figure 6**). Forest Practice Rules 14 CCR § 923.10(k) [943.10(k), 963.10(k)] requires diversion potential on constructed (new) and existing logging roads to be addressed; similar requirements have existed since 1990. As specified in 14 CCR § 923.10(j) [943.10(j), 963.10(j)], critical dips are incorporated into the construction or reconstruction of logging road watercourse crossings utilizing culverts, except where diversion of overflow is addressed by other methods stated in the plan. The critical dip should be constructed at the point where the potential for erosion and the loss of fill is minimized (Refer to **Figure 7**).

IV. Crossings with Higher Risk of Failure and Higher Risk to the Environment

Some watercourse crossings have a higher relative risk of failure due to the landscape in which they are installed (e.g., areas prone to debris flows or landsliding); or due to seasonal lack of access or remoteness, both of which limit effective emergency maintenance. Additionally, crossings that employ larger than typical fills to achieve running surface elevations often present a higher risk to the environment if they fail due to the large volumes of fill that could be introduced to downstream watercourses. In these cases, it is recommended and/or required (Forest Practice Rule 14 CCR § 923.11(i) [943.11(i), 953.11 (i)] that such crossings be oversized, designed for low maintenance, reinforced, or removed before the completion of timber operations. As discussed in *Designing Watercourse Crossings for 100-year Flood Flows, Wood and Sediment* (Cafferata et al., 2004), where temporary crossings are not used, rock ford or rock armored fill crossings are often a better alternative to culverts on small to medium sized watercourses in areas where winter maintenance is difficult or debris flows are more likely; the same holds true in areas prone to earthflows or other types of landsliding. Overall, fords (including native surface, rock, armored fill, and vented) are more apt to effectively transport flows, sediment, and debris in unstable landscapes and areas with poor access for emergency monitoring and repairs than culvert crossings. Where culverts are used, and fills are large, Cafferata et al. (2004) recommend that the diameter of the culvert be increased by 6 inches for every 5 feet of fill above the culvert on the discharge side of the crossing. The additional culvert diameter reduces the risk of failure by allowing more room for transport of flow, sediment and debris, and is relatively inexpensive compared to the cost of replacement of a failed crossing. Crossings may also be reinforced by utilizing large rock designed to resist movement during high

flows to line fill faces and by incorporating large critical dips to allow flow passage if the culvert becomes plugged. Temporary crossings typically provide the least environmental risk since flow is unimpeded after the crossings are removed.

V. Table and Figures

The following table and figures are provided as examples to illustrate design concepts. These are not intended to serve as default performance standards.

TABLE 1.

An example of ditch-relief culvert and rolling dip spacing guidelines is found in the University of California's Publication 8262, *Rural Roads: A Construction and Maintenance Guide for California Landowners* (Kocher et al. 2006, adopted from Keller and Sherar 2003). Note that spacing of rolling dips and ditch relief culverts should be a function of proximity to a watercourse, with closer spacing near the channel.

Road Grade (percent)	Soil Erodibility	
	Low to Nonerosive soils	Erosive soils
0–3%	400'	250'
4–6%	300'	160'
7–9%	250'	130'
10–12%	200'	115'
12+	160'	100'

Note: (1) **Low Erosion Soils** = Coarse Rocky Soils, Gravel, and Some Clay
 (2) **High Erosion Soils** = Fine, Friable Soils, Silt, Fine Sands

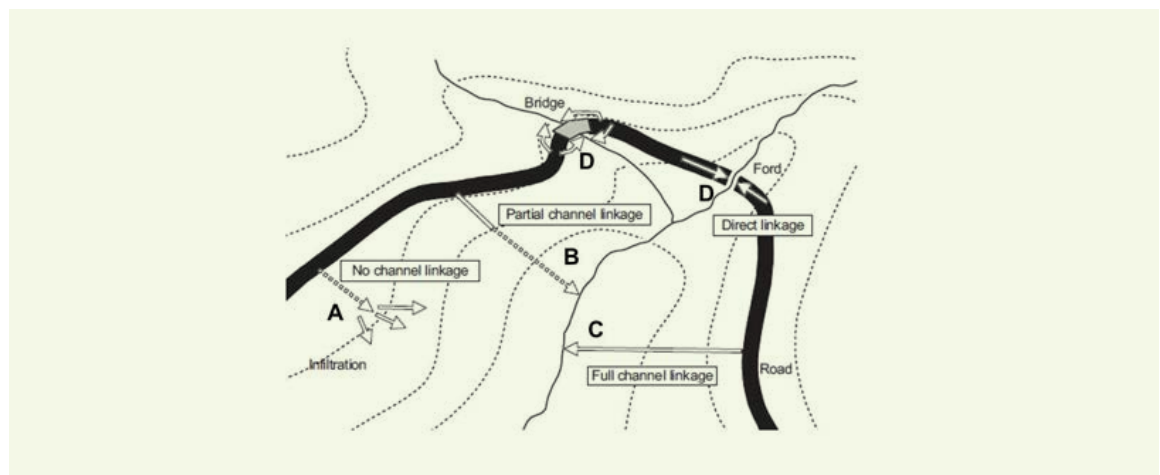
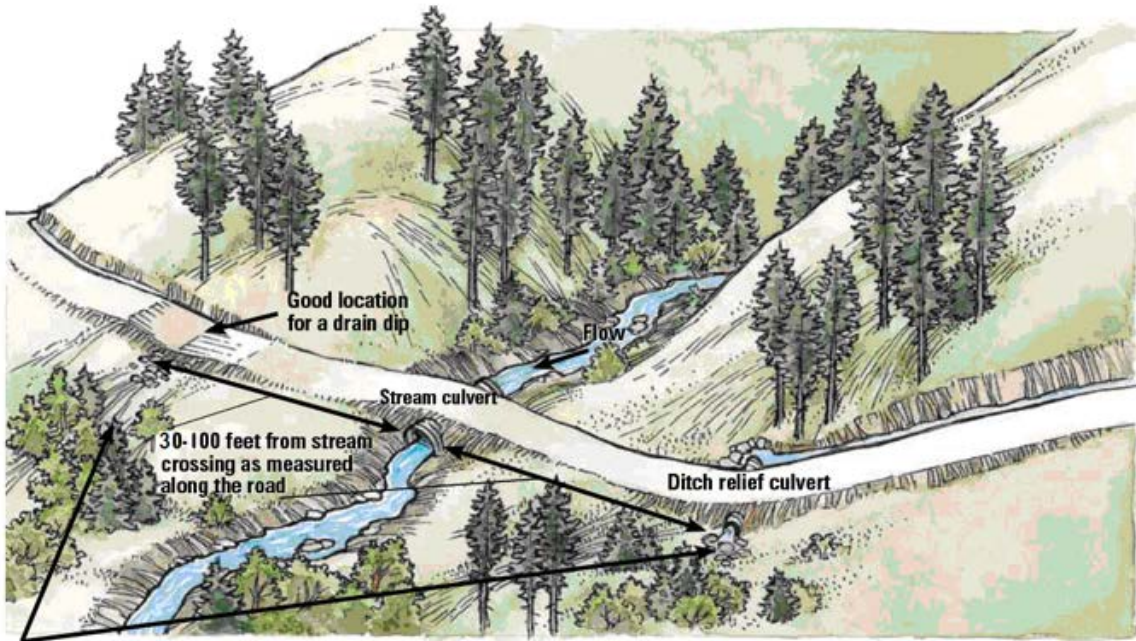


FIGURE 1. The range of hydrologic connectivity (i.e., linkage) for a road. Ideally, road runoff is drained to an effective filter strip where runoff and sediment is dispersed onto the forest floor (A). Roads can be partially connected when a portion of runoff and sediment reaches the watercourse (B). Full hydrologic connectivity can occur when road runoff initiates channels or gullies (C), or is drained directly into watercourses at road crossings (D). Figure adapted from Croke and Hairsine, 2006.



Ditch drainage should be directed into vegetation and undisturbed soil filter, and not allowed to continue flowing down the ditch and into the stream.

FIGURE 2. Diagram showing implementation of road drainage disconnection facilities/structures to limit sediment delivery into a watercourse. Note the absence of an apparent critical dip at the crossing. (modified from Oregon Forest Resources Institute 2011, 2nd Ed., used with permission).

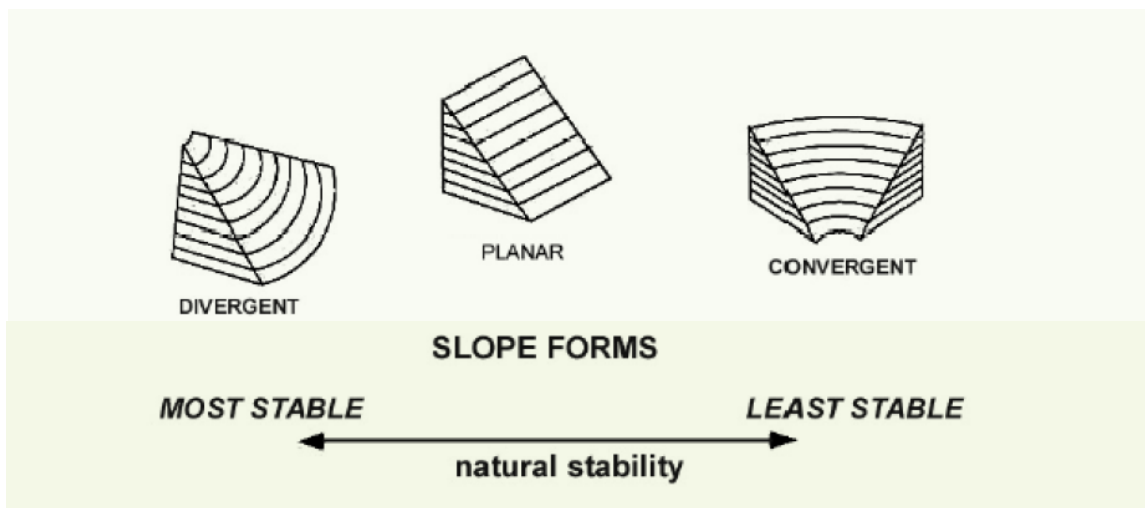


FIGURE 3. Three major slope forms; water should be discharged onto divergent (convex) to planar slopes where possible (from WFPB 2004).

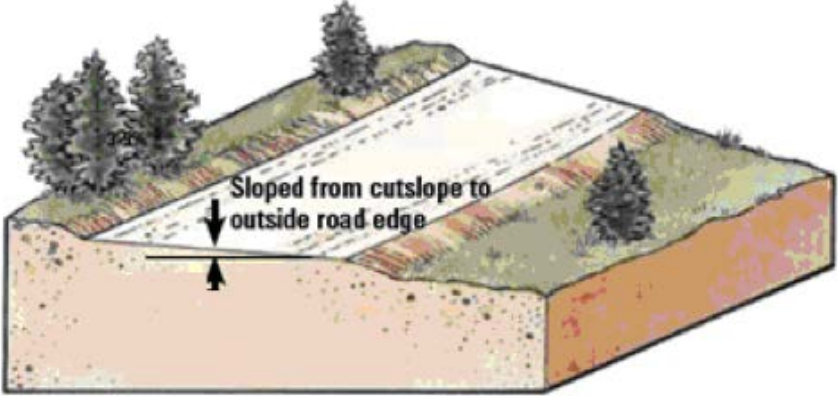


FIGURE 4. Diagram displaying a typical outsloped road (Modified from Oregon Forest Resources Institute 2011, 2nd Ed., used with permission).

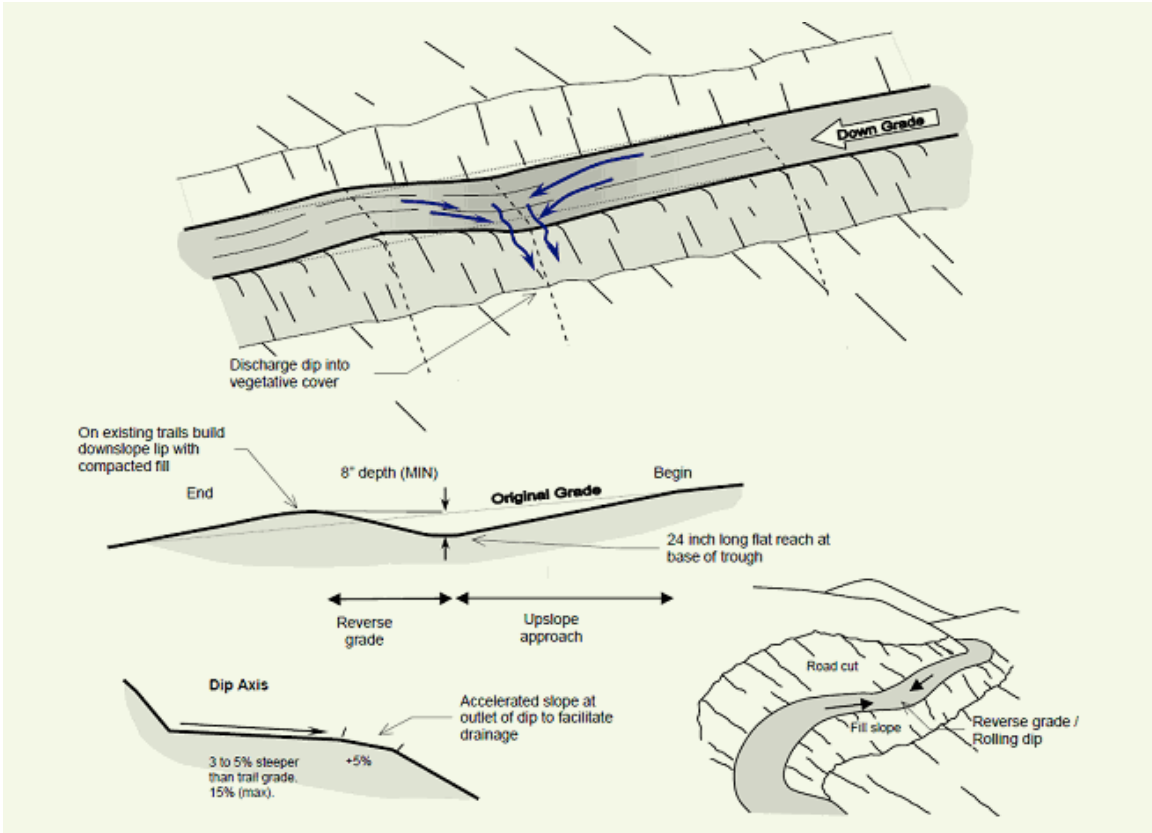


FIGURE 5. Example of rolling dip specifications (Modified diagram provided by Tim Best, CEG).



FIGURE 6. Diagram illustrating diversion potential at a watercourse crossing (from DFG 2006).



FIGURE 7. Illustration of a critical dip installed at a watercourse crossing to remove diversion potential (from DFG 2006). The critical dip should be constructed at the point where the potential for erosion and the loss of fill is minimized.

APPENDIX D: STICK METHOD OF CURVE LAYOUT

A. HORIZONTAL CURVE LAYOUT

Two simple procedures are described. The first, the center stake method, has been described in the text of the Handbook. The second, a stick procedure, is described below. The center stake method is limited to gentle terrain and good visibility while the latter is more suitable to difficult sites.

1. STICK METHOD

Simple curves may be staked on the ground with a stick and a tape. Using a 25- or 50-foot staking distance, consult **Table D-1** for the proper stick length to set the radius shown. **Figure D- 1** shows the process.

a. Adjustments Needed for Topography and Grade

The curve layout description assumes that the area is flat. Seldom is this the case. Measurements of length then need adjustment to compensate for slopes.

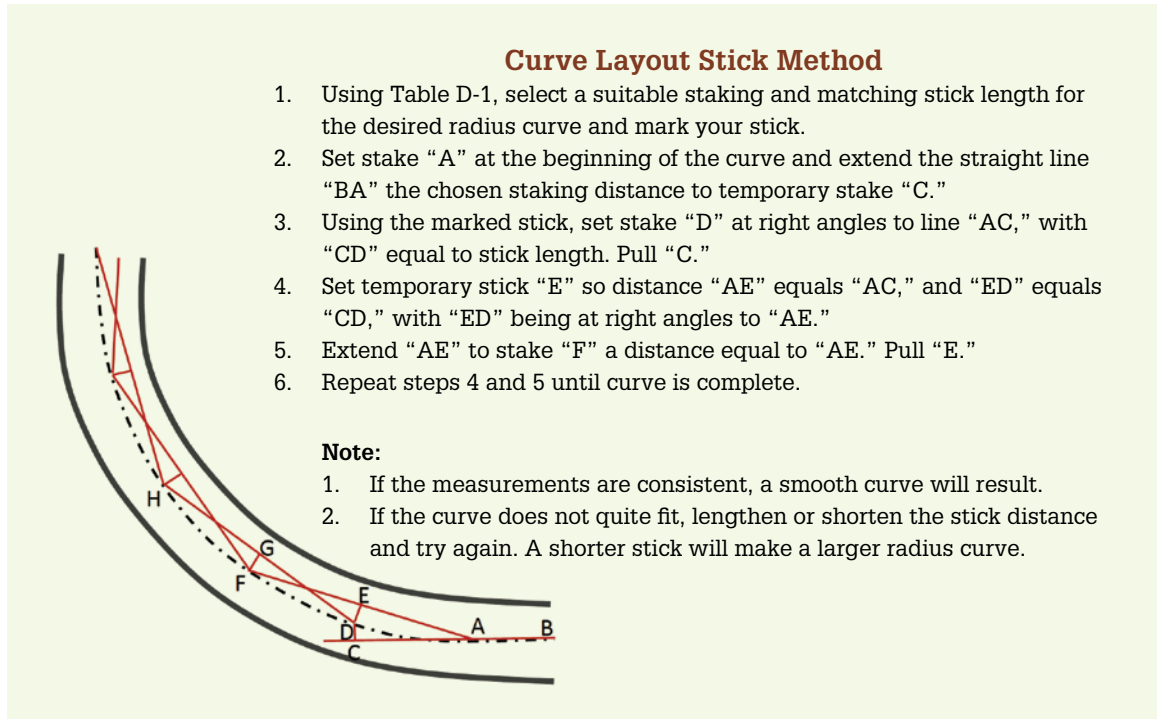
When the distance being measured is short, the tape can be held level. For longer lengths, measure the distance by segments—each held level. Where the

TABLE D-1. Stick length for curve radius by stake distance

Curve radius (ft)	Stake distance (ft)	
	25 ft	50 ft
50	6.7 ¹	–
60	5.5	26.8
80	4.1	17.6
100	3.2	13.4
150	2.1	8.6
200	1.6	6.4
250	1.3	5.1
300	1.1	4.2
350	0.9	3.6
400	0.8	3.1
600	0.5	2.1
800	0.4	1.6
1,000	0.3	1.3

¹Convert tenths of feet to inches by multiplying 12 x decimal shown in table. For example, 6.7 ft; 0.7 x 12 = 8.4 or 8; 6 ft 8 inches.

FIGURE D-1.
Curve layout *Stick Method*.



distance is longer than convenient for the leveling method, adjust the measured slope's length by using [Table 13](#) (see Chapter 3).

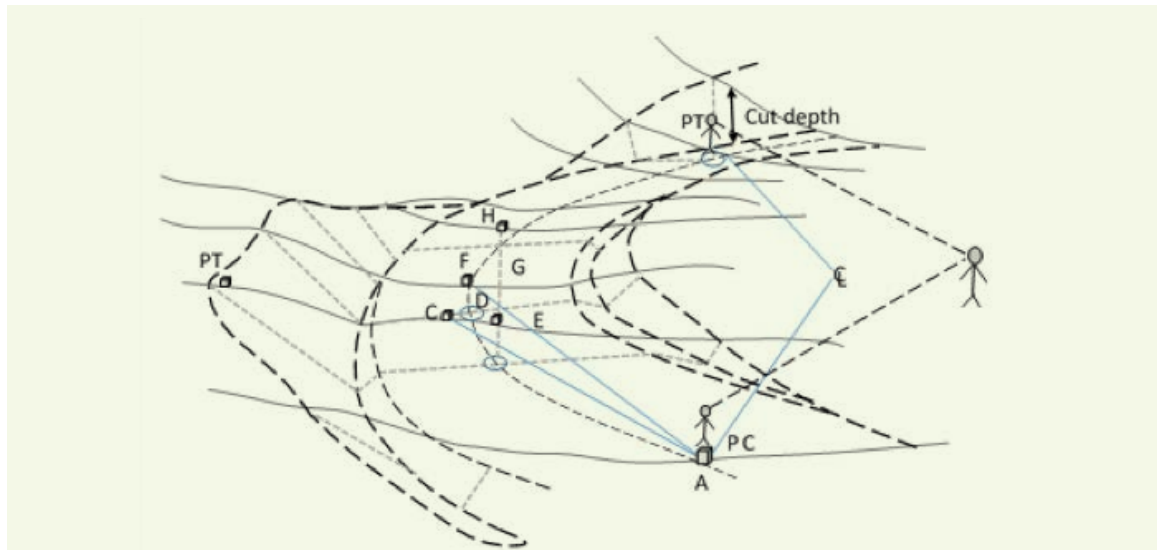
Grade may be carried around the curve by running a line with the desired slope for the distance of the curve. This will often be away from the center line of the road due to the topography. If this occurs, run

a level line to the point of tangency (PT), where the curve ends (see [Figure D-2](#)).

b. Switchbacks

Where two control points cannot be reached by running maximum grade in a single direction, switchbacks are required. They are placed at the point where a grade reverses direction on a slope. Find the location for a

FIGURE D-2.
Curve layout and bringing grade forward.



switchback by running the greatest allowable grade downhill from the higher control to a location suitable for the turn.

Good switchback sites are areas with little side slope where the loop may be constructed with the least excavation. Look on low gradient benches or along broad, flat ridges for suitable sites.

Once the switchback has been located, you reverse the course of the tagline and continue downhill to see if additional turns are needed. Maximum grade is maintained until all switchbacks are located. Some adjustment can take place after one is assured of reaching the two control points.

Switchbacks usually require much earth movement. For this reason a comparison should be made between crossing controls and the added work to install a switchback.

Reduce the grade of the straight stretches into and out of the switchback. This will help maintain the grade through the curve. The curve itself is set at not more than 8 percent grade, and preferably much less.

There should be no more excavation of the hillslope than that needed to form fill along the lower side of the switchback. This is accomplished by offsetting the center of the curve until about half the curve is excavated.

To construct a switchback, do the following:

1. Stake intersection of the two grade lines, stake 1, **Figure D-3**.
2. Bisect the intersection angle, and set stake 2 on the line a curve radius distance from the point of intersection (PI).
3. Along the line bisecting the angle, place a stake 3 on its path where a right angle line equal to the curve diameter just touches the two grade lines. Set stakes 3'.
4. From the upper tagline, run a new grade line back to the curve from stake 3 feet at approximately 2 percent less than the tagline grade. Where this new line reaches the extension of a right angle line from stake 2, set a new stake 4.
5. Measure the radius distance along the right angle line from stake 4 and place a new stake 5 for the center of the curve.

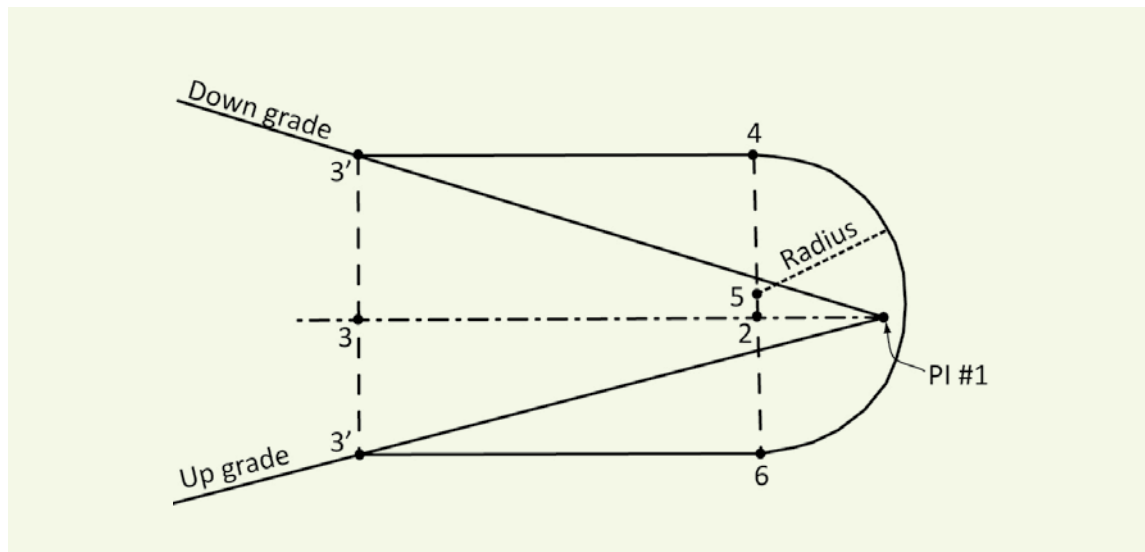


FIGURE D-3.
*Setting a
switchback.*

6. Mark out a curve using the center stake 5 until the extended right angle line from stake 2 is again reached. Set a stake 6.
7. From stake 7 run a grade line that will reach stake 3 feet along the lower side of the curve.
8. Note: Distances measured are horizontal (correct for slope, [Table 13](#) (Chapter 3). Constructing a right angle, [Figure D-4](#). Bisecting an angle, [Figure D-5](#).

FIGURE D-4.
Constructing a right angle.

Constructing a Right Angle

Steps:

1. Set stake "A."
2. Set stakes "B" and "C" equal distance from "A."
3. Set stake "D" so "BC," "CD," and "DB" are equal.
4. Line "AD" is at right angles to line "BC."

Alternatives:

1. Lay out a triangle with the measurements shown in feet.
2. Hold up arms shoulder high and straight. Line up extended arms with survey line. Now, bring arms forward until the fingertips touch. The line of sight over the fingertips is approximately a right angle.

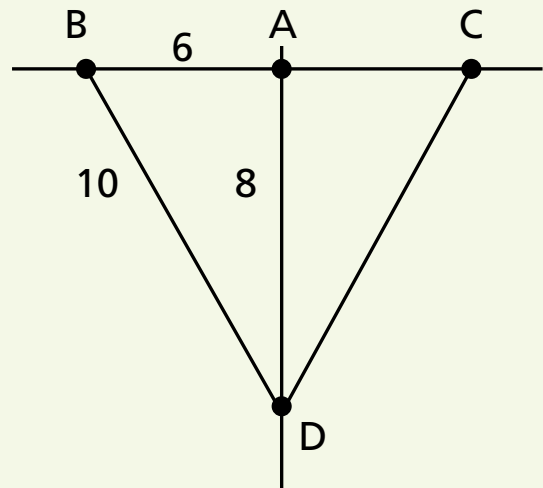
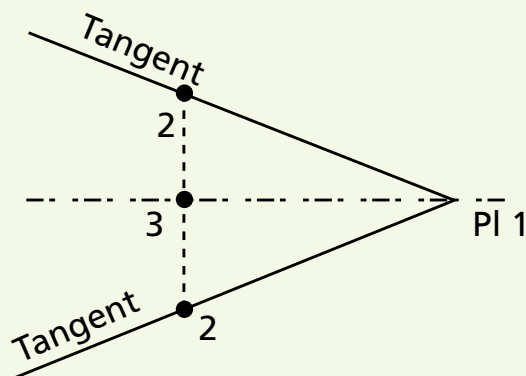


FIGURE D-5.
Bisecting an angle.



Bisecting an Angle

Steps:

1. Place stake "1" at intersection point.
2. Measure equal distance along tangents and set stake "2."
3. Halfway between the two stakes along a straight line place stake "3."
4. The line between the stakes "1" and "3" bisects the angle.

APPENDIX E: ESTIMATING CULVERT LENGTHS

A. DETERMINING NEEDED CULVERT LENGTHS

The following simplified procedure¹ can be used to determine culvert lengths needed for installation of a new stream crossing or a ditch relief drain. Refer to the following diagram (**Figure E-1**) for specific locations and distances described in the step-by-step procedure. A complete example follows the step-by-step instructions outlined in **Table E-1**.

Example 1: Converting horizontal distance to slope distance
44 feet horizontal distance equals 52.4 feet slope distance on a 65% slope.

$$\begin{array}{rclcl} \text{horizontal distance} & \times & \text{correction factor} & = & \text{Slope distance} \\ (44 \text{ ft}) & \times & (1.19) & = & 52.4 \text{ ft} \end{array}$$

Example 2: Estimating culvert length for a 14 foot wide road crossing a stream with a 55% gradient. The estimated inside fill depth, above the cmp inlet, will be 6 feet and the fill depth above the outlet will be 13 feet.

Step 1: Estimated depth of fill at culvert inlet (F_{inlet}) = 6 ft

Step 2: $C = 1.5 \times 6 = 9$ ft

Step 3: If 14 ft wide road (W), then $\frac{1}{2}$ (14) = 7 ft

Stake A (the location of the culvert inlet) should be placed on the ground a distance of $(9 + 7) = 16$ horizontal ft up the stream channel from the flagged centerline of the road. According to **Table E-2**, 16 ft horizontally on a 55% slope is equal to **18.2 ft** slope distance ($16 \text{ ft} \times 1.14 = 18.2 \text{ ft}$). **Place the inlet stake (A) 18.2 ft up the channel from the centerline of the road.**

Step 4: Estimated depth of fill at culvert outlet (F_{outlet}) = 13 ft

Step 5: $C = 1.5 \times 13 = 20$ ft

Step 6: If 14 foot wide road (W), then $\frac{1}{2}$ (14) = 7 ft

Stake B (the location of the culvert outlet) should be placed on the ground a distance of $(13 + 20) = 33$ horizontal ft down the stream channel from the flagged centerline of the road. According to the **Table E-2**, 33 ft horizontally on a 55% slope is equal to **37.6 ft** slope distance ($33 \text{ ft} \times 1.14 = 37.6 \text{ ft}$). **Place the outlet stake (B) 37.6 ft down the channel from the centerline of the road.**

Step 7: Length of culvert needed = $18.2 \text{ ft} + 37.6 \text{ ft} = 55.8 \text{ ft}$ or approximately 56 feet.

Approximately 4 ft (2 ft on inlet and 2 ft on outlet sides) should be added to this length to make sure the culvert inlet and outlet extend sufficiently beyond the base of the fill.

Final culvert length to be ordered and delivered to the site = 56 ft + 4 ft = 60 ft

¹ Method for estimating required culvert lengths described in USDA-SCS/USFS (1981).

FIGURE E-1.
Determining
culvert length

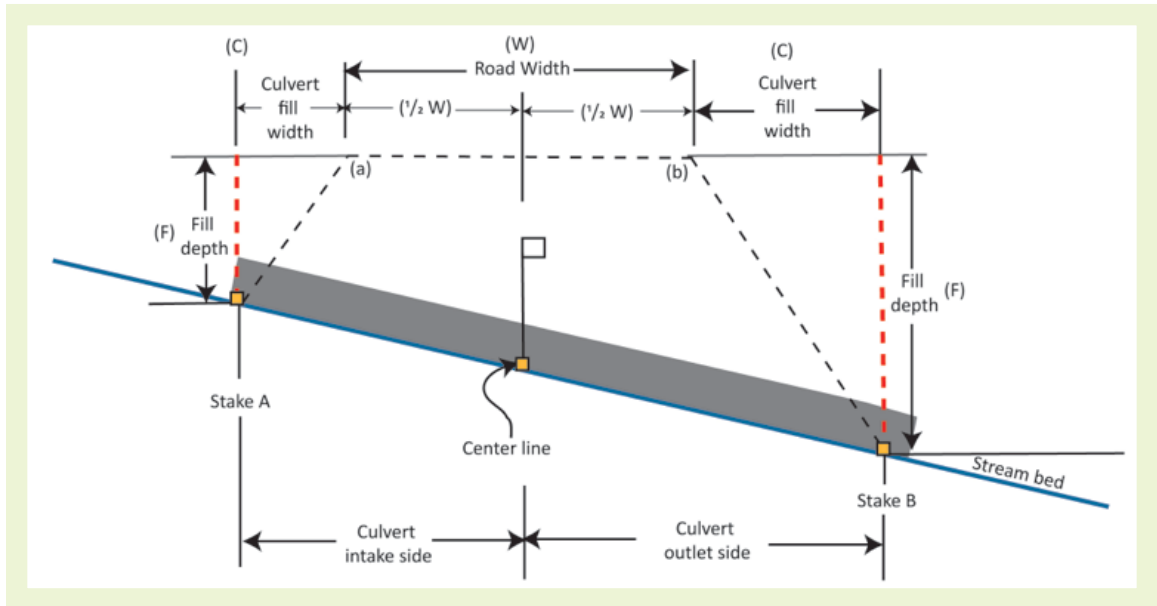


TABLE E-1. Steps to calculate culvert lengths

Step	Do this...
1	Estimate the depth of fill (F) at the running surface on the inside of the road above the culvert inlet (point "a").
2	Additional width (C) due to fill is then estimated as 1½ times the fill depth (F) (assuming all fill slopes are 1½ : 1 in steepness)
3	Add half the road width (½ W) and the fill width (C). Measure this distance horizontally upstream from the center line of the road and place stake at location A. The horizontal distance must be converted to slope distance before you can tape it off on the ground. Converting horizontal distance to slope distance (on-the-ground distance) is simple using Table E-2.
4	Repeat steps 1 through 3 for the culvert outlet side of the crossing and place stake at location B.
5	Measure the slope length between stakes A and B. This measurement, plus 4 extra feet (2 ft at the inlet and 2 ft at the outlet beyond the edge of the inboard and outboard fill slopes, respectively), is the length of culvert needed for the installation.

TABLE E-2. Slope correction factors to convert horizontal distance to slope distance

Hillslopes or stream channel gradient (%)	Correction factor (multiplier)	Hillslopes or stream channel gradient (%)	Correction factor (multiplier)
10	1.00 ¹	45	1.10
15	1.01	50	1.12
20	1.02	55	1.14
25	1.03	60	1.17
30	1.04	65	1.19
35	1.06	70	1.22
40	1.08	75	1.25

¹for a slope of 10% or less, no correction factor is needed

APPENDIX F:**Estimating Stream Crossing Fill Volumes for Upgrading and Decommissioning**

In order to determine the magnitude of a stream crossing upgrading or decommissioning project it is important to be able to accurately determine the volume of fill that will need to be removed and/or backfilled. Knowing the size of the stream crossing fill will allow you to better determine the overall cost of the project, the type of equipment needed, and the type and size of materials needed for the project (e.g., riprap size, culvert diameter and lengths, etc.). Road stream crossing geometries can be quite complex depending on site conditions and therefore it is important to use a systematic and repeatable method for determining stream crossing fill volumes. There are three basic methods for calculating stream crossing fill volumes in order from least accurate to more accurate:

1. Using field measurements of average length, width, and depth.
Where, $(\text{Length} \times \text{Width} \times \text{Depth})/27 = \text{volume (yd}^3\text{)}$;
2. Taking systematic field measurements and use equations of plain geometry and end area computations to calculate volume; and
3. Utilizing simple field surveys and a specialized computer program (e.g., AutoCAD) to perform volume calculations.

Two systematic methods that do not require computer programs or detailed field surveys include the PWA/CDFW method described in “Chapter X: Upslope Erosion Inventory and Sediment Control Guidance” (Weaver et al., 2006) within the California Salmonid Stream Habitat Restoration Manual (Flosi et al., 2006) and the US Forest Service method discussed in “Methods for inventory and environmental risk assessment of road drainage crossings” (Flanagan et al., 1998). The PWA/CDFW method is based on a series of field measurements of slope lengths, slope angles, and road and channel width. This information is used to calculate stream crossing fill volume using a series of double end area calculations. The method allows calculation of three typical road stream crossing types (**Figure F-1**).

The USFS method for stream crossing fill calculation involves a simpler calculation using field measurements of slope length, slope angles, and road and channel width (**Table F-2** and **Figure F-2**). The limitation of the USFS method is that it only allows calculation of one type or geometry of road stream crossing. Although this type of stream crossing is the most common, there are several other road stream crossing shapes that are prevalent on road systems (**Figure F-1**). This may result in an under- or over-estimate of the stream crossing fill volume, and therefore an unreliable estimate for determining the overall project cost, project equipment times, or the types and sizes of materials needed.

Of the two types of volume calculation methods, the PWA/CDFW is more accurate and reliable for road construction project design. This method does require more field information than the USFS method and is more computationally complex, but it does allow for more site-specific and accurate estimates of stream crossing fill volume. **Remember the more accurate your volume estimates, the more accurate your estimates of project cost and material needs.**

TABLE F-1. Method 1: Field data collected for the PWA/CDFW stream crossing fill volume calculation method. (Weaver et al., 2006). The data covers three stream crossing geometries and each volume calculation is listed at the bottom of the table. First determine the general fill geometry (Type 1, 2 or 3); then collect the appropriate data. See Figure F-1 for the diagrammatic description of the location of each variable used in the volume calculation. All distances are in feet and angles in degrees: H=horizontal distance; V=vertical distance; D = depth; L=slope length; A=angle (degrees)

Method 1: PWA/CDFW Stream Crossing variable calculation		
Horizontal components	H1 = L1(cosA1) = _____ ft * (cos (_____ °) = _____ ft	
	H2 = L2(cosA2) = _____ ft * (cos (_____ °) = _____ ft	
	H3 = L3(cosA3) = _____ ft * (cos (_____ °) = _____ ft	
	H4 = L4(cosA4) = _____ ft * (cos (_____ °) = _____ ft	
Vertical components	V1 = L1(sinA1) = _____ ft * (sin (_____ °) = _____ ft	
	V2 = L2(sinA2) = _____ ft * (sin (_____ °) = _____ ft	
	V3 = L1(sinA3) = _____ ft * (sin (_____ °) = _____ ft	
	V4 = L1(sinA4) = _____ ft * (sin (_____ °) = _____ ft	
Fall rate	F = (V1 + V2 + V3 + V4)/(H1 + H2 + H3 + H4) = (_____ + _____ + _____ + _____) / (_____ + _____ + _____ + _____) = _____ ft	
Depth	D1 = V1 - (F*H1) = _____ - (_____ * _____) = _____ ft	
	D2 = (V1 + V2) - (F*(H1 + H2)) = (_____ + _____) - (_____ * (_____ + _____)) = _____ ft	
	D3 = (V1 + V2 + V3) - (F*(H1 + H2 + H3)) = (_____ + _____ + _____) - (_____ * (_____ + _____ + _____)) = _____ ft	
Cross section Area (n=1 for 1:1 slope ratio; n = 2 for 2:1 slope ratio, etc.)	XSA1 = C * D1 + (D1) ² = (_____ * _____) + n * (_____) ² = _____ ft	
	XSA2 = C * D2 + (D2) ² = (_____ * _____) + n * (_____) ² = _____ ft	
	XSA3 = C * D3 + (D3) ² = (_____ * _____) + n * (_____) ² = _____ ft	
Stream Crossing volume calculation for each crossing type		
Type 1 Crossing	Vol TOP to IBF	T2 = 1/3 * (XSA2 * H2) = 1/3 * (_____ * _____) = _____ ft ³
	Vol IBF to OBF	T3 = 1/3 * ((XSA2+XSA3) * H3) = 1/3 * ((_____ + _____) * _____) = _____ ft ³
	Vol OBF to BOT	T4 = 1/3 * (XSA3 * H4) = 1/3 * (_____ * _____) = _____ ft ³
Type 2 Crossing	Vol TOP to IBF	T1 = 1/3 * (XSA1 * H1) = 1/3 * (_____ * _____) = _____ ft ³
	Vol IBT to IBF	T2 = 1/3 * ((XSA1+XSA2) * H2) = 1/3 * ((_____ + _____) * _____) = _____ ft ³
	Vol IBF to OBF	T3 = 1/3 * ((XSA2+XSA3) * H3) = 1/3 * ((_____ + _____) * _____) = _____ ft ³
	Vol OBF to BOT	T4 = 1/3 * (XSA3 * H4) = 1/3 * (_____ * _____) = _____ ft ³
Type 3 crossing	Vol TOP to OBF	T3 = 1/3 * (XSA3 * H3) = 1/3 * (_____ * _____) = _____ ft ³
	Vol OBF to BOT	T4 = 1/3 * (XSA3 * H4) = 1/3 * (_____ * _____) = _____ ft ³
Total volume calculation	T(t) = (T1 + T2 + T3 + T4)/27 = (_____ + _____ + _____ + _____) / 27 = _____ yd ³	

From: Weaver et al., 2006

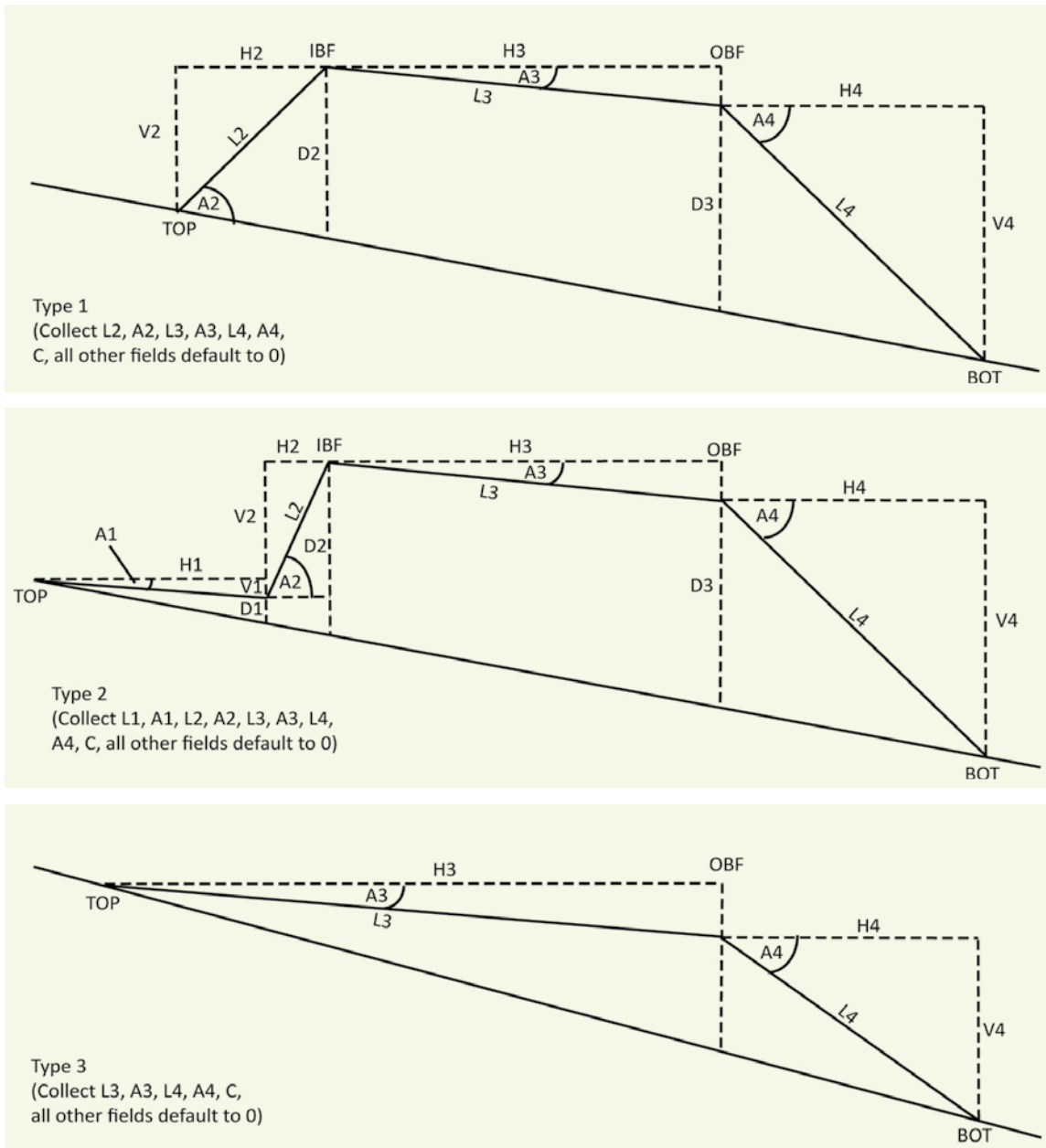


FIGURE F-1.
 Field data collected for the PWA/CDFW stream crossing fill volume calculation method (Weaver et al., 2006).

Field data

Length of sediment fan (L1): _____ ft

Length of inboard fillslope (L2): _____ ft

Length of road bed (L3): _____ ft

Length of outboard fillslope (L4): _____ ft

Channel width (C): _____ ft

Slope (in degrees) of sediment fan (A1): _____^o

Slope (in degrees) of inboard fillslope (A2): _____^o

Slope (in degrees) of road bed (A3): _____^o

Slope (in degrees) of outboard fillslope (A4): _____^o

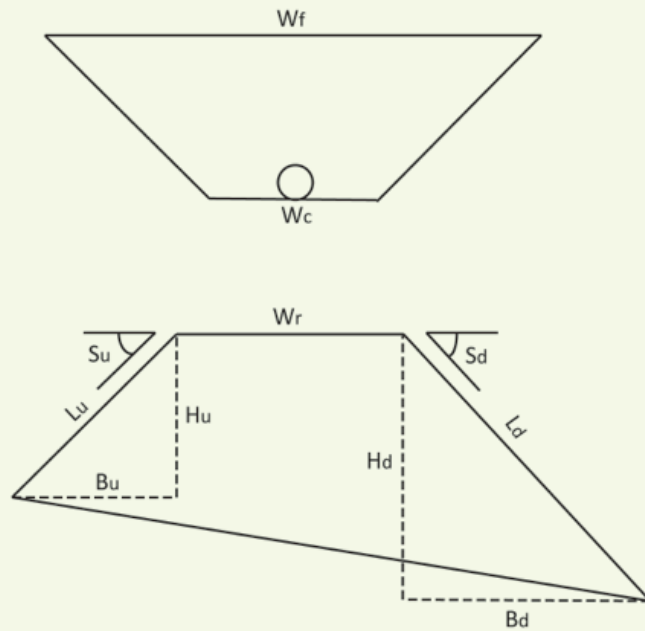
TABLE F-2. Method 2: USFS Stream Crossing volume calculation variables

Upstream prism volume (V_u)	$V_u = 0.25*(W_f + W_c)*(L_u*\cos(S_u))*(L_u*\sin(S_u)) =$ $= 0.25*(______ + ______)*(______*\cos(______))*(______*\sin(______)) = ______ \text{ft}^3$
Downstream prism volume (V_d)	$V_d = 0.25*(W_f + W_c)*(L_d*\cos(S_d))*(L_d*\sin(S_d)) =$ $= 0.25*(______ + ______)*(______*\cos(______))*(______*\sin(______)) = ______ \text{ft}^3$
Volume under road surface (V_r)	Inboard fill depth – $H_u = L_u * \sin(S_u) = ______ * \sin(______) = ______ \text{ft}$
	Outboard fill depth – $H_d = L_d * \sin(S_d) = ______ * \sin(______) = ______ \text{ft}$
	$V_r = \left(\frac{H_u + H_d}{2} \right) \left(\frac{W_f + W_c}{2} \right) W_r \left(\frac{______ + ______}{2} \right) \left(\frac{______ + ______}{2} \right) ______ = ______ \text{ft}^3$
Total volume calculation	$V = V_u + V_d + V_r = (______ + ______ + ______)/27 = ______ \text{yd}^3$

From: Flanagan et al., 1998

FIGURE F-2.

Field data required for USFS method for Type 1 stream crossing fill volume calculations (Flanagan et al., 1998).



Field data	
Width of road bed (W_r):	_____ ft
Width of flood-prone channel (W_c):	_____ ft
Fillslope length from inboard edge of road to culvert inlet (L_u):	_____ ft
Fillslope length from outboard edge of road to culvert outlet (L_d):	_____ ft
Slope (in degrees) from inboard edge of road to culvert inlet (S_u):	_____ °
Slope (in degrees) from outboard edge of road to culvert outlet (S_d):	_____ °



The Handbook for Forest, Ranch and Rural Roads is meant to be used as an educational and teaching resource for learning about common road problems, their impacts on streams and water quality, and the various tools that are available to reduce their environmental impact while providing for lower maintenance, lower cost wildland roads.

The ideas and concepts presented in here are not particularly new or uniquely innovative, but they are assembled in one place and focused on ways in which landowners, land managers, equipment operators and others can develop and maintain low cost, low impact roads. The information should be equally valuable for large or small landowners with roads, for others who are responsible for resource conservation and protection, and for anyone who is interested in learning about the relationships between wildland roads and the environments through which they pass.



The Handbook can be used as a resource from which to identify and discuss specific points of road design, road building, road upgrading, road maintenance, and road closure from a common knowledge base. The Handbook is a starting point; a place to start those conversations and to expand people's knowledge. The information and examples in the Handbook can be used in the classroom, during field trips, for large group discussions or for individual study. There is nowhere better to learn about these topics than in the field, where problems and solutions can be seen and discussed first-hand.





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