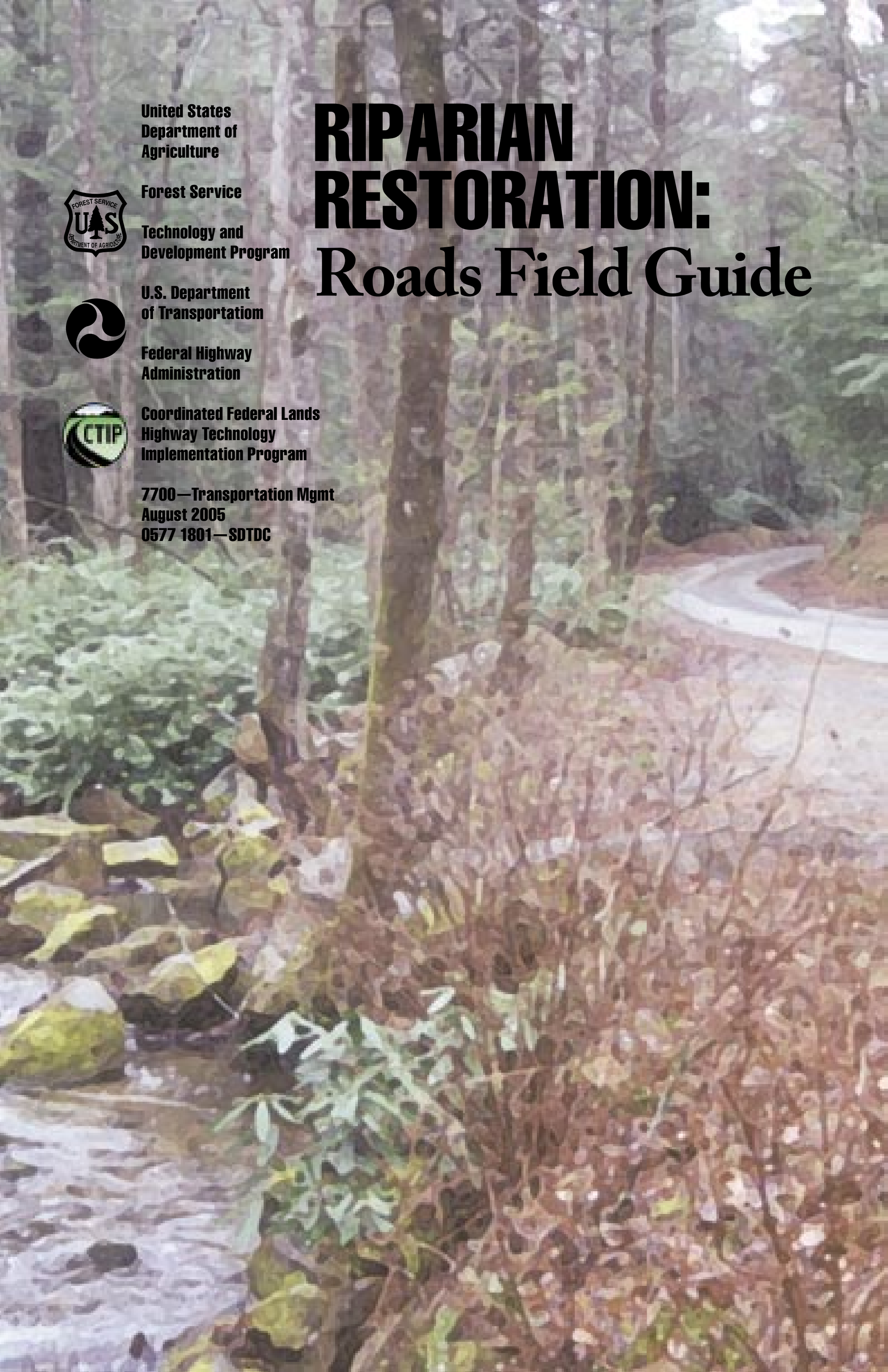


United States
Department of
Agriculture

Forest Service

Technology and
Development Program

U.S. Department
of Transportatiom

Federal Highway
Administration

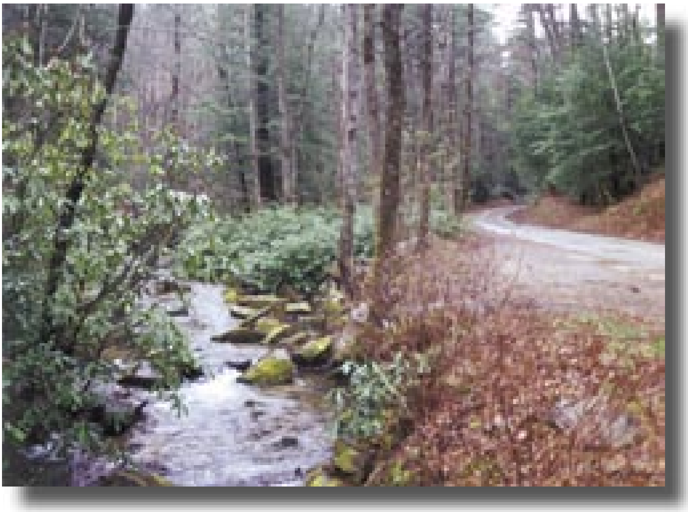
Coordinated Federal Lands
Highway Technology
Implementation Program

7700—Transportation Mgmt
August 2005
0577 1801—SDTDC

RIPARIAN RESTORATION:
Roads Field Guide

RIPARIAN RESTORATION:

Roads Field Guide



National Riparian Roads Team

In August 1999, the U.S. Department of Agriculture (USDA) Forest Service, Washington Office (WO), Office of the Chief, sanctioned the formation of the National Riparian RoadsTeam. "The team will refine methods to manage roads in riparian/ wetland areas that will minimize negative impacts and restore or improve ecosystem health and provide guidance and training servicewide." In this document, the team recommends strategies and techniques that are based on the watershed restoration principles defined by Cairns, J., Jr. (1988):

Restoration is reestablishment of the structure and function of an ecosystem, including its natural diversity.

Support for this initial effort includes interagency partners, such as the U.S. Environmental Protection Agency (EPA), U.S. Department of Transportation's Federal Highway Administration, and U.S. Department of the Interior's Bureau of Land Management, and the nonprofit organization Ducks Unlimited. Special thanks to FHWA Coordinated Federal Lands Highway Technology Implementation Program.

Team Members

The National Riparian Roads Team includes the following individuals:

Greg Napper—*Civil Engineer, San Dimas Technology and Development Center (SDTDC), USDA Forest Service*

Terry Warhol—*P.E., Assistant Forest Engineer, Umatilla National Forest, Region 6, USDA Forest Service*

James Doyle—*Fish Biologist, Mt. Baker-Snoqualmie National Forest, Region 6, USDA Forest Service*

Sandra Jacobson—*Wildlife Biologist, Pacific Southwest Research Station, USDA Forest Service*

Roy Jemison—*Ph.D., Research Hydrologist, Rocky Mountain Research Station, USDA Forest Service*

Lisa Lewis—*Soil Scientist, National Riparian Service Team, WO, USDA Forest Service*

Wendy Melgin—*Deputy Branch Chief/Hydrologist, Region 5, EPA*

Carolyn Napper—*Soil Scientist, SDTDC, USDA Forest Service*

Former members of the National Riparian Roads Team include the following individuals:

Tom Ratcliff—Wildlife Biologist, Modoc National Forest, Region 5, USDA Forest Service

Steve Adair—Ph.D., Director of Conservation Programs, Great Plains Regional Office, Ducks Unlimited

Mary Lee Dereske—P.E., Regional Water/Wastewater Engineer, Region 3, USDA Forest Service

Anthony Edwards—Civil Engineer, Team Leader, SDTDC, USDA Forest Service

FORWARD

Goals and Objectives

Organizations and agencies that strive to protect and restore ecosystem function, structure, and composition also must consider social, political, and economic impacts within these watersheds. Consequently, a road system sometimes simultaneously benefits humanity while degrading its surrounding biological environment. The interagency team aims to help individuals and organizations achieve a sustainable balance between both sets of considerations by sharing its recommendations through this field guide and training sessions. This field guide represents road management from the USDA Forest Service perspective that embraces the following overarching requirement:

> *36 CFR 212.5 Road System Management (1) Identification of road system. For each national forest, national grassland, experimental forest, and any other units of the National Forest System, the responsible official must identify the minimum road system needed for safe and efficient travel and for administration, utilization, and protection of National Forest System lands. The minimum system is the road system determined to be needed to meet resource and other management objectives adopted in the relevant land and resource management plan (36 CFR 219), to meet applicable statutory and regulatory requirements, to reflect long-term funding expectations, to ensure that the identified system minimizes adverse environmental impacts associated with road construction, reconstruction, decommissioning, and maintenance.*

One basic principle of watershed restoration is that efforts toward this goal address the fundamental causes of the loss of ecosystem structure and function rather than merely the symptoms. More than 50 years of research and many case examples have identified the effects of roads on geomorphic processes and demonstrated that roads are one of the fundamental causes of accelerated erosion.

Process

The team has incorporated historical work and has taken a large-scale, or "big picture," approach in its review of sites across the country and in developing this field guide. The team's interdisciplinary approach is described by Copstead (1997):

> *Iterative, interdisciplinary planning processes and comprehensive protocols are key to ensuring that we make progress toward meeting the goals of the Clean Water Act, NFMA, and the regulatory framework regarding water quality, watershed, and aquatic ecosystem function.*

Although the team developed this guide to maintain consistency with USDA Forest Service regulations, it easily could be applied to other jurisdictions. A recent revision to USDA Forest Service road policy incorporated a roads analysis process to inform decisionmakers and the public of road benefits and effects in preparation for a National Environmental Policy Act study. The team highly recommends review of the new road policy, 36 CFR 212, which states the reason for the change.

> *The intended effects of this final policy are to ensure that decisions to construct, reconstruct, or decommission roads will be better informed by using a science-based roads analysis; that the availability of road maintenance funding will be considered when assessing the need for new road construction; and that, instead of focusing on constructing new roads, emphasis will be given to reconstructing and maintaining classified roads while decommissioning unnecessary classified and unclassified roads.*

The team believes the USDA Forest Service's renewed focus on road management is proactive and sets an example for interdisciplinary teams across the country to evaluate access needs and resource impacts in an objective, scientific, and comprehensive manner. The final road management policy notice can be viewed at

http://www.fs.fed.us/eng/road_mgt/01_03_01_FINAL_disk_ROAD_MGMT_POLICY_NOTICE.pdf.

Using This Field Guide

This guide is designed to go to the field in a pack or a pocket. Interdisciplinary teams can use the guide as a resource for state-of-the-art restoration strategies and techniques to encourage field dialogue and communication.

This field guide is one of many publications on roads, watershed restoration, and aquatics. See section 9 for additional reading. Some key publications include the following:

- San Dimas Technology and Development Center. 2000. Water/road interaction technology series. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

- Clarkin, Kim. [and others] [In preparation] Aquatic organism passage at road-stream crossings. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

- Bassel, James. Wildlife Crossings Toolkit Web site: http://www.wildlifecrossings.info. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

- Gucinski, Hermann; Furniss, Michael J.; Ziemer, Robert R.; [and others], eds. 2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNW- GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.120 p.

- Forman, R.T.T.; Sperling, D.; Bissonette, J.A. [and others]. 2003. Road Ecology: Science and Solutions. Washington, DC: Island Press. 481 p.

This field guide and the techniques discussed are intended to complement rather than replace current direction or field techniques described in road-related works published in the past several years.

TABLE OF CONTENTS

Introduction 1

Chapter 1: Riparian Area Considerations 5

Chapter 2: Project Checklist Questions 11

Chapter 3: Laws and Regulations 16

Chapter 4: Monitoring 25

Chapter 5: Management Strategies and Field Techniques 31

- Aquatic Organism Passage 33
- Beaver Pond Structures 36
- Biotechnical Stabilization 38
- Bridges 41
- Controlling Access 44
- Culverts 48
- Ditch Treatments 51
- Erosion Control Devices 54
- Energy Dissipaters and Debris Racks 57
- Invasive Species Management 60
- Landslide Mitigation Strategies 63
- Logjam Complexes 65
- Low-Water Crossings and Ford 68
- Outsloping 70
- Permeable Fill With Culvert Array 72
- Raised Culvert Inlets 74

Reconnecting Cutoff Water Bodies 76
Retaining Walls 78
Roadway Dips 80
Road Relocation or Realignment 82
Soil Bioengineering 84
Surfacing Techniques 87
Wildlife Crossings... 90

Chapter 6: Glossary 93

Chapter 7: Literature Cited and Additional Reading 105

INTRODUCTION

This field guide presents information on management strategies and techniques but emphasizes also the importance of monitoring.

INTRODUCTION

Riparian areas are degraded from improperly constructed or maintained roads. Roads can cause increased bank and channel erosion, increased sediment deposition into channels, increased flooding, and increased species mortality or injury. Impacts in riparian areas from improperly constructed roads are also indicated by a decrease in riparian vegetative cover, dewatered meadows, a decrease in water quality, and a compromised recreational experience. To cultivate an understanding of riparian areas, we begin this field guide with a discussion of riparian area considerations, which includes a listing of the various types of impacts one might observe in riparian areas.

Management strategies and restoration techniques can be used to protect riparian areas as a part of new road construction planning and design or as applied to existing roads. Some techniques are valid to only one or two ecoregions, but others are applicable nationwide. Techniques may be used singly or in concert with other techniques, depending on the road problem and the riparian objectives. The project checklist questions are intended to help you analyze your site for issues and prepare you to identify good solutions.

Trapper Peak, Bitterroot National Forest

Identifying riparian impacts issues and solutions requires a measure or context for magnitude or significance. One way to arrive at such a context is to evaluate sites and solutions with respect to laws and regulations that apply to riparian areas. This guide addresses this topic by providing selected regulatory references from the U.S. Environmental Protection Agency (EPA) and directives from the U.S. Department of Agriculture (USDA) Forest Service Manuals (FSMs) and Forest Service Handbooks (FSHs).

This field guide presents information on management strategies and techniques but emphasizes also the importance of monitoring. As a result of its professional experience and site visits to several ecoregions, the National Riparian Roads Team recognizes that monitoring is an essential ingredient to a riparian restoration program. An explanation of monitoring and topics to consider when planning a monitoring program follows the section on laws and regulations.

Finally, the team hopes that the presentation of techniques in this guide is comprehensive enough to get you started or advise you along the way in your efforts toward restoration of riparian areas. For access to more Technology and Development publications, visit our Web site at http://www.fs.fed.us/eng/pubs.

Chapter 1
Riparian Area Considerations

Five basic elements—topography, hydrology, local climate, soil properties, and vegetation—define the structure and function of riparian areas that need to be accessed before restoration.

RIPARIAN AREA CONSIDERATIONS

The ecosystems of riparian areas contain terrestrial and aquatic components. Terrestrial components include saturated soil and water-tolerant plants. Aquatic components include the water, water body (stream, river, lake, pond, bog, wetland), and aquatic vegetation. In forest and rangeland landscapes, riparian areas contain the greatest number of terrestrial and aquatic animal species.

Road encroaching on riparian area.

Riparian Area Attributes

Many forest ecosystem functions and processes occur in riparian areas. Riparian area attributes include waterflow dispersal and energy dissipation, sediment detention, toxicant retention, ground water recharge and discharge, erosion control, and a diversity of vegetative species. Because of these attributes, riparian areas provide food, water, cover, migration, and reproductive requirements for a vast number of terrestrial and aquatic animal species.

Riparian Area Elements

The diversity of riparian areas across the country and within an ecoregion is remarkable. Identifying physical and biological differences is important to successfully maintain, protect, and restore these areas. Five basic elements—topography, hydrology, local climate, soil properties, and vegetation—define the structure and function of riparian areas that need to be assessed before restoration.

Impacts of Roads

Road construction, operation, and maintenance in and adjacent to riparian areas can cause negative impacts to riparian area processes, structures, and functions. By using solutions in this field guide, impacts to or from these roads can be reduced and riparian areas restored. Although this field guide cannot include all impacts or every potential mitigation method, some impacts identified by the team are listed below:

Soil Impacts

- Erosion and deposition
- Compaction and displacement
- Sedimentation

Vegetative Impacts

- Invasion of exotic species
- Decreased diversity of native species

Hydrologic Impacts

- Hillslope drainage alterations
- Baseflow alterations
- Ground water alterations (recharge/discharge)
- Alterations to precipitation-runoff relationship

Channel Impacts

- Diversions
- Alterations to morphology
- Alterations to organic debris

Water Quality

- Hazardous spills
- Dust abatement
- Herbicide use

Animal Impacts

- Habitat fragmentation
- Restricted movement
- Direct mortality
- Disturbance from human use

Headcut in meadow.

Chapter 2
Project Checklist Questions

Ideally, an interdisciplinary team will determine the issues and the appropriate treatments onsite, possibly with the help of this field guide.

PROJECT CHECKLIST QUESTIONS

This section of the field guide is designed to help you analyze your site for issues and solutions. Ideally, an interdisciplinary team will determine the issues and the appropriate treatments onsite, possibly with the help of this field guide. Because of the complex, interdisciplinary nature of riparian restoration, jargon and functional interests can easily result in inadvertent misunderstandings. One way to ensure everyone's voice is heard is to develop a "charter" that documents agreements by participants and clarifies expectations. See the Roads Riparian Restoration Web site (http://fsweb.sdtdc.wo.fs.fed.us) for a tested design you can use. The glossary in the back of this field guide is intended to provide a common language base to avoid misunderstandings.

Try approaching the site analysis using the following five steps:

1. Identify the issues.
    - What are the management objectives for the site?
    - What is the riparian restoration objective for the site?
    - What are the safety issues associated with the road?
    - Who owns the land?
    - What are the public and administrative access needs now or in the future?
    - Are threatened, endangered, or sensitive species habitats present?
    - Does the road impact channel features such as pattern or meander?
    - Does the road location or use level cause excessive streambank erosion or channel deposition?
    - Does the road affect riparian vegetation composition or diversity?
    - Are noxious weeds or invasive invertebrates present?
    - Does the road cause movement problems for terrestrial wildlife?

- Does the road or its structures cause passage problems for aquatic organisms?
- Does the road have visual or scenic value?
- Are any of these problems recurring?

2. Identify information needed to address the issues.
   - What environmental documentation is required for this project?
   - What permits are required?
   - Is this a Clean Water Act (CWA) 303(d)-listed water body, and if so, what are the water quality parameters?
   - Is there a completed roads analysis for the area that addresses this road?
   - Is there a current road management objective (RMO) for this road?
   - What is the traffic volume?
   - Is the streamflow intermittent or perennial?
   - Are flow records available for the channels in question?
   - What are the channel types?
   - Has a riparian analysis been completed for the area? If yes, on what date was this completed?
   - Have the channels been field surveyed? If yes, on what date was this completed?

3. Identify resources needed to resolve the issues.
   - What specialists are needed to address the issues and suggest solutions?
   - What are the specific funding sources for the treatments needed?
   - Are contract specialists needed?
   - How urgent is the restoration need, and how can the timeline be met?

4. Identify specific appropriate treatments.
   - Does the road need to be repaired to address the issue?
   - Do larger and/or smaller scale analyses suggest a different treatment?
   - Does the site have recurring problems that may affect treatment selection now?
   - What previous treatments have been used at the site, if any, and when did they occur?
   - Have treatments been successful on similar sites with similar conditions?
   - Which specific treatments suggested in this field guide may work?
   - Will the proposed treatment exacerbate any existing problems?

5. Identify a monitoring strategy.
   - What are the best and worst possible outcomes?
   - Have any previous treatments been monitored, and if so, what were the results?
   - Is monitoring required to be in compliance with any regulations?
   - What parameters should be monitored, and how often?
   - What resources are available for monitoring?
   - Who will be responsible for monitoring?
   - How and where should the monitoring information be stored?
   - What types of monitoring are appropriate for the restoration treatments being considered?

Chapter 3

Laws and Regulations

This section provides a brief overview of the most common Federal laws and regulations pertaining to wetlands and waters of the United States.

LAWS AND REGULATIONS

Work on roads in riparian areas on Federal lands may require a Federal permit or compliance with State laws and regulations. This section provides a brief overview of the most common Federal laws and regulations pertaining to wetlands and waters of the United States. Because State laws and regulations vary, contact the appropriate State agency before project work begins for information about compliance.

Clean Water Act

The intent of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. More information is available at http://www.epa.gov/r5water/cwa.htm.

The following sections of the CWA may apply to work in riparian and wetland areas.

Section 303 Water Quality Standards—Water quality standards are the foundation of the water-quality-based control program mandated by the CWA. Water quality standards define the goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. Web site: http://www.epa.gov/waterscience/standards.

Section 303(d)—The total maximum daily load program provides the calculation of the maximum amount of a pollutant that a water body can receive. Web site: http://www.epa.gov/owow/tmdl/.

Section 319(b)—The nonpoint source pollution program requires that States develop management programs for the control of nonpoint source pollution. Web site: http://www.epa.gov/owow/nps/cwact.html.

Section 401—This section pertains to federally permitted or licensed activities that involve discharges to waters of the United States. Web site: http://www.epa.gov/owow/wetlands/facts/fact24.html.

Section 402—The national pollutant discharge elimination system regulates the discharge of a pollutant (other than dredged or fill material) from a point source into waters of the United States.
Web site: http://cfpub1.epa.gov/npdes/.

Section 404—The wetland regulatory program establishes programs to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. The basic premise of the program is that no discharge of dredged or fill material can be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the Nation's waters would be significantly degraded. In other words, when you apply for a permit, you must show that you have performed the following actions:

1. Taken steps to avoid wetland impacts where practicable;
2. Minimized potential impacts to wetlands; and
3. Provided compensation for any remaining, unavoidable impacts though activities to restore or create wetlands.

Section 404(f) exempts some activities from regulation under Section 404. These include many ongoing farming, ranching, and silvicultural practices. Call the EPA Wetlands Hotline at 800–832–7828 with questions or send an e-mail to wetlands.helpline@epa.gov.

For a general review of Federal, State, and local regulations, visit the Association of State Wetland Manager's Web site at http://www.aswm.org, which contains helpful information.

Recommended Web Sites

These Web sites also may be useful:

http://www.epa.gov/owow/wetlands/

http://www.usace.army.mil/inet/functions/cw/cecwo/reg/

http://www.epa.gov/owow/wetlands/pdf 40cfrpart232.html

Coastal Zone Act Reauthorization Amendments of 1990

Section 6217(g)—This section requires States to develop and implement coastal nonpoint source pollution programs.
Web site: http://www.epa.gov/owow/nps/czmact.html.

Endangered Species Act

The 1973 Endangered Species Act provides for the conservation of ecosystems necessary for threatened and endangered fish, wildlife, and plants. It requires Federal agencies to ensure that any action authorized, funded, or carried out by them is not likely to jeopardize the continued existence of listed species or modify their critical habitat.
Web site: http://endangered.fws.gov/.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires Federal agencies to make informed, environmentally responsible decisions when considering Federal actions that may have a significant impact on the environment (for example, issuing a Section 404 permit). Agencies must evaluate potential environmental consequences of proposed actions using environmental assessments and/or environmental impact statements. Web site: http://ceq.eh.doe.gov/nepa/nepanet.htm.

Forest Service Manual

FSM 2526—Riparian Area Management provides national policy, objectives, and guidelines and minimum standards for protection and improvement of riparian areas on National Forest System lands.

FSM 2527—Flood plain Management and Wetland Protection ensures that flood plain management and wetland protection and management considerations are included in all USDA Forest Service activities and programs affecting land use.

FSM 7701.3—Transportation System Management contains various acts and regulations that authorize and define the road and trail system on the national forest.

FSM 7701.4—Cooperation and Coordination cites various acts that authorize cooperation and assistance to public and private agencies and to organizations.

FSM 7701.5—Executive orders contain a unified national program for flood plain management and guidance for protection of the Nation's wetlands.

Best Management Practices (States)

In some States, responsibilities for water quality management on the national forests are delegated through the execution of a formal Management Agency Agreement between the State Water Quality Control Board and the USDA Forest Service. For example, in California a portion of the State Water Quality Management Plan contains guidance for the Forest Service in the document "Water Quality Management for National Forest System Lands in California—Best Management Practices". These Best Management Practices, or BMPs, become USDA Forest Service practices and procedures by virtue of the following agreement from Water Quality Management for Forest System Lands in California, Best Management Practices (Pacific Southwest Region September 2000).

> *Pursuant to Section 208 of the Clean Water Act, all agencies responsible for carrying out any portion of a State Water Quality Management Plan must be designated as a Water Quality Management Agency (WQMA). Through the execution of a formal Management Agency Agreement (MAA) with the Forest Service in 1981, the SWRCB designated the Forest Service (USFS) as the WQMA for NFS lands in California.*


NO
DUMPING
ALLOWED
M.C. 8.12.170
DETOUR
INTERSTATE
CALIFORNIA
10
NO
STOPPING
ANY TIME
DO NOT
ENTER
R
R
WRONG
WAY
STOP
ONE
WAY

Chapter 4
Monitoring

Monitoring can indicate whether the restoration efforts were designed and implemented properly, determine whether the restoration met the project objectives, offer new insights into riparian area physical and biological processes, and provide justification for further work and research.

MONITORING

The degree of success or failure of road treatments and techniques to benefit riparian areas needs to be documented. Monitoring is an effective way to do this. Monitoring can indicate whether the restoration efforts were designed and implemented properly, determine whether the restoration met the project objectives, offer new insights into riparian area physical and biological processes, and provide justification for further work and research. Monitoring should not be an afterthought and must be identified as a cost component in the restoration project. Monitoring plans for restoration projects should use systematic processes and procedures. For example, Kershner (1997) described a seven-step template for restoration monitoring, and MacDonald (1991) identified six types of monitoring that are appropriate for aquatic resources.

Coweeta Creek Weir, Cherokee National Forest

The type of monitoring used depends on the questions asked and the degree of certainty needed for the answers. Adequate time, attention, and input from others should be used to develop a monitoring plan that is appropriate for the specific situation. Others may have developed suitable monitoring designs and tools that can be directly applied or used with minimal modifications for your project.

Sources for this information can be found at Web sites such as the following.

- The Center for Transportation and the Environment— http://www.itre.ncsu.edu/cte.
- U.S. Department of Transportation National Transportation Library— http://search.bts.gov/ntl/.

Planning Restoration Monitoring

This section lists some topics to consider when planning the monitoring of your restoration project.

Restoration Objective—A statement that succinctly describes the purpose of the treatment. This usually includes an amount of change to be induced over a specified time period. Inclusion of the objectives and the expected amount of change allows for documentation of the degree of success or failure of the treatment.

Monitoring Objective—A statement that clearly describes the expected result of a restoration treatment. This statement must be linked to the restoration objective statement.

Parameters Monitored—One or more items to be measured repeatedly over time that, when analyzed, provide direct or indirect evidence of the success or failure of the treatment.

Methods Used—A list of procedures and methodologies to evaluate the monitored parameters. Although many standard methods and procedures exist in current literature, new procedures may need to be developed and tested.

Where and When To Monitor—Statements that outline the spatial and temporal scope of the evaluation of project results.

Experimental Design—Statements that outline how the monitoring will be planned, organized, implemented, and analyzed.

Assumptions and Data Limitations—A list of all pertinent and relevant assumptions and data limitations necessary for developing and implementing this monitoring plan.

Distribution of Results—A plan to make monitoring results available to all interested parties through established channels, including professional meetings, publications, and the Internet.

Archive of Results—A plan to document and store results for future reference. The documentation for each monitoring program should include copies of all materials collected.

Chapter 5
Management Strategies and Field Techniques

This section describes treatments and techniques for reducing impacts in riparian areas.

MANAGEMENT STRATEGIES AND FIELD TECHNIQUES

This section describes treatments and techniques for reducing impacts in riparian areas. Some of the topics are referred to as management strategies because they affect how people access riparian areas. Changing access requires a roads analysis process and a NEPA analysis and is therefore part of an overall strategy for access and resource protection. On the other hand, many field techniques are administrative or remedial in nature, do not typically change access, and require less strategic planning.

Aquatic Organism Passage

Structural plate arch.

Description—Many roads originally were constructed without thorough consideration for adult and juvenile fish passage upstream and downstream of road/channel crossing structures, primarily culverts. Bridges, structural plate arches, larger full-pipe culverts, or box culverts can restore unrestricted fish passage at these sites. Fish passage design aims to provide unrestricted passage for adult and juvenile fish across roads or other barriers. Fish passage structures can be designed to accommodate other aquatic organisms, such as salamanders.

Application—Aquatic organism passage structures are appropriate in all ecosystems wherever road/stream crossings are obstructing passage by fish or other animals. Direct field inventories, time-lapsed video, or photography may reveal isolated fish populations. Absence of one or more life stages of fish in historic fish habitat above or below a channel crossing structure may indicate a fish blockage. Effective passage structure types mimic the natural habitat attributes for fish and other organisms native to the site.

Imbedded corrugated metal pipe.

Considerations—Appropriate structures (such as bridges or open structural plate arches), length, width, and installation grade are determined by analyzing data from stream and site surveys. The USDA Forest Service FishXing software can assist in this determination. Consider all onsite wildlife and aquatic organisms and their needs for passage, as well as flow regimes, when designing passage structures. Conduct fish and fish habitat surveys before and after project implementation to help determine and confirm passage structure size and design selection. Data on swimming speed of target fish species is critical to developing specifications. Install structures at the lowest flow period of the year to reduce the amount of heavy equipment disturbance, sedimentation, and turbidity. Employ techniques to keep fish adults or juveniles out of the immediate construction area.

Potential Outcome/Benefits—Unrestricted fish passage can significantly increase fish access to spawning and rearing habitats. Increased habitat access and utilization can greatly increase fish production. Other potential benefits are more efficient passage of high flows and bedload and increased channel complexity (channel meander and geometry). If wildlife crossings also are considered, the ecological integrity of the drainage can be maintained.

Alternate and Complementary Techniques—Low-water crossings (fords), culvert variations, bridges, cutoff channels, wildlife crossings, and beaver control are alternate and complementary techniques.

Beaver Pond Structures

Beaver deceiver.

Description—Roads passing through riparian and wetland areas can function as dikes or dams to impede water flow. Beavers are attracted to roads crossing streams because they can impound water easily by blocking or plugging culverts. Several water control structures, such as beaver pond levelers, facilitate water movement through roads subject to beaver activity. These devices can maintain the valuable fish and wildlife habitat created by beavers while reducing damage to roads and other structures because they allow water movement but prevent complete removal of water from the ponded area.

Application—Beaver pond levelers manage the water level of beaver ponds next to roads, maintain wetland habitat created by beavers, and reduce the risk of road erosion. Beavers search for and detect leaks along the road berm or embankment by the sound and velocity of moving water. Beaver pond levelers lower pond water levels by extending the water intake well beyond the road berm or embankment and dispersing the water through a perforated pipe instead of one large culvert opening. This technique is appropriate when beavers dam culverts causing the road prism to become saturated, or when beavers cause road erosion by building above the culvert inlet. Bridges or culverts large enough to discourage beavers from plugging can be used to avoid the damage caused by beavers. These more expensive structures are appropriate when beavers are overly abundant or when a road is more valuable than additional beaver pond habitat.

Considerations—Beaver pond levelers maintain ponded water levels at an appropriate chosen level during normal flow conditions. Typically, they are not designed to transport runoff from large storm events. Construct spillway areas to transport high flows (floods) across roads. Beaver dam removal and beaver trapping are generally temporary measures and can be ineffective.

Potential Outcome/Benefits—Beaver pond levelers can maintain fish and wildlife habitat created by beaver ponds, reduce damage to adjacent roads and culverts, maintain floodwater storage, and maintain the water purification functions of beaver ponds.

Alternate and Complementary Techniques—Road relocation or realignment, bridges, and large culverts may avoid beaver dam issues. Roadway dips, low-water crossings such as fords, and fish passage structures are alternate and complementary techniques.

Beaver pond.

Biotechnical Stabilization

Stabilizing slopes with jute netting.

Description—Biotechnical stabilization integrates living vegetation and inert structural or mechanical components, such as concrete, wood, stone, and geofabrics, to reinforce soil and stabilize slopes. Geofabrics are made from synthetic polymers or natural materials such as jute and coir. Biotechnical stabilization uses mechanical elements of engineered structures in combination with plants to arrest and prevent slope failures and erosion. Biological and mechanical elements are integrated and complementary.

Application—Engineers use inert systems (retaining structures, revetment systems, and inert ground cover) for slope stabilization and erosion control. Inert systems have standard protocols for their use, are widely available, easy to install, familiar, and accepted by designers, engineers, and the public. Although inert materials presumably have predictable and invariant properties, even inert materials slowly degrade, decompose, and decay (Gray and Sotir 1996). Vegetation can be incorporated into any of the following retaining structures, revetments, or inert ground covers that are porous or that have openings (interstices):

- *Retaining structures*. These structures include gravity walls (gabions, crib, and bin walls) or reinforced earth structures (stacked and backfilled three-dimensional webs). Retaining structures are designed to resist lateral earth forces.
- *Revetment systems*. These systems also include riprap (gravity wall) and cellular confinement systems (reinforced earth structure). Revetments are designed primarily to armor a slope against scour and erosion from streamflow.

One year later, vegetation reclaims the site.

- *Articulated block systems*. Articulated block systems and rock breast walls provide some lateral earth support and protect the toe of slopes. Both provide shear displacement between blocks (or rocks) by interlocking or articulating between individual components.
- *Geofabrics*. Geofabrics or ground covers that provide a seedbed and retain moisture to promote plant growth include artificial mulches (fiberglass roving and cellulose fibers), blankets, mats, and nettings.

Considerations—Many inert systems or products integrate well with vegetation. For plant survival, moisture and sunlight must be available. See Gray and Sotir (1996) for more information.

Potential Outcome/Benefits—Biotechnical methods can stabilize cut and fill slopes along highways or streambanks, which in turn reduces sediment delivery to the stream.

Alternate and Complementary Techniques—Soil bioengineering, retaining walls, and erosion control devices are recommended as possible alternate and complementary techniques.

Bridges

Single span concrete girder bridge.

Description—Bridges provide safe and easy vehicle access over naturally impassable features, such as waterways, canyons, or tidal areas. Bridge elements typically consist of spans, piers, and abutments.

Application—Properly designed bridges restore and maintain riparian function in ecosystems where roads cut off water bodies, interrupt streamflow, fragment wildlife habitat, or block aquatic organism passage. Other situations suitable for bridges include flood-prone areas where bridges can handle much larger quantities of water than culverts, or in drainages with high flow and floatable debris which may plug or constrict flow in culverts. Bridges, when properly designed, can promote more natural stream velocities thorough a road crossing, which in turn can reduce or eliminate excessive bank erosion and sedimentation above and below the crossing.

Considerations—Bridges can minimize road impacts on surrounding areas by limiting disturbances to natural riparian area processes during and after construction. Bridge impacts depend on the span length and height and the amount of fill required for the approaches. The fill approaches and abutments for a bridge can restrict natural channel dimension. Although minimizing the span length may be less expensive, it increases the amount of fill material dumped in the crossing to build the approaches. Bridges with long spans reduce the amount of fill material needed, allow more natural flood plain width and water-carrying capacity, and increase wildlife passage opportunities. Consider replacing culverts with bridges when greater capacity for water and floatable debris is indicated or when fish and/or wildlife passage is an issue.

Asymmetric bridge, White Mountain National Forest.

Potential Outcome/Benefits—Longer and higher bridges allow for the passage of larger runoff flows, greater bedload volumes, and larger woody debris. Bridges provide much better passage for fish and wildlife than culverts do, especially when a portion of the streambed under the bridge is designed to be unwetted. High bridges and long spans are the least restrictive.

Alternate and Complementary Techniques—Bottomless culverts are an alternative to bridges. Paved approaches or surfacing are an excellent complement to bridges. Low-water crossings can be an effective alternative to bridges.

Controlling Access

Accessible picnic site, Cherokee National Forest.

Description—Controlling access is a management strategy in which a collection of techniques and strategies are employed to modify use in riparian areas to prevent adverse effects. Use the following steps to help reverse the effects of uncontrolled access:

- Use access and travel management (ATM) plans to define access needs. A forest planning team should define access needs and specific resource concerns for an area while including public input to the ATM plan. The team must clearly identify resource objectives for an area and match the appropriate technique(s) to the management strategy.
- Restrict vehicle use in riparian areas. This management strategy addresses concerns of vegetative loss, soil compaction, increased erosion, and sedimentation. Successful techniques include placement of boulders, construction of rustic fences, use of

downed logs, and designated parking areas. These techniques remove the vehicle from the sensitive areas of a riparian zone where adverse effects have occurred.

- Modify high-use dispersed recreation areas with designated facilities. This management strategy responds to the carrying capacity of an area. The planning team must determine the level of use in an area from its analysis. If a dispersed area is heavily used throughout the recreation season, and adverse impacts are identified, the team should recommend modifying the existing use. Some of the techniques the team can use include redesign of an existing facility to reduce the number of dispersed sites available, redesign of an existing facility to mitigate the adverse impacts (armoring and relocating campsites away from a stream), or new design and construction of a facility in a location that accommodates the increased use without adverse effects.
- Informational displays and signs. Sharing information about what the USDA Forest Service does is very important to visitors of the national forests. The planning team should develop a message that it wants to share with forest visitors and incorporate this into any management strategy selected. Forest information signs should explain what the visitor's role is in maintaining healthy riparian areas and how they can help. Post signs before, during, and after any changes in use to an area. If you are in the process of relocating an access road to dispersed sites, be sure to post a sign to inform visitors about what is being done and why. Informational displays at kiosks are also a great place to summarize findings of a watershed analysis or an ATM plan. Regardless of the scope of your access modifications, be sure to share the information with the public.
- Monitor and maintain dispersed recreation sites. Working together, recreation and resource staffs should maintain a regular inspection of dispersed recreation areas. The adverse effects of dispersed recreation or uncontrolled access can develop quickly in some areas.

Application—The following are indicators of adverse effects in riparian areas:

- Vegetation trampling and soil cover loss.
- Soil compaction.
- Increased runoff and erosion.
- User-made roads and trails.
- Increased trash and unsanitary conditions.

Travel Management sign at Tahoe Basin Management Unit

Considerations—When determining the appropriate management strategy and techniques for controlling access, the planning team should identify the following:

- Has an access and travel management plan been completed?
- What is the resource concern at the site or sites?
- What is the existing use, and how will that change?
- Has the public been involved in the planning process?
- Does the proposed technique address the resource issues identified?
- Are resources available to enforce the proposed management strategy?
- What monitoring questions need to be incorporated into the monitoring plan?

Potential Outcome/Benefits—Riparian areas are unique ecosystems that provide aquatic species, wildlife, and humans with an area to live in and enjoy. The benefits of controlling access vary depending on the specific problems, but generally an improvement to vegetation, habitat, soil health, and water quality is achieved with controlled access.

Alternate and Complementary Techniques—Complement access control with signage and public information displays. In situations in which road closure is not possible, surfacing the road can reduce impacts.

Culverts

Concrete box culvert with wing walls.

Description—Culverts are conduits that convey streamflow, sediment, and debris through a roadway embankment. Properly designed and constructed culverts also enable the passage of aquatic and terrestrial species. Culverts are made from a variety of materials including corrugated metal pipe, concrete, and plastic. End sections placed on culverts control and improve hydraulic efficiencies.

Application—Culverts provide cross-drainage to a roadway ditch system or an existing road/stream crossing. Culvert arrays help disperse flows at meadow crossings. Typically, structural plate arches simulate stream conditions and encourage aquatic organism and fish passage at channel crossings. Dry culverts can create wildlife passages through the road prism even if no water conveyance is needed.

Considerations—Effective culvert sizing and spacing requires hydrologic and hydraulic studies. Pipe sizing is determined from a hydrologic analysis of flow associated with runoff. Dialog between designers and resource specialists can help to ensure proper culvert design. Consider stream function, stream classification, alignment, and wildlife and aquatic passage when designing culverts. Maintain channel dimensions of profile, cross-section, and planform to promote debris passage. The culvert should neither restrict the channel width nor change the channel alignment. Improperly placed or sized culverts can destroy aquatic habitat or eliminate fish and wildlife passage. Culverts can constrain a meandering stream and degrade riparian functions, increase erosion, or alter flood plain characteristics. If beavers are present, additional measures may be necessary to maintain drainage capacity, because they often try to plug culverts.

Precast triple box culvert.

Potential Outcome/Benefits—Properly designed culverts maintain stream integrity while accommodating aquatic organism and wildlife passage. One significant potential negative outcome with the inappropriate use of culverts is stream diversion. Diversion potential is influenced by the culvert plugging potential, shape and slope of the roadway, and often an inslope ditch configuration. Riparian habitat is improved by reducing sediment delivery to streams associated with stream diversion, streambed scour, and culvert washouts.

Alternate and Complementary Techniques—Bridges provide similar watershed benefits to culverts at channel crossings and are preferred as wildlife passages. Outsloped roads and dips can reduce the need for culverts. Low-water crossings can replace or supplement culverts. Culverts often require energy dissipaters and can be used with raised inlets when management objectives are to keep water on the land longer.

Ditch Treatments

Rock lined ditch.

Description—Ditch treatments reinforce or otherwise protect ditches from excessive erosion. Typical ditch treatments can be vegetated or rock-lined (riprap).

Application—Ditches on roads with steep grades, sensitive soils, and particularly in areas with high-intensity storms are susceptible to erosive forces from concentrated water. A scoured and gullied roadside ditch in these circumstances may indicate the need for a ditch treatment.

- Vegetated ditches. Vegetation in ditches reduces water velocity. Typically, erosion control grass mixtures are used to vegetate ditches. Ensure erosion control grass mixtures do not have invasive species.

- Rock-lined ditches. Rock-lined ditches reduce velocity and capture sediment. Ensure that ditch capacities are not compromised.

Considerations—Channelized flow that creates significant erosion may require energy dissipaters. Vegetation or rock-lined ditches reduce ditch flow energy. The softest approach to developing vegetated ditches is to avoid heeling or pulling the ditch with a grader unless this technique is necessary to restore ditch capacity. Ditch grades between 2 and 8 percent usually perform well. Grades greater than 8 percent create high runoff velocities and more erosive force, requiring more ditch relief and/ or ditch armor. Grades of less than 2 percent drain water too slowly, causing siltation, ditch plugging, and increased moisture content in the road's traveled way.

Rock-lined ditch grown in with native grass.

Potential Outcome/Benefits—Ditch treatments can have immediate and long-term benefits to roadside areas. Gaining control of runoff will lead to reduced sediment transport and less erosion and consequently improve habitat and lower road maintenance costs.

Alternate and Complementary Techniques—Consider outsloping as an alternative to ditch treatments. Insloping is the most common complementary technique for ditch treatments. Rock check dams are an alternative technique effectively used when completely filling a deeply scoured ditch is not practical.

Erosion Control Devices

Retention structure sediment basin.

Description—Erosion control devices slow water runoff and trap small amounts of sediment. These devices are barriers to overland flow and trap and store sediment produced on disturbed areas (for example, burned areas, new construction, and eroded areas). Use temporary erosion control devices during construction activities to provide interim protection until long-term or permanent erosion control treatments become effective.

Application—Some recommended erosion control devices are the following:

- Barriers. Sediment barriers intercept and detain sediment and decrease runoff velocity. The most common temporary barriers are filter fences, straw bales, and straw wattles.
- Retention Structures. The most common type of retention structure is the sediment basin used to control runoff in large

storm events. Often they are used as mitigation measures for disturbances during construction and sited below known sources of sediment.

- Mulches. Straw, woodchips, and soil adhesives can protect bare soil or recently seeded areas. Gravel can surface temporary roadways or parking areas.

Erosion fabric jute netting.

Considerations—Generally, filter fence and straw bale check dams effectively trap sediment as a temporary measure until long-term erosion control can take over. Install temporary measures where they are unlikely to fail and cause additional damage. Straw bales can have the residual benefit of serving as mulch after they have served their initial erosion control purpose and have deteriorated. Straw wattles make good contact with the ground surface and provide effective, low-risk barriers to soil movement. Straw wattles are used primarily in the upper end of swale areas and have a life expectancy of 2 to 4 years. Although sediment basins are effective in removing sediment, constructing temporary sediment basins for small projects with small runoff areas and limited sediment production may not be cost effective. Sediment and retention basins are more appropriate for larger areas and when dealing with longer term recurring sediment and flow metering needs. Ensure that chemical mulches or tackifiers are nontoxic.

Potential Outcome/Benefits—Water quality protection is the primary benefit of erosion control devices.

Alternate and Complementary Techniques—Suitable alternate and complementary techniques include filter strips, jute mats, sediment traps, biotechnical stabilization, and soil bioengineering.

Energy Dissipaters and Debris Racks

Debris rack well upstream of culvert.

Description—Energy dissipaters and aprons at culvert inlets and outlets reduce water velocity and prevent erosion. Dissipaters include riprap, vegetated ditches, and concrete or steel baffles. Debris racks at culvert stream crossings can prevent clogging. Debris racks can be installed in the channel upstream of the culvert to intercept and detain woody debris, allowing only water to pass through to the culvert.

Application—Energy dissipaters are used primarily at culvert outlets when velocities exiting the pipe are expected to be higher than natural stream velocity. Good culvert design practice, however, is to match culvert diameter with channel width and gradient through culverts to minimize this expected increase in velocity. In stream channels where the designer expects woody debris to be mobilized by streamflow, debris racks can be used to prevent plugging. Debris racks, however, are typically an adaptive measure and are used only when replacing existing culverts with a structure capable of passing debris is neither feasible nor affordable.

Considerations—Types of dissipaters range from riprap basins to heavy concrete forced jump basins. Consider energy dissipaters when excessive water velocities are expected (for example, water exiting a paved road onto natural ground). Consult the Federal Highway Administration publication “Hydraulic Design of Energy Dissipaters for Culverts and Channels” (FHWA HEC-14) (sec. 6.08e) for the design of energy dissipaters. Debris racks installed too close to the culvert inlet can become clogged and may reduce flow though the culvert. Install debris racks only when regular maintenance is possible. Consider an attached vertical “riser” to serve as a debris structure. This vertical perforated riser with a screened opening at the top is another design option to control debris.

Modification of existing culverts to prevent plugging.

Potential Outcome/Benefits—Energy dissipaters can reduce water velocity and the potential for erosion. Debris racks detain or intercept debris and bedload to prevent culvert clogging or plugging.

Alternate and Complementary Techniques—Energy dissipaters complement the use of culvert entrance treatments, such as headwalls with wingwalls, and flared culvert inlets where water velocities might be increased from improved hydraulic efficiency. Diversion prevention dips that act as a safety valve at culvert crossings complement the use of debris racks. A combination of dips and debris racks can provide a relatively low-cost solution to a potential erosion source.

Invasive Species Management

Non-native Purple Loosestrife, Idaho.

Description—Exotic plants and animals can disrupt ecological processes with invasive behavior or growth patterns. Roaded riparian areas and wetlands are particularly vulnerable because roads provide an avenue for spread. Brown-headed cowbirds follow roads into riparian areas and lay their eggs in other birds' nests. Invasive mussels damage water systems and native species. Noxious weeds crowd out native species and cause erosion by reducing soil cover and other means.

Application—The following control strategies apply primarily to noxious weeds, but some apply to all invasive species.

- Prevention. Wash equipment before entering worksites; inspect for weeds, and, where possible, pretreat infested access roads, gravel, and borrow sources before use; and limit access at active road construction sites to necessary vehicles. Pretreatment techniques depend on the biology of the target species, but may include physically pulling plants or applying appropriate herbicides.

- Identification. Consult with the local extension office, county weed superintendent, or USDA Forest Service weed specialist on weeds currently at worksites; know potential invaders from adjacent areas; and be attuned to all life stages. Many noxious weed species look very different at different life stages. Because controlling weeds is sometimes easier before they mature, identifying them as young as possible is helpful.

- Prioritization. Differentiate invasive weed species from more common noninvasive species; sometimes closely related native species look similar. Treat small or outlying populations or new invaders first. Develop threshold strategies depending on the degree of competition of the invader. For competitive species, control is the appropriate strategy; for moderately competitive species, populations can be suppressed or contained; for noncompetitive species, deferral of treatment may be possible.
- Treatment. Fill in bare ground with fast-growing native cover species, weed-free mulch, geotextile, or crushed rock. Overseed with certified weed-free-compatible or native seed. Fertilize to encourage competitive growth of native species. Use biological controls to control seed production on existing widespread weed populations and herbicides for a definitive response in smaller populations.
- Monitoring. Evaluate the effectiveness of integrated pest management programs. Map existing and expanding populations or new invasions to ensure prioritization strategies are appropriate as conditions change. Modify treatment to increase control if needed.

Considerations—Pretreating access roads and borrow sources will not deplete existing noxious weed seed banks because many noxious weed seeds are viable for many years. Identification of noxious species can be difficult because some native noninvasive species look similar to invasive ones. During treatment program development, consider erosion potential, high water tables or surface water, sensitive plants, recreation areas, cost, equipment or skill needs, and application timing. Factor cost and timing into evaluating monitoring effectiveness.

Potential Outcome/Benefits—Benefits include protection or restoration of existing native biodiversity, erosion control, and forage production for livestock and wildlife.

Alternate and Complementary Techniques—Try biotechnical stabilization or soil bioengineering as possible alternate and/or complementary techniques.

Vehicle washing station.

Landslide Mitigation Strategies

Landslide removal.

Description—Landslides can occur in road cut and fill slopes and are typically triggered by the road traversing natural landslides or unstable areas. Landslide mitigation strategies include avoidance, stabilization, control, prevention, and recurring road maintenance. Mitigation techniques discussed here include improving surface and subsurface drainage (prevention), increasing resistive forces and reducing driving forces (control), and slide removal (road maintenance).

Application—Landslide mitigation is used on roads with the potential for cut slope and fill slope failures. Landslide mitigation techniques include installing ditches to prevent surface flows from entering the slide and improving subsurface drainage by installing underdrains, trenches, or horizontal drains. Landslides can be stabilized by increasing the resisting forces against them (for example, gravity walls, reinforced earth, soil bioengineering), or by decreasing the driving forces behind them (removing “head” of slide mass or backfilling a portion of slide mass with lightweight fill).

Considerations—Landslides are a geologic hazard that can injure or kill, so safety of employees, contractors, and road users is important. Slide removal can trigger even more movement of the slide. Perform a geologic inspection of the slide and the slope above the slide to assess landslide hazards before slide removal. A safe and rational design for landslide mitigation incorporates engineering geologic investigations (stability of cut slopes and fill slopes), ground water assessments, and the identification of unique geologic structures.

Potential Outcome/Benefits—The potential outcomes of this technique are stabilization or prevention of cut slope and fill slope failures, reduction of sediment delivered to streams, and improved safety for the public in general.

Alternate and Complementary Techniques—Retaining walls and soil bioengineering are possible alternate or complementary techniques.

Landslide. Gordon Keller photo.

Logjam Complexes

Cispus River "before" showing eroded banks.

Description—Logjam complexes are multiple-log structures placed in rivers and streams to protect channel banks, roadways, and other adjacent features.

Application—Logjam complexes protect roadways adjacent to river channels by emulating natural river processes. They usually are placed in series or in combinations for channels third order or higher. Engineered logjams are one type of logjam complex that can have up to 500 wood pieces. Logjam complexes are most appropriate in ecosystems where source trees are large and decay rates are relatively low. Logjam structures can stabilize channel banks and protect roads using native materials; deflect and catch large woody debris in transport; promote establishment of vegetated riparian areas, such as channel banks and in-channel riparian islands; improve and create new fish habitats; and restore and maintain natural river system characteristics.

Cispus River "after" showing an engineered log jam.

Considerations—Install logjam complexes at the lowest flow period of the year to reduce riparian area disturbance by heavy equipment. Use sediment reduction treatments and keep fish away from the construction area to reduce mortality. Assess the proximity of these structures to adjacent property ownership and the potential risk downstream before and during project implementation.

Potential Outcome/Benefits—Engineered logjams initiate channel scour and deposition around the structures; retain woody debris in transport within the river system; increase channel complexity, such as meander pattern and geometry; and restore and improve aquatic and terrestrial habitats.

Alternate and Complementary Techniques— A complementary technique is soil bioengineering.

Low-Water Crossings and Fords

Low-water bridge.

Description—Low-water crossings (also know as fords) allow water and debris to pass over a road. Types of low-water crossings include vented and unvented fords and low-water bridges. Vented fords and low-water bridges pass seasonally low flows beneath the traveled way. Unvented fords pass all flows over the traveled way. Fords can be simple native-surfaced, stream-grade crossings, or more complex designs using concrete and steel.

Application—Low-water crossings are appropriate on low-standard roads where continuous access is not required. They are ideal for channel systems that transport debris and bedload during high-water events and for roads that receive limited maintenance. To pass fish and aquatic organisms, low-water crossings require special design features, such as a simulated stream bottom in a vented ford, or closing the road when the animals are moving.

Considerations—Construction materials for low-water crossings include riprap, concrete, asphalt, and Jersey barriers. Consider geotextile materials beneath roadway surfacing to provide subgrade support for traffic. Other important design considerations are the amount of traffic and types of vehicles using a ford. Both vertical and horizontal curvatures (determined from design vehicle capabilities) entering and exiting the ford can be critical factors in determining the feasibility of a ford at a given site. For design information on turning radii and vertical curvature, refer to Chapter 4.3, Alignment, in FSH 7709.56.

Potential Outcome/Benefits—Benefits of low-water crossings include lower construction costs, reduced maintenance, and reduced potential for catastrophic road failure. Decrease fill heights to maintain riparian vegetation diversity and reduce the area impacted. Low-water crossings disperse flow, reduce water velocity, and decrease channel bank erosion. Smaller fills reduce the potential of catastrophic road failure.

Alternate and Complementary Techniques—Outsloping the approaches to low-water crossings complements this techniques by reducing the concentration of water (and transport of sediment) into the stream. Culverts and bridges, on the other hand, are considered alternative techniques.

Vented-ford crossing with removable steel deck.

Outsloping

Dozer and excavator outsloping.

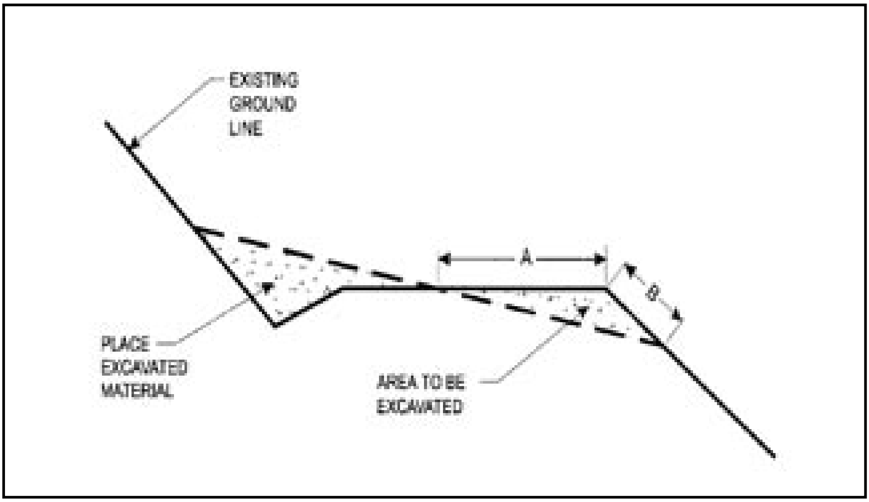
Description—Outsloping prevents concentration and channeling of water by shaping a road surface towards the downhill side. The cross slope of an outsloped road varies from 3 to 5 percent, depending primarily on traffic service needs.

Application—Outsloping has application nationwide. Use outsloping to promote a dispersing of runoff where concentration of water can cause erosion. On an insloped road with frequent cross-drain culverts, use outsloping intermittently to prevent a "domino effect" (consecutive or cascading culvert failure). Outsloping may be preferred on closed roads where dispersing hillside drainage reduces the need for maintenance.

Considerations—Designers need to address safety concerns before outsloping a road. In areas where a road becomes icy or snow-covered during normal use, the risk of vehicles sliding off the road may be unacceptable. Some soil types become slick when wet and pose a danger to drivers on an outsloped road. Travel speeds, design vehicles, season of use, erosive soils, and steep fill slopes factor into deciding whether or not to outslope.

Potential Outcomes/Benefits—Outsloping disperses surface runoff, which reduces erosion and potential sediment from entering the fluvial system, thereby reducing adverse impacts on fish and wildlife habitat. Outsloping also eliminates inside ditches, decreases road maintenance, has a smaller footprint on the landscape, and lowers initial road clearing and construction costs.

Alternate and Complementary Techniques—An alternative to outsloping may be road relocation or realignment. Outsloping is often used with roadway dips. Where an outsloped template fails to meet safety requirements, an insloped or crowned template may be necessary.



Outslope diagram.

Permeable Fill With Culvert Array

Permeable fill with culvert array.

Description—Permeable fills promote the passage of subsurface flows with minimum flow concentration and maximum spreading across meadows. The road fill is permeable because of its construction with relatively large, preferably angular, uniformly graded rock sandwiched between layers of a geotextile fabric that preserves voids in the structure and promotes uninterrupted ground water flow. Culvert arrays are a series of culverts within the permeable fill placed to allow surface flow in defined channels and to give floodwaters access to the entire flood plain. Permeable fills and culvert arrays can be used alone or in combination.

Application—Road crossings act as barriers to subsurface and overland flow, resulting in altered hydrologic and meadow function. Permeable fills are appropriate when there is a need to cross meadows to promote subsurface water passage and maintain and restore wet meadow systems. They are not recommended in flash-flood-prone areas or for fish-bearing perennial streams unless passage is provided in the main channel. Permeable fills work well where the road restricts ground water flow, causing drier conditions down slope. Where spreading of surface flows is a concern but subsurface flow is not, culvert arrays alone may be a good solution.

Considerations—Place multiple culverts in an array to enable spreading of flood flows and imitate the natural flooding event in the meadow. Consider designing culverts or the stream crossing to accommodate 100-year storm events or greater. Install all culverts at natural stream channel elevations to prevent accelerating water through or dropping water from culvert outlets. Culverts may require outlet energy dissipaters. Fill heights should be kept low to reduce consolidation pressures on underlying soils. In areas with large woody debris or significant bedload, adding an overtopping structure or ford will provide passage of water and debris. Culverts should be designed to accommodate unrestricted passage for all life stages of amphibians, fish, or small wildlife. The use of permeable fills alone without culverts may fragment habitat for terrestrial and aquatic species. To prevent fragmentation of habitat, consider traffic and road width when designing these crossings.

Potential Outcome/Benefits—Permeable fills maintain and/or restore natural wet meadow hydrology, wildlife habitat, vegetation diversity, and water storage. Culvert arrays help to maintain stream access to the flood plain.

Alternate and Complementary Techniques—Road relocation or realignment avoids the need to use permeable fills or culvert arrays by removing the road and its effects from sensitive areas. Low-water crossings and fords and overtopping structures can be combined with permeable fills.

Permeable fill during construction.

Raised Culvert Inlets

Timber raised inlet.

Description—Raised culvert inlets are used to keep water on the land longer and promote water infiltration. Culvert inlet elevations are raised by constructing a dike at the inlet or installing a culvert elbow.

Application—Raised inlets installed on culverts in low-gradient stream systems or in large or small flood plains are applicable in all ecoregions. Culverts installed in low-gradient streams tend to concentrate and accelerate flows above and below the road, which can dramatically change the hydrology of the area. Vertical instability (headcutting) in the stream channel above the road is one indication that the road drainage has had a negative impact on the stream. Other indicators of road impacts in low-gradient stream systems and small flood plains include eroding banks in straight stretches, loss of meander patterns, lowered ground water tables, and a change or loss of upstream riparian and wet meadow vegetation. Raised inlets can create and/or restore wetlands that may have existed before construction of the road. Raised inlets can be constructed from a variety of materials, including rocks, timbers, concrete drop inlets, or culverts, placed on end to serve as dikes. Prefabricated elbows attached to the existing pipe with bands provide another method for creating the ponding effect; they are inexpensive and easy to install.

Considerations—Raised culvert inlets may—

- Create a wetland environment.
- Reduce passage of fish, aquatic organisms, and small animals.
- Restrict transport of debris and bedload.
- Establish a fixed water level.

Potential Outcome/Benefits—Raised culvert inlets reduce headcutting, increase riparian vegetation vigor and diversity, reduce flash flood damage, create a sediment basin, raise the water table, and increase infiltration.

Alternate and Complementary Techniques—Raised culvert inlets are often used with culvert arrays to recharge meadows yet provide for natural flood flow dispersal. Permeable fills may be an alternative to raised inlets in maintaining more natural subsurface flows.

Slot board riser.

Reconnecting Cutoff Water Bodies

Completed project, Clackamas River.

Description—Reconnecting cutoff water bodies reconnects side channels, ponds, wetlands, and flood plains that have become cut off from the main channel by the construction of a road prism. Structures used to reconnect water bodies cut off by roads typically involve the use of culverts and bridges.

Application—Roads constructed in the flood plain and adjacent to rivers or streams can cut off portions of the natural channel or wetland network, straighten the channel, increase water velocity, and cause loss or degradation of valuable aquatic and terrestrial riparian habitats. Structures installed in the road prism can create as many reconnections as needed to restore stream hydrology and increase channel meander, channel length, or the amount of wetland surface area. Reconnection structures can restore aquatic access to significant habitat, and increase channel or wetland diversity.

Any of the following can indicate the need to reconnect cutoff water channels.

- When a road is placed across meandering watercourses, it can impede seasonal or year-round movement or migration of fish species, or cause a noticeable loss of fish and/or wildlife habitat.
- The presence of nonnative vegetation and/or animals may

indicate the road has caused changes in wetland conditions less favorable to native species.

- Channel scour and downcutting due to shorter and steeper stream profile because of loss of channel length.

Considerations—Reconnecting water bodies to river and stream channels could increase the risk of damage from high flow events (flood flow) to road and channel crossing structures. These structures require medium to high annual maintenance, especially in systems that move significant amounts of bedload and coarse woody debris. Restoring historic habitats and access to them could increase the incidence of human interactions with fish and/or wildlife species such as disturbance and poaching.

Potential Outcome/Benefits—Reconnecting flood plain water bodies can significantly restore aquatic habitat quality and quantity, such as fish access to spawning or rearing habitat. Other potential benefits are long-term recovery of flood plain structure and function, including moderated effects of flood flows, and restored native riparian wetland vegetation.

Alternate and Complementary Techniques—In some cases, low-water crossings can be used to reconnect cutoff water bodies. Complementary techniques include culvert variations, wildlife crossings, aquatic passage, and beaver control.

Large, woody debris placement.

Retaining Walls

Rock retaining wall.

Description—Retaining structures can be used to reduce disturbance to the landscape and environment by decreasing the quantities of excavation and fill material for construction and decreasing cut and fill slope length and angle.

Application—Retaining walls used in a riparian restoration application can narrow the footprint of the road by allowing near-vertical cut and fill slopes. Narrowing this footprint or impact can leave more room for stream meander (in the case of a road fill encroaching on a stream), or stabilize steep cut slopes where erosion is a problem and sediment is easily mobilized by the roadway drainage (for example, ditches).

Considerations—Construction considerations, methods, and materials can vary due to differing site conditions of geology, soil, slope, and vegetation. Designers can choose from four classifications of retaining walls: mechanically stabilized backfill, cantilever, tieback, and gravity. Where roads must remain along streams, consider whether retaining walls can provide sufficient increase in stream floodplain that would improve stream function and protect the road. Design retaining walls to be located well above flood prone areas; do not use retaining walls as an in-stream structure. When erosion sources are from steep cut slopes, consider using retaining walls to reduce slope and allow stabilizing vegetation to become established.

Potential Outcome/Benefits—Retaining walls can reduce or eliminate the sloughing of soil and debris into the ditchline, which reduces sediment delivered to the stream. Retaining walls can allow more natural stream function (flood plain and meander) by removing road fill from the channel.

Alternate and Complementary Techniques—Road relocation may be more cost effective than constructing retaining walls and, therefore, are a potential alternative to a retaining wall. Soil bioengineering can be used alone or applied with appropriate retaining wall construction. Vegetative plantings in front of a retaining wall can improve the visual esthetics of the structure.

Welded wire tieback retaining wall.

Roadway Dips

Rolling dip.

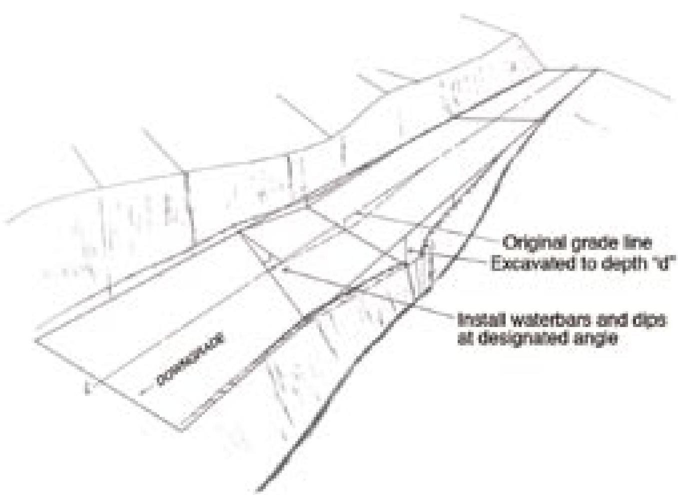
Description—Roadway dips are designed and constructed to divert water off the road surface, disperse surface water flows, and reduce erosion. The road profile (vertical alignment) is changed so that it turns surface flows in the direction of the roadway template. Ideally, this turning of surface flows diverts water off the road surface before the combination of water volume and velocity begins to displace the surface materials.

Application—Roadway dips have nationwide application. Dips work well with outslope in road grades up to 10 percent. Roadway dips can replace or supplement cross-drain culverts. Roadway dips can help reduce erosion when used to prevent stream diversion if natural channel culverts overtop. Dips also work well to reduce the effects of cascading culvert failures when inserted periodically between cross-drain culverts because dips interrupt hydrologic connectivity. The proper construction and application of dips can reduce maintenance costs, and provides for the smooth flow of traffic.

Considerations—Roadway dip design and construction vary according to road maintenance objectives (for example, design vehicle). Consider traffic limitations and install the proper length of dip to accommodate the design vehicle (logging truck, chip van, horse trailer, cattle truck). See design manuals (FSH 7709.56, Design) for more detail on dip geometry. In some cases (for example, intercepting water from a ditch or spring) riprap and/or asphalt is used to effectively armor and prevent erosion in the bottom of the dip where water is concentrated. Roadway dip spacing is critical. Placement may be at ditch relief culverts or changes in grade. Do not locate drainage dips within the confines of curves that have radii of less than 100 feet. Roadway dips are among the least expensive and most effective techniques to reduce erosion and improve riparian function. Inform grader operators on the need to maintain the dips' physical dimensions to ensure they will continue to function.

Potential Outcome/Benefits—Roadway dips reduce maintenance costs, sediment transport, the need for culverts, and the risk of catastrophic road or slope failure.

Alternate and Complementary Techniques—Use outsloping in combination with dips. Energy dissipaters often are placed on the downstream end of dips.



Dip diagram.

Road Relocation or Realignment

Convert road to trail.

Description—Road relocation or realignment completely removes a road from areas of concern or changes the placement to reduce or eliminate negative impacts caused by the road on the surrounding ecosystems.

Application—Negative impacts from road encroachments on stream and river corridors include the following:

- Restricted flood plain functions (for example, meandering and transporting materials).
- Increased flood frequency and damage.
- Increased sediments and runoff washed into channels.
- Blocked fish passages.
- Increased wildlife/vehicle collisions.
- Reduced numbers of riparian species.
- Fragmented wildlife habitat.

Considerations—Realigning or relocating a road requires removal of enough of the old road prism to allow the surface and subsurface water drainage networks to regain their natural function and pattern. Heavy equipment (dozers, compactors, graders, and excavators) are used for both road construction and road removal. Road relocation or realignment provides an opportunity to improve road design. Consider proactively adding wildlife and fish passage features with realignment in addition to erosion control measures.

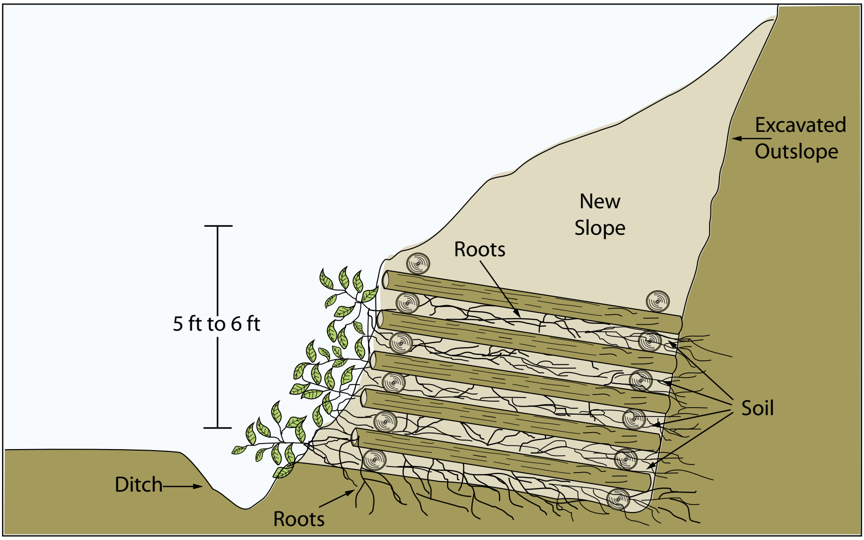
Potential Outcome/Benefits—Benefits of relocating or realigning a road include the following:

- Improved fish and wildlife habitat.
- Restored flood plain structure and function.
- Reduced risks of road failures from catastrophic events, such as road-generated debris torrents and avalanches.
- Created recreational use areas on closed road surfaces for hiking, biking, and all terrain vehicles.
- Reduced vehicular speeds may be possible by changing vertical and horizontal road alignments, thereby increasing safety and decreasing liability.

Alternate and Complementary Techniques—The new construction associated with road relocation and realignment can cause considerable disturbance to an area. Techniques to help reduce negative effects to riparian areas are soil bioengineering, landslide mitigation strategies, and erosion control devices.

Road realignment needed.

Soil Bioengineering



Live cribwall.

Description—Biotechnical stabilization and soil bioengineering stabilization use live vegetation as important structural as well as aesthetic components (Gray and Sotir 1996). Soil bioengineering is a specialized subset of biotechnical stabilization. Live plant parts (roots and stems) are the main structural and mechanical elements in a slope protection system to stabilize surface erosion features and shallow rapid landslides. Soil bioengineering treatments provide sufficient initial stability to enable native vegetation and surrounding plants to become established. Implementing soil bioengineering stabilization successfully is dependent on understanding mass and surface reinforcements and drain factors, as well as the hydraulic and mechanical effects of slope vegetation.

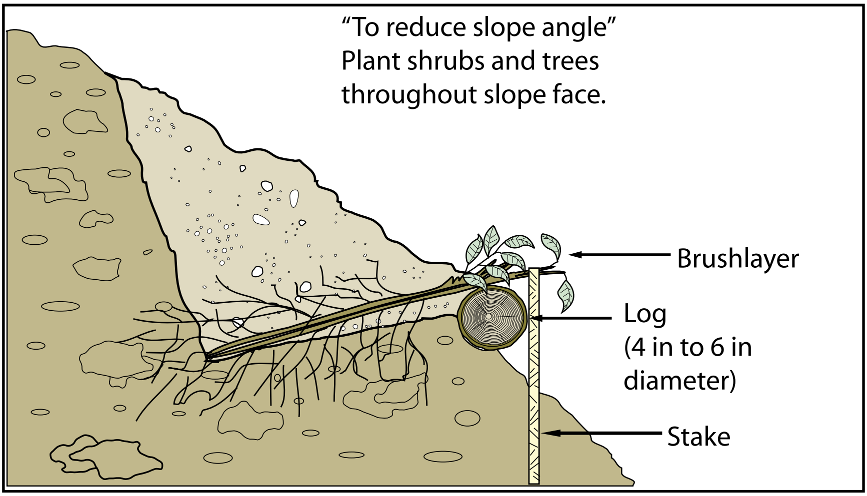
Application—Use any of the following techniques:

- Live staking. Live staking utilizes branch cuttings that are inserted into the ground to stabilize shallow earthen slips and slumps.
- Live cribwalls. Live cribwalls are box-like structures constructed of timbers, backfilled with soil, then planted with branch cuttings extending outward. Cribwalls cannot resist large, lateral earth stresses.
- Live fascines. Live fascines are long bundles of branch cuttings bound together into cigar-like structures to reduce surface erosion on steep rocky slopes where digging is difficult. On long or steep slopes, intense runoff can undermine fascines near drainage channels.
- Brushlayering. Brushlayering stabilizes hillslopes and channel banks with horizontal and vertical plantings of live plant cuttings. Buried cuttings provide immediate site reinforcement. Secondary soil stabilization occurs as buried stems take root. Leafed-out cuttings provide a natural look.
- Branchpacking. Branchpacking repairs small slumps or holes by alternating layers of live branch cuttings and compacted backfill. As plant cuttings grow, trapped sediment refills holes, and roots increase soil stability. This technique is not effective in slump areas greater than 4 feet deep or 5 feet wide.
- Gully repair. Small gully repair can be accomplished by alternating layers of live branch cuttings and compacted soil. This technique immediately reinforces soil, reduces runoff velocities, and provides a barrier to erosion.
- Log terracing. Earthen terraces reinforced with logs reduce slope length and steepness. Terraces provide stable areas for plantings that further stabilize the sites.

Considerations—Soil bioengineering is an effective solution when used with a geotechnically engineered system. Plant species vary depending on ecoregion and soil conditions.

Potential Outcome/Benefits—Soil bioengineering techniques stabilize surface erosion and arrest shallow rapid landslides, reduce excess surface/subsurface drainage, and strengthen soils.

Alternate and Complementary Techniques—Other techniques to use in place of or in conjunction with soil bioengineering are retaining walls, gabions, road relocation or realignment, erosion control devices, landslide mitigation strategies, biotechnical stabilization, and outsloping.



Brush layer with log terrace.

Surfacing Techniques

Paved bridge approach.

Description—Surfacing a road strengthens the native surface to accommodate traffic loading by placing imported material on top of the native surface. The three main types of surface material used are aggregate, cinders or pit run, and asphalt.

Application—The condition of a roadway surface can determine how the road impacts the surrounding environment and how and when traffic can be permitted. Traffic can cause shallow ruts to develop that frequently disrupt drainage on the surface of the traveled way and cause water to concentrate in wheel paths. Surfacing can prevent these impacts and thereby protect the watershed and riparian areas. Use surfacing where native material surfaces are susceptible to rutting or yearlong access or wet season use is needed. Surface treatments include the following:

- Gravel surfacing. When native materials are structurally inadequate to support traffic, gravel surfacing may minimize sediment transport. Imported material is placed over native subgrade.

- Asphalt pavements. Asphalt paving is used on high-volume roads and selectively on bridge approaches to reduce sediment deposition to water bodies. Pavements are commonly a bituminous mixture but can be made from concrete as well.

Considerations—Check the road's road management objectives to determine if wet season use is consistent with the objectives for access. Use surfacing (preferably asphalt) at stream crossings where surface erosion is easily delivered to a flowing channel, even if native surfacing is appropriate for the rest of the road. Surfacing is of particular value when used on the approaches to low-water crossings to reduce sediment delivery to the stream. Surfacing may result in faster vehicle speeds and increased access to remote areas during wet weather conditions. Interdisciplinary teams that include wildlife and fisheries specialists can determine if these changes in access have the potential to impact wildlife and fisheries.

Potential Outcome/Benefits—Surface treatments protect designed surface drainage patterns from traffic and ensure the control of water. Grass covered roads are another possible surfacing application suitable to some areas under certain circumstances (San Dimas Technology and Development Center publication 2000). Reducing sediment in water bodies maintains aquatic and riparian biological health and diversity.

Gravel surfacing.

Alternate and Complementary Techniques—Outsloping protects the road from the impacts of traffic by dispersing water from the surface when used in conjunction with surfacing.

Wildlife Crossings

Reptile crossing.

Description—Wildlife often use streams, riparian areas, and flood plains as travel corridors. Roads constructed near water can fragment habitat and contribute to vehicle-caused mortality. Wildlife crossing structures, such as large culverts, bridges, and overpasses reduce wildlife/vehicle collisions and restore habitat connectivity.

Application—Wildlife crossing structures work well across all ecoregions when designed to accommodate target species or groups. Indicators for establishing wildlife crossings are a high number of wildlife/vehicle collisions, presence of important habitat connectivity zones, and disturbance of sensitive wildlife habitats. As traffic volume and speeds increase, crossing structure complexity and size generally increase, but some structures are suitable for all traffic volumes. High bridges enable the most number of species to cross safely under a road, especially if it provides unsubmerged areas along streams. Culverts can be installed to enable fish and wildlife passage, and dry culverts can accommodate the passage of many smaller animals. Slotted-drain culverts facilitate amphibian crossings by providing for sunlight and air exchange. Where road modifications are impossible, and traffic volume is low, seasonal road closures may be a useful tool for controlled access. More information on applications can be found in the Wildlife Crossings Toolkit (http://www.wildlifecrossings.info).

Considerations—Warning signs are usually ineffective to alert drivers to wildlife crossings. Directional fencing is often necessary to encourage wildlife to use constructed crossings. Livestock crossings and water conveyance structures, culverts, and bridges can be retrofitted to enable wildlife passage. Large rock riprap placed from bridge abutment to water line will not enable wildlife passage unless a trail of finer material is provided. Consider the estimated traffic on low-volume roads in the next 10 years, and install wildlife crossing structures before impacts to habitat connectivity and mortality are problems because impacts may be more difficult or impossible to correct later.

Potential Outcome/Benefits—Decreased wildlife mortality, decreased vehicle damage, improved protection or maintenance of existing habitat, and increased habitat connectivity are benefits.

Alternate and Complementary Techniques—Road relocation or realignment, road decommissioning, bridges, controlled public access, and fish passage are alternate and complementary techniques.

Bear crossing, Florida.

Chapter 6
Glossary

GLOSSARY

A

abutment—The structure that supports the end of a bridge or anchors the cables of a suspension bridge.

aggregate—Granular materials such as sand, gravel, crushed stone, slag, and cinders used to manufacture concrete and asphaltic concrete. Also used for leach fields, drainage systems, landscaping, and as a base course for pavement and grade slabs. Classified by size and gradation.

apron—An erosion protection mat placed to protect against erosive energy of waterflow.

arch—An open-bottom road/stream crossing structure usually formed from bolted structural plates.

B

bankfull discharge—The flow volume at which natural channel maintenance is most efficient, considering sediment transport, forming or removing bars, changing meanders, and performing work resulting in average channel morphology.

base flow—The proportion of streamflow derived from ground water.

bed load—The soil and rock material transported along the bottom of a stream combined with the suspended load that, make up the total sediment discharge.

berm—A curb or dike constructed to control or direct surface drainage.

bollard—One of a series of short posts set to prevent vehicular access or protect property from damage by vehicular encroachment. Sometimes used to direct traffic.

C

catastrophic event—A significant natural disaster, such as a major flood (50- to 100-year flood event), earthquake, or volcanic eruption that can cause major damage to roads and significantly alter or modify riparian area conditions.

channel—A noticeable natural or artificial waterway featuring periodic or continuous running water and having a definite bed and banks that serve to confine the water.

channel scour—The underwater erosion of a stream bottom or bank (that is, at a drainage structure outflow).

clearing limits—The delimitation of vegetation clearing for a road.

cofferdam—A temporary enclosure built in a watercourse and pumped dry to permit work on a structure by separating the work from the water.

corridor—A linear strip of land identified for the present or future location of transportation or utility rights of way within its boundaries; or, in ecological terms, a large-scale pathway that animals use to travel from one suitable habitat to another.

cross drain—A ditch relief culvert or other structure or shaping of the traveled way designed to capture and remove surface water from the road.

culvert—A conduit or passageway under a road or other obstruction for the passage of water, debris, sediment, and fish that is backfilled with embankment material.

D

deposition—The mechanical or chemical process through which sediments accumulate in a resting place.

E

ecoregion—A large area of land or water that contains a geographically distinct assemblage of natural communities that (a) share a large majority of their species and ecological dynamics, (b) share similar environmental conditions, and (c) interact ecologically in ways that are critical for their long-term existence.

ecosystem—The total community of living species and its interrelated physical and chemical environment.

embankment—A ridge constructed of earth, fill rocks, or gravel. The length of an embankment exceeds its width and its height. Embankments retain water or carry a roadway.

ephemeral channel—A river or stream channel that flows seasonally and/or in direct response to runoff events.

erosion—The wearing away of the land surface by detachment and movement of soil and rock fragments by water, wind, and other geological agents.

exotic—Plants, animals, or materials nonnative to the site.

F

flood plain—(a) To ecologists, areas that are periodically inundated (usually annually) by the lateral overflow of rivers or lakes or by direct precipitation or ground water, resulting in a physciochemical environment that causes the biota to respond by morphological, anatomical, physiological, phonological, and/or ethological adaptations and to produce characteristic community structures. (b) The flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge.

fluvial geomorphology—The study of landforms and processes associated with rivers.

G

gabion—A woven galvanized wire basket sometimes lined with geotextile and filled with rock that is stacked or placed to form erosion-resistant structures.

geomorphology—The study of the Earth's landscapes and landforms, the processes by which the landforms originated, their age, and the nature of the materials underlying them.

geotechnical—The application of civil engineering technology to some aspect of the Earth.

geotextile—Synthetic fibers forming a woven, nonwoven, or spun-bonded fabric used to separate soil from engineered materials and add strength to a facility.

grade dip—A roll or undulation in a road's vertical alignment that facilitates surface drainage.

H

habitat—Conditions essential for fish or wildlife, including sufficient water, food, space, and conditions to meet reproductive needs.

habitat connectivity—Larger areas of suitable fish or wildlife habitat that are connected by smaller areas of suitable habitat.

headcutting—The erosional process moving upstream from the location of initial downcutting.

heeling—The temporary, severely angular planting of trees and shrubs, often in trenches, to facilitate their removal before permanent transplanting.

hydrologic connectivity—The extension of a drainage network through connected flow paths (such as road and surface runoff becoming directly connected to the runoff channels).

hydromulching—Hydromulching is used to reach steep, inaccessible slopes. It is a composition of wood cellulose, paper pulp, and recycled newsprint/or cardboard fiber suitable for a one-step application in which seed, fertilizer, soil amendments, and mulch are placed in a single pass of a hydraulic mulcher, sometimes with the addition of a tackifier or synthetic fibers to the hydraulic slurry to improve the cohesiveness of the fibers and their adhesion to the ground surface.

I•J•K

inlet/outlet control—Culvert flow in which the cross-sectional area of the barrel, inlet configuration, and amount of headwater or ponding are of controlling importance to the hydraulics of flow.

L

live fascines—The elongated bundles of stems and branches from rootable plant material (for example, willow and dogwood) that are tied together and placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow-mass wasting.

M

morphology—A complex process by which river and stream channels form as a function of the interactions among hydrology, lithology, vegetation, and land uses.

N•O

native—Plants, animals, and materials indigenous to a site.

P•Q

passage (fish or wildlife)—A structure to enable fish or wildlife to cross safely from one side of the road to the other.

perennial stream—A watercourse that runs all year as opposed to an intermittent stream that has dry periods.

pier—(a) A short column designed to support a concentrated load. (b) An isolated foundation member of plain or reinforced concrete.

R

road management objective—A road management objective establishes the intended purpose of an individual road based on management area direction and access management objectives. Road management objectives contain design criteria, operation criteria, and maintenance criteria.

road template—The shape and cross-sectional dimensions of the roadway to be constructed, as defined by the construction staking notes and the characteristics of the typical sections.

roads analysis—A process to assess the extent and current condition of the road system on a national forest or group of national forests in the context of other public and private road systems and land ownership patterns. Comparing this current condition to a desired condition will identify the need for change. Roads analysis will provide the information to develop the agency's strategic intent for road management; that is, what will happen to balance the need for public access with the need to minimize risks.

riparian area—An area containing moist soils and hydric vegetation along and interacting with a stream composed of two ecosystems, riparian and aquatic.

riparian ecosystem—Terrestrial ecosystems characterized by hydric soils and plant species dependent on the water table and/or its capillary fringe.

S

sediment loading—(a) The total sediment in a stream system, whether in suspension (suspended load) or on the channel bottom (bedload). (b) The addition of sediment to water flowing in streams and rivers from adjoining soil surface areas and roads.

sedimentation—The detachment, transport, and deposition of sediment particles in streams and other water bodies.

shotcrete—Mortar or concrete pneumatically projected at high velocity onto a surface.

soil permeability—The ease of movement of liquid or gas through a soil mass.

spawning bed—A habitat used by fish for producing or depositing eggs.

stop-log structure—A partially submerged log that spans a portion of a channel or an entire channel to pool water and retain bedload on the upstream side of the structure to prevent channel bank scour on the downstream side; in many cases, for the most effective treatments, required as a series of these structures above or below a road- and channel-crossing site.

stream integrity—The state of a stream system when it is able to process the range of water, sediment, and organic debris supplied while maintaining a balanced relationship among channel width, velocity, depth, and the flood plain within a normal dynamic range for the local geology, soils, vegetation, and climate.

subgrade—(a) The layers of roadbed that bring the bed to the top surface and upon which the subbase, base, or surface course is constructed. (b) For roads without a base or surface course, that portion of roadbed prepared as the finished wearing surface.

surface course—The top layer of pavement structure, sometimes called the wearing course, usually designed to resist skidding, traffic abrasion, and the disintegrating effects of climate.

surface drainage—The concentration and surface waterflow on roads, related surfaces, and ditches.

suspended load—Fine materials eroded from locations higher in the watershed and transported buoyantly, with the bedload, to make up the total sediment discharge.

T•U

tackifier—A binder for vegetative mulch.

tailwater—The area immediately downstream of a drainage structure.

V

vented ford—A crossing where the road grade is above the stream channel bottom through which all the water passes during periods of low flow, with most flow overtopping the structure during floods.

W•X•Y•Z

waterbar—A ditch-and-berm combination installed perpendicular or skewed to the road center line to facilitate drainage of surface water; sometimes nondrivable and used to close the road.

weir—A small dam for impounding water, sometimes with a notch to control flow.

wetland—The transitional lands between aquatic and terrestrial systems where the water table is at or near the surface of the land. This area is covered by shallow water. To be classified as a wetland, an area must have one or more of the following three attributes: (a) The land supports plants that are adapted to wet soil conditions and are known as hydrophytes, (b) the base land is predominantly undrained hydric soil, or (c) the base is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of every year.

windrow—A ridge of loose soil that is produced by the spill from a grader blade.

Chapter 7
Literature Cited and Additional Reading

LITERATURE CITED

This literature will help you plan, implement, and monitor roads projects. Additional information and links to road-related sites on the Internet are listed on the Roads Riparian Restoration Web site at http://fsweb.sdtdc.wo.fs.fed.us/programs/eng/RRR/

Bassel, J. Wildlife Crossings Toolkit Web site: http://www.wildlifecrossings.info. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

Cairns, J., Jr. 1988. Increasing diversity by restoring damaged ecosystems. E.O. Wilson, ed. Biodiversity. Washington, DC: National Academy Press.

Clarkin, K. [and others] [In preparation] Aquatic organism passage at road-stream crossings. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

Code of Federal Regulations, Title 36. Parks, Forests, and Public Property. Chapter II Forest Service, Department of Agriculture. Part 212 Administration of the forest transportation system. http://www.access.gpo.gov/nara/cfr/cfr-table-search.html#page1

Copstead, R. 1997. Summary of historical and legal context for water/road interaction. Tech. Rep. 9777 1815—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 18 p.

Gray, D.H.; Sotir, R.B. 1996. Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. New York: John Wiley and Sons, Inc. 400 p.

Gucinski, H.; Furniss, M. J.; Ziemer, R.R.; [and others], eds. 2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNW- GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.120 p.

Kershner, J.L. 1997. Monitoring and adaptive management. In: Watershed Restoration: Principles and Practices. Williams, J.E.; Wood, C.A.; Dombeck, M.P., eds. Bethesda, MD: American Fisheries Society.

MacDonald, L.H.; Smart, A.W.; Wismarr, R.C. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. Tech. Rep. EPA 910/9-91-001. Seattle, WA: U.S. Environmental Protection Agency, Region 10.

San Dimas Technology and Development Center. 2000. Water/road interaction technology series. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

U.S. Department of Transportation, Federal Highway Administration. 1983. Hydraulic design of energy dissipators for culverts and channels. Hydraulic Engineering Circular No. 14. Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

U.S. Department of Agriculture, Forest Service. 2000. Management for national forest system lands in California, Best Management Practices. Vallejo, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region.

ADDITIONAL READING

Abbe, T.B.; Montgomery, D.R. 1996. Channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management. 12: 201–222.

Blinn, C.R., et al. 2000. Temporary stream and wetland crossing options for forest management. Gen. Tech. Rep. NCRS-GTR-202. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 125 p.

Bolander, P.; Yamada, A. 1999. Dust palliative selection and application guide. Tech. Rep. 9977 1207—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 23 p.

Brown, E.R., ed. 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. Tech. Rep. R6-F&WL-192. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 634 p.

Committee on Restoration of Aquatic Ecosystems. 1992. Restoration of aquatic ecosystems: science, technology, and public policy. Washington, DC: National Academy Press. 576 p.

Federal Interagency Stream Restoration Working Group. 1998. Stream corridor restoration: principles, processes, and practices. GPO-0120-A. Washington, DC: An Interagency Partnership.

Furniss, M.; Ledwith, T.; Love, M.; McFadin, B.; Flanagan, S. 1998. Response of road-stream crossings to large flood events in Washington, Oregon, and Northern California. Tech. Rep. 9877 1807—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 18 p.

Hall, D.E.; Long, M.T.; Remboldt, M.D., eds. 1994. Slope stability reference guide for national forests in the United States. Vol. I, II, and III. Eng. Man. EM-7170-13. Washington, DC: U.S. Department of Agriculture, Forest Service.

Jones, J.A.; Swanson, F.J.; Wemple, B.C. [and others]. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology. 14 (1): 76–85.

Lewis, L. 2000. Soil bioengineering: an alternative to roadside management. Tech. Rep. 0077 1801—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 47 p.

Meehan, W.R., ed. 1991. Influences of forest and rangeland management. Special Publication 19. Bethesda, MD: American Fishery Society. 622 p.

Moll, J. 1996. A guide to road closure and obliteration in the Forest Service. Tech. Rep. 9677 1205—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 52 p.

San Dimas Technology and Development Center. 2000. FishXing, software and interactive learning for fish passage through culverts. In: Water/road interaction toolkit–CD. Tech. Rep. 0077 1402–SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program.

Smit, K., ed. 1985. Means illustrated construction dictionary. 1st ed. Kingston, MA: Robert S. Means Company. 500 p.

Trombulak, S.C.; Frissell, C.A. 2000. Review of the ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14 (1): 18–30.

Turner, A.K.; Schuster, R.L., eds. 1996. Landslides—investigations and mitigation. Transportation Research Board Special Report 247. Washington, DC: National Academy of Sciences. 36–75.

U.S. Department of Agriculture, Forest Service. 1996. Forest Service specifications for construction of roads and bridges. EM-7720-100. Washington, DC: U.S. Department of Agriculture, Forest Service. 615 p.

U.S. Department of Agriculture, Forest Service. 1999. Roads analysis—informing decisions about managing the national forest transportation system. FS-643. Washington, DC: U.S. Department of Agriculture, Forest Service. 222 p.

Verry, E.S.; Hornbeck, J.H.; Dolloff, C.A. 2000. Riparian management in forests of the continental eastern United States. Boca Raton, FL: Lewis Publishers, CRC Press.

William, R.D.; Ball, D.; Miller, T.L.; [and others], compilers. 2002. Pacific Northwest weed management handbook. Corvallis, OR: Oregon State University. 432 p.

Williams, J.E.; Wood, C.A.; Dombeck, M.P., eds. 1997. Watershed restoration: principles and practices. Bethesda, MD: American Fisheries Society. 549 p.

Winward, A.H. 2000. Monitoring the vegetation resources in riparian areas. RMRS-GTR 47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Yamanouchi, T. 1986. The use of natural and synthetic geotextile in Japan. IEM-JSSMFE Joint Symposium on Geotechnical Problems, 27–28 March, Kuala Lumpur, Malaysia. 82–89.

Zeedyk, W.D. 1996. Managing roads for the wet meadow ecosystem recovery. Tech. Rep. FHWA-FLP-96-016. Washington, DC: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, and U.S. Department of Transportation, Federal Highway Administration.

For additional information on this Riparian Restoration project, contact Greg Napper at SDTDC. Phone: (909) 599-1267, ext. 290
E-mail: gnapper@fs.fed.us

Recommended Web Sites

On the USDA Forest Service Intranet:
Access and travel management:
http://fsweb.wo.fs.fed.us/eng/access_and_travel_mgt/.

Roads analysis:
http://fsweb.wo.fs.fed.us/eng/roads_analysis/.

Forest Service and U.S. Department of the Interior, Bureau of Land Management employees can also view videos, CDs, and SDTDC's individual project pages on their internal computer network at:
http://fsweb.sdtdc.wo.fs.fed.us/

On the Internet:
Overview of road management in the USDA Forest Service:
http://www.fs.fed.us/eng/road_mgt/overview.shtml.

SDTDC's National publications: http://www.fs.fed.us/eng/pubs/