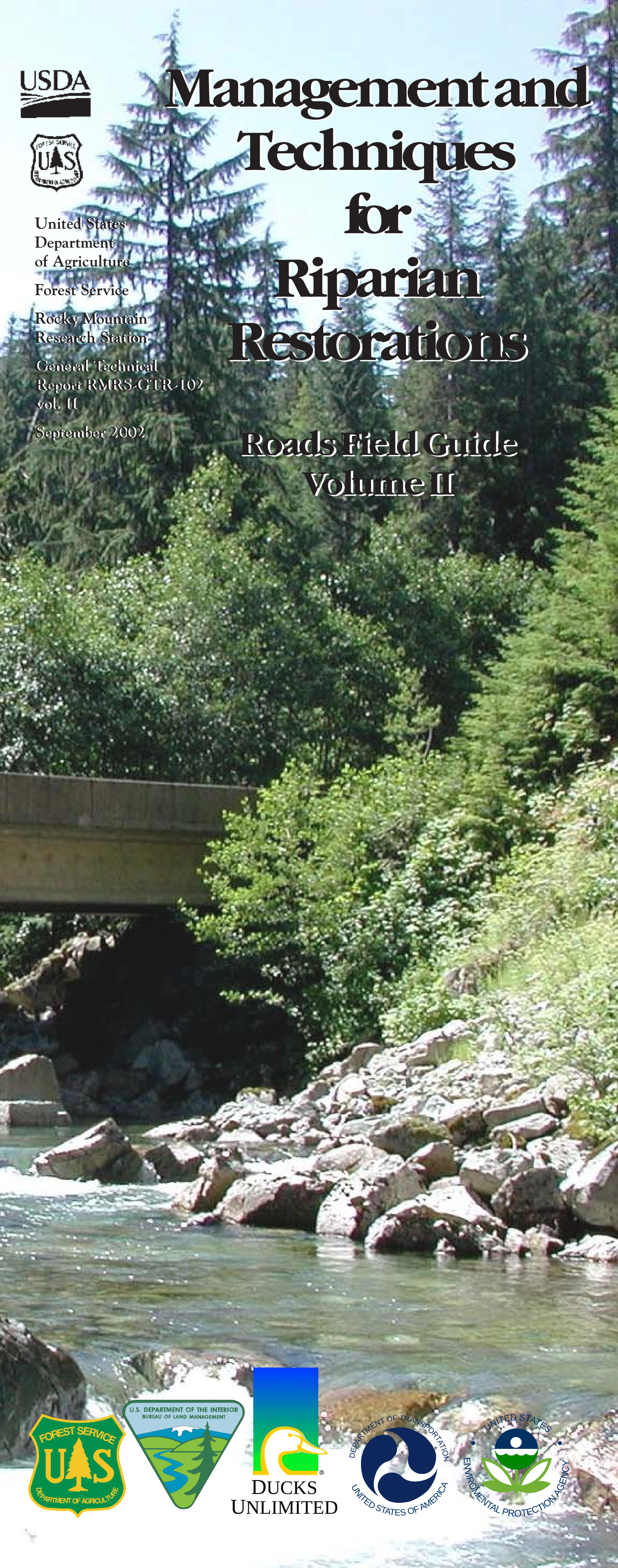


USDA

United States
Department
of Agriculture

Forest Service

Rocky Mountain
Research Station

General Technical
Report RMRS-GTR-102
vol. II

September 2002

Management and Techniques for Riparian Restorations

Roads Field Guide
Volume II

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

DUCKS UNLIMITED

DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY

The information in this publication has been assembled by the Members of the Roads/Riparian Restoration Team:

Steve Adair	*Phd., Director of Conservation Programs, Great Plains Regional Office, Ducks Unlimited*
Mary Lee Dereske	*P.E. Regional Water/Wastewater Engineer, Southwestern Region, Forest Service*
James Doyle	*Fish Biologist, Mt. Baker Snoqualmine National Forest*
Anthony Edwards	*Civil Engineer, Team Leader, San Dimas Technology & Development Center, Forest Service*
Sandra Jacobson	*Wildlife Biologist, Pacific Southwest Research Station, Forest Service*
Roy Jemison	*Phd., Research Hydrologist, Rocky Mountain Research Station, Forest Service*
Lisa Lewis	*National Riparian Service Team, Soil Scientist, Washington Office, Forest Service*
Wendy Melgin	*Deputy Branch Chief/Hydrologist, Environmental Protection Agency, Region 5*
Carolyn Napper	*Soil Scientist, Lassen National Forest*
Tom Ratcliff	*Wildlife Biologist, Modoc Natioinal Forest*
Terry Warhol	*P.E., Assistant Forest Engineer, Umatilla National Forest*

List of authors is in alphabetical order.

COOPERATIVE riparian RESTORATION

SDTDC

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and series number.

Fort Collins Service Center

Telephone	(970) 498-1392
FAX	(970) 498-1396
E-mail	rschneider@fs.fed.us
Web site	http://www.fs.fed.us/rm
Mailing Address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526

Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

Management and Techniques for Riparian Restoration
Roads Field Guide
Volume II

Table of Contents

15. Retaining Walls

16. Slope Rounding and Revegetation

17. Revegetation

18. Soil Bioengineering

19. Invasive Species

20. Biotechnical Stabilization

21. Landslide Mitigation Strategies

22. Ditch Treatments

23. Roadway Dips

24. Low Water Crossings and Fords

25. Permeable Fill with Culvert Array

26. Culverts

27. Raised Culvert Inlets

28. Energy Dissipaters and Debris Racks

29. Bridges

30. Surfacing Techniques

31. Mobile Rock Crushing/Rotor Trimmer

32. Stream Channel Modification Structures

33. Reconnecting Cutoff Water Bodies

34. Log Jam Complexes

35. Fish Passage

36. Wildlife Crossings

37. Beaver Pond Structures

38. Wetland Maintenance

15

Retaining Walls

Description: Retaining walls stabilize slopes where erosion and safety is a concern. There are four basic retaining wall classifications: mechanically stabilized backfill, driven cantilever pile, tie-back and gravity.

Application: Retaining walls are primarily used to stabilize inherently weak sections of ground, to minimize damage from surrounding erosive forces, or at any location where a vertical slope is needed. Construction and function vary by ecoregion. Unstable slopes, or slopes eroding continuously into roads, ditches, and streams may benefit from retaining walls. Large fractures forming along a slope may indicate a potential future slump or slide that needs reinforcement. Retaining walls can be used on both cut and fill slopes, and can physically separate roads from channels.

Considerations: Along streams, retaining walls may straighten the stream segment, increase water velocity, eliminate vegetation and decrease shading. This may harm aquatic life, make access to the stream difficult for wildlife, and increase bank erosion, sedimentation and water temperature. Designers must weigh the benefits of controlling sediment production, preserving slopes, and stabilizing roads against other impacts retaining walls may have on a stream.

Retaining walls require geotechnical investigations prior to design. Ground water infiltration behind a retaining wall can cause failure if wall drainage is not provided. Construction methods must be true to the design. Aesthetics play an important part in roadway design. Working with landscape architects assures a pleasing and appropriate design.

Soil nail walls allow for vertical, or near vertical slopes without footings (see below). This minimizes exposure to erosion and reduces the area of environment impacted. The shot-crete facing provides a natural rock appearance and texture, and provides habitat for cliff dwelling wildlife. Construction costs and methods depend on the retaining wall.

Potential Outcome/Benefits: Retaining walls stabilize slopes, reduce erosion, and if faced with shot-crete, provide a natural rugged look. Eliminated output of soil and debris to ditchline and road reduces maintenance needs and subsequent costs.

Alternate and Complementary Techniques: *Road relocation (11)* may be more cost effective than constructing retaining walls. *Soil bioengineering (18)* can be used alone, or together with some types of retaining wall construction. Vegetative plantings in front of a retaining wall can soften the visual harshness of the structure.

Slope Rounding and Revegetation

Description: Slope rounding and revegetation lays back hillslopes to a natural angle of repose to reduce runoff and sediment transport, and to promote vegetation re-establishment. Seeding or planting often follows slope shaping. If additional erosion mitigation work is required, *soil bioengineering (18)* techniques may be effective.

Application: Use slope rounding and revegetation where there is potential for the site to erode, slump or fail, and cause damage and/or create hazardous conditions to roadways, water bodies, structures and property. This technique works on slopes disturbed by natural events such as fire and landslides, or human-disturbed slopes such as road cuts and fills, borrow areas, waste areas, or timber harvest areas. Size and severity of disturbance, and slope steepness, dictates the level of slope rounding and revegetation required. Project sequence usually requires reshaping hillsides with heavy equipment, spreading grass seed and protective mulch, then implementing soil bioengineering and *biotechnical stabilization (20)* projects.

Considerations: Native plant species should be used when replanting to avoid introducing exotic *invasive species (19)* that could adversely affect other ecosystem components. Using plant species attractive to wildlife may increase the risk of disturbance or mortality by attracting them to the road. Treatments implemented immediately after disturbances reduce negative effects from unstable slope conditions.

Monitor recently completed projects to check plant survival. In areas where excessive runoff and erosion could be a problem, visit sites during and immediately following runoff events. Annual checking and documentation of newly treated sites is recommended. Harsh growing sites may require multiple plantings or temporary irrigation.

Potential Outcome/Benefits: Stabilized slopes have minimal onsite and offsite sediment movement, are aesthetically pleasing, and provide better conditions for vegetation re-establishment.

Alternate and Complementary Techniques: Hydro-mulching, mulching, *temporary erosion control (12), retaining walls (15)*, terracing, and any *soil bioengineering (18)* practices are alternate and complementary techniques to slope stabilization.

In this picture, the Forest Service required the contractor to seed the exposed cut slope immediately after excavation (on the lower right) to reduce the potential of sediment transport from the site (Tonto National Forest, AZ).

Revegetation

Description: Roads are often constructed adjacent to streams and floodplains, resulting in excessive degradation and removal of riparian vegetation. Riparian and wetland vegetation is critical to regulating stream microclimate, providing food and cover for wild-
17 life, and controlling erosion and surface runoff. Removal of vegetation for road construction and associated land management activities creates a need for effective riparian-wetland vegetation restoration. Depending on the source of impacts, numerous techniques can be used to re-establish vegetation or allow stressed vegetation to recover.

Application: Replanting of riparian areas has been successful nationwide, especially along major stream and river corridors. If hydrology is to be restored, it may be delayed 2–3 years to allow seedlings to become well established.

Indicators of appropriate use include: (1) lack of understory vegetation; (2) elevated browse height on trees and shrubs; (3) fragmented forest and riparian corridors; (4) sediment loading and turbidity in adjacent streams; (5) elevated stream temperatures; (6) erosion and soil compaction; (7) the need to enhance effectiveness of wildlife crossing structures.

Considerations: Techniques to reduce compaction and erosion may need to be applied to accelerate vegetation recovery. Replanting riparian forest considerations are: soil permeability, hydrologic alterations, wind-borne seed sources, adjacent forest blocks, current recreational use, and wildlife and fish species present. Restoration will be most effective if the replanted site is reconnected to the adjacent stream or river channel. If the replanted site is connected to other forest blocks, wildlife requiring large forest blocks will benefit. Additional considerations are the presence of sensitive species or current recreational use of the area.

Potential Outcome/Benefits: Improved riparian vegetation, increased wildlife and fisheries habitat, improved water quality, decreased erosion, decreased fragmentation, larger habitat blocks for area-sensitive wildlife species if the replanted site is connected to other forest blocks.

Alternative and Complementary Techniques: *Controlled public access (10), soil bioengineering (18), temporary erosion control (12), road relocation/realignment (11)* and allowing for natural revegetation.

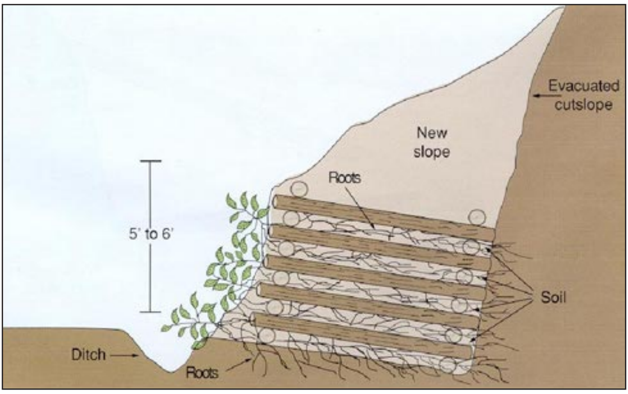
Soil Bioengineering

Description: *Biotechnical stabilization (20)* and soil bioengineering stabilization both use live vegetation as important structural as well as aesthetic components (Gray and Sotir, 1996). Soil bioengineering is a specialized subset of *biotechnical stabilization (20)* that uses live plant parts (roots and stems) as 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 stability so that native vegetation and surrounding plants can gain a foothold to eventually take over this role. Successful implementation of soil bioengineering stabilization requires knowledge of the factors governing the mass and surficial reinforcements and drains, and the hydraulic and mechanical effects of slope vegetation.

Application:

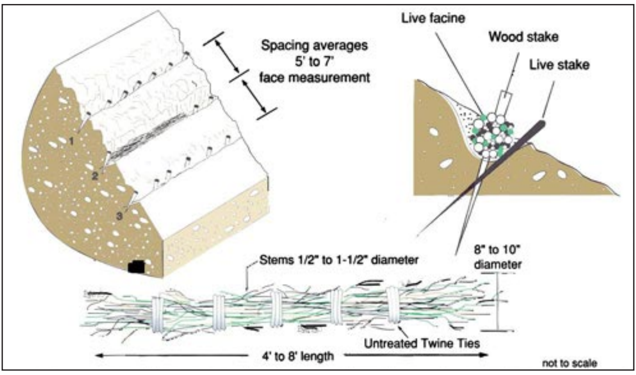
Live staking is branch cuttings inserted into the ground to stabilize shallow earthen slips and slumps.

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.

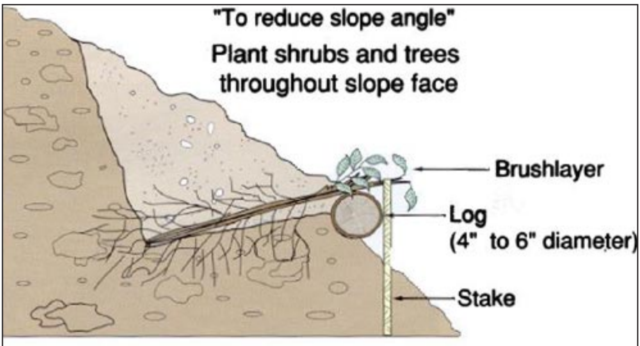


Live cribwall construction.

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 can stabilize 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, and leafed-out cuttings provide a natural look.



Brushlayer with log terrace

Branchpacking is used to repair 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 in small gullies can be accomplished by alternating layers of live branch cuttings and compacted soil. This technique immediately reinforces soil, reduces runoff velocities, and provides erosion barriers.

Log terracing uses earthen terraces reinforced with logs to reduce slope length and steepness. Terraces provide stable areas for plantings that further stabilize the sites.

Considerations: Soil bioengineering is an effective solution that may need to be 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 shallow rapid landslides, reduce excess surface/subsurface drainage, and strengthen soils.

Alternate and Complementary Techniques: *Retaining walls (15), gabions, road relocation /realignment (11), temporary erosion control (12), landslide mitigation strategies (21), biotechnical stablization (20)* and *outsloping (13)*.

Gray, D.H. and R.B. Sotir. 1996. Biotechnical and Soil Stabilization. John Wiley and Sons. Inc. New York, NY. p. 378.

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

Invasive Species

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 facilitate infestation. Brown-headed cowbirds follow roads up 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.

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

Prevention: Power wash equipment before entering worksites; inspect and pre-treat infested access roads, gravel and borrow sources for weeds prior to use; limit active road construction sites to necessary vehicles. Limit grain-feeding livestock near riparian areas to reduce spread of brown-headed cowbirds.

Identification: Consult with local extension office, county weed superintendent, or forest weed specialist on weeds currently at worksites; know potential invaders from adjacent areas; watch for all life stages.

Prioritization: Differentiate invasive weed species from more common non-invasives. Attack small or outlying populations, or new invaders first. Develop threshold strategies: competitive species (control), moderately competitive (suppress or contain), non-competitive (defer).

Treatment: Fill in bare ground with fast growing native cover species, weed-free mulch, geotextiles or crushed rock. Over-seed 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 effectiveness of integrated pest management programs. Map existing and expanding populations or new invasions. Modify treatment to increase control.

Considerations: Pre-treating access roads and borrow sources will not deplete existing noxious weed seed banks. Identification of noxious species can be a problem because early growth stages and some native non-invasive species look similar. During treatment program development, consider erosion potential, high water tables or surface water, sensitive plants, recreation areas, cost, equipment or skill needs, application timing. Factor cost and timing into monitoring effectiveness.

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

Alternate and Complementary Techniques: *Biotechnical stabilization (20), soil bioengineering (18), slope revegetation (16)*. See the annual *Weed Management Handbook* (Extension Services, Oregon State University) for more details.

William, R.D., D. Ball, T.L. Miller (OSU), R. Parker, J.P. Yenish, T.W. Miller (WSU), D.W. Morishita, P.S. Hutchinson (UI), compliers. 2002 Pacific Northwest Weed Management Handbook. Oregon State University. p. 432.

Biotechnical Stabilization

Description: *Biotechnical stabilization (20)* and *soil bioengineering (18)* both use live vegetation as important structural as well as aesthetic components. Biotechnical stabilization uses mechanical elements in combination with plants to arrest and prevent slope failures and erosion, and biological and mechanical elements are integrated and complementary. 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 from natural materials such as jute and coir (Yamanouchi 1986).

Application: Engineers usually use inert systems for slope stabilization and erosion control. Reasons for widespread use include availability, ease of installation, familiarity, existence of standards, and acceptance by specifiers. Inert materials are presumed to have predictable and invariant properties, but even inert materials slowly degrade, decompose, and decay with time (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:

- Rock breast walls
- Gravity walls (gabions, crib, and bin walls)
- Articulated block walls
- Reinforced earth structures (stacked and backfilled three-dimensional webs)

Revetment Systems:

- Riprap (quarry stone, rubble, natural rock)
- Gabion mattresses
- Concrete facings (gunnite and concrete filled mattresses)
- Cellular confinement systems (three-dimensional webs that cover the surface and are backfilled with aggregate above)
- Articulated block systems (concrete blocks linked by cables or other methods)

Ground Covers:

- Artificial mulches (fiberglass roving and cellulose fibers)
- Blankets, mats, and nettings (slope coverings that protect the surface and promote/enhance the growth of vegetation)
- Cellular confinement systems (three-dimensional honeycomb webs that cover the surface and are backfilled with soil or aggregate)

Considerations: Many inert systems or products lend themselves to integrated or combined use 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.

Alternate and Complementary Techniques: *Soil bioengineering (18), retaining walls (15), slope rounding and revegetation (16), temporary erosion control (12).*

Landslide Mitigation Strategies

Description: Road-associated landslides are cut slope failures and fill slope failures caused by the road and/or natural landslides. Landslide mitigation strategies include avoidance, stabilization, control, prevention, and acceptance of recurring road maintenance. Several of the multiple mitigation techniques are:

- Surface drainage
  - ☐ Ditches to prevent surface flows from entering the slide
  - ☐ Grading of slide to drain the surface and prevent ponding
- Subsurface drainage
  - ☐ Underdrains and trenches
  - ☐ Horizontal drains
- Increased resisting forces
  - ☐ Rock buttresses
  - ☐ *Retaining walls (15)*
  - ☐ Reinforced earth
  - ☐ *Revegetation (17)* and *soil bioengineering (18)*
- Reduced driving forces
  - ☐ Removal of top (head) of slide mass
  - ☐ Backfilling a portion of slide mass with lightweight fill.

Application: Roads with cut slope failures and fill slope failures. Guidance for applying landslide mitigation strategies and techniques is available at *http://www.fs.fed.us/rm/RRR* and in the following:

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. Engineering Staff, FS, USDA, EM-7170-13.

Turner, A.K. and Schuster, R.L., eds, 1996. Landslide Investigation and Mitigation. Special Report 247, Transportation Research Board, National Research Council.

Considerations: Safety of employees, contractors and visitors is an important consideration because landslides are geologic hazards that can injure or kill people. Slide removal can trigger landslides. For safety, a geologic inspection of the slide and the slope above the slide must be done for landslide hazards prior to slide removal. A safe and rational design for landslide mitigation considers engineering geologic investigations (stability of cut and fill slopes), groundwater conditions, and adverse geologic structures.

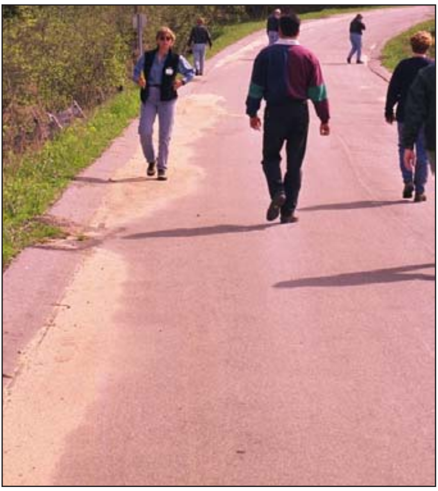
Potential Outcome/Benefits: Stabilization, reduction or prevention of cut and fill slope failures; improved safety.

Alternate and Complementary Techniques: *Retaining walls (15), soil bioengineering (18).*

Ditch Treatments

Description: Ditch treatments are man-made features that channel water away from the road. Variations of ditch treatments include vegetated, rock-lined, and lead-out ditches, and raised curbs and berms.

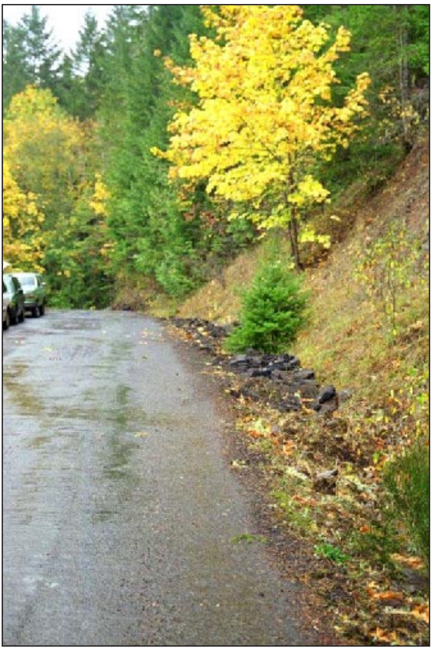
Application: Raised curbs, or berms (below), prevent water from entering or exiting the roadway. Numerous lead-out ditches are typically installed to remove water impounded by the curbs, then released where water would cause minimal resource damage. A scoured, entrenched roadside ditch and gullying on the down-slope side indicate that a ditch treatment may be necessary.



Vegetated ditches (below) use vegetation in ditches to reduce water velocities. Erosion control grass mixtures are typically used to vegetate ditches.

Rock-lined ditches reduce velocities and capture sediment.

Lead out-ditches carry water away from the roadway onto the forest floor, allowing infiltration and water dispersal.



Considerations: If channelized flow creates significant erosion, *energy dissipaters (28)* may be needed. Vegetation or rock-lined ditches reduce ditch flow capacity, so remaining ditch capacity must be enough to protect the road during moderate storms. Native material curbs or berms can be developed using a grader. Vegetating berms enhances durability. The softest approach to developing vegetated ditches is to avoid heeling or pulling the ditch with a grader except when necessary. Ditch gradient between 2 and 8 percent slopes usually perform well. Slopes greater than 8 percent create high runoff velocities and more erosive force, requiring more ditch relief. Slopes of less than 2 percent drain water too slowly, causing saturation.

Potential Outcome/Benefits: Ditch treatments can have immediate and long-term benefits to roadside areas. Management of runoff will lead to less erosion, better habitat, reduced sediment transport, and lower long-term maintenance.

Alternate and Complementary Techniques: *Outsloping (13),* insloping, *mobile rock crushing (31).*

Roadway Dips

Description: Roadway dips modify roadway drainage by altering the road template and allowing surface flows to frequently disperse across the road.

Application: Roadway dips have applications nationwide, even on steep grades. They disperse surface water flows and reduce erosion in areas where sediment loading to a water body is a concern. Roadway dips may replace or supplement culverts for cross drainage, especially where existing culverts fail often or require high maintenance.

Roadway dips may help solve erosion, ditch sloughing, culvert failures, cascading effects from overtopping culverts, high maintenance costs, and hydrologic disconnectivity.

Considerations: Roadway dip design and construction vary by road management objectives. Consider traffic limitations and install the proper length of dip to ensure that the design vehicle can be accommodated (logging truck, chip van, horse trailers, cattle trucks). See design manuals for dip spacing and depth. Depending on traffic volume and kind, warning signs may be needed to alert drivers to road changes. Dips may be used up to 10–15% road slope. Steeper slopes require longer dips. In some cases riprap and/or asphalt can be used to harden the dip and disperse water for wet weather conditions or year round roads. Roadway dip spacing is critical. Placement may be at ditch relief culverts or change in grade. This technique reduces maintenance, and it is important for grader operators to understand the need for the dip so they do not blade out the structure. Where *fish passage (35)* is a concern, dips alone are not an appropriate treatment.

Potential Outcome/Benefits

Roadway dips reduce maintenance costs, sediment transport, the need for culverts, and the risk of catastrophic road or slope failure. They can lower traffic speeds to facilitate *wildlife crossings (36)*.

Alternate and Complementary Techniques: Road drainage techniques such as *outsloping (13),* insloping, *ditch treatments (22), low water crossings and fords (24), culverts (26),* and crossdrain or waterbars. *Energy dissipaters (28)* are often placed on downstream end of dips.

Low Water Crossings and Fords

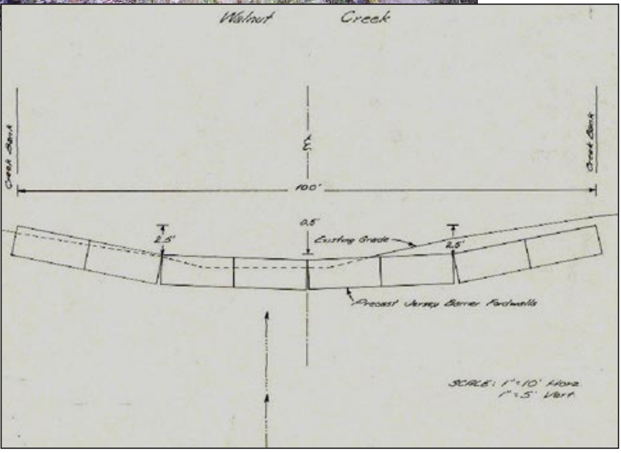
Description: Low water crossings pass water and transport debris over a road continuously or intermittently. Types of low water crossings include vented fords (*top photo*), un-vented fords (*botom photo*), and low water bridges. These structures can range from simple, stream-grade elevation, native-surfaced crossings to larger more massive structures.

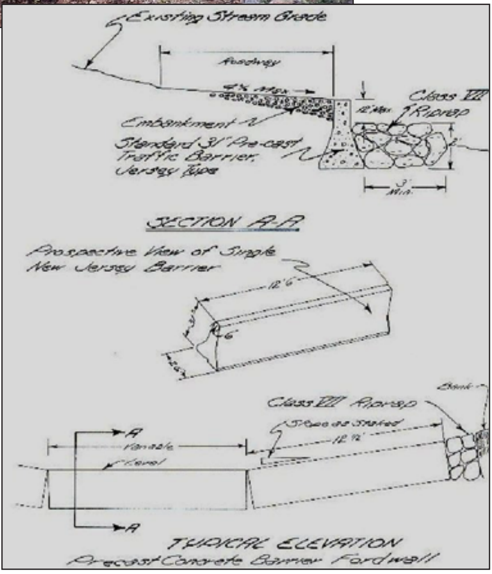
Application: Low water crossings may be used on lower standard roads where continuous access is not required. They are ideal for channel systems that transport debris and bed load during high water events and for roads that will not receive periodic maintenance. Low water crossings require special designs to pass fish and aquatic organisms.

Considerations: Low water crossings construction materials include riprap, concrete, asphalt, Jersey barriers, and native materials. Geosynthetics may be used to provide separation of materials, subgrade support and restraint.

Potential Outcome/Benefits: Benefits include lower construction costs, reduced maintenance and potential for catastrophic road failure. Ponding water increases infiltration. Decreased fill heights result in fewer cleared acres and maintained riparian vegetation diversity. A low water crossing over a culvert disperses flow, reduces water velocity and channel bank erosion. The potential consequences of catastrophic road failure are less due to reduced fill amounts, lower water velocity, and more erosion-resistant construction materials.

Alternate and Complementary Techniques: *Outsloping (13)*, insloping, *ditch treatments (22), culverts (26), bridges (29)*.


Walnut Creek
Creek Bank
Creek Bank
100'
0.5'
2.5'
2.5'
Existing Grade
Precast Jersey Barrier Fordwalls
SCALE: 1" = 10' Horz.
1" = 5' Vert.


Existing Stream Grade
Roadway
4% Max.
Embankment
Standard 31" Pre-cast
Traffic Barrier,
Jersey Type
Class VII
Riprap
12" Max.
3'
Min.
SECTION A-A
Prospective View of Single
New Jersey Barrier
12'6"
6"
Class VII Riprap
Bank
Slope as Stated
12'½'
Variable
Level
A
A
TYPICAL ELEVATION
Precast Concrete Barrier Fordwall

Permeable Fill with Culvert Array

Description: Permeable fills are generally used to cross meadows and promote the passage of sheet and subsurface flows with minimum flow concentration and maximum spreading. The road base and/or subbase is constructed of relatively large, preferably angular, uniformly graded rock to allow uninterrupted ground and surface water flow. Culverts within the permeable fill and above the drainage grade allow ponding of the water and percolation through the fill.

Application: Roads crossing wet meadows act as barriers to subsurface and sheet flow, resulting in altered hydrology and a loss of meadow functions. This technique may be used on ephemeral channels or meadow systems to promote water passage and maintain and restore wet meadow systems, or in high meadow areas that do not experience significant flooding. This technique is not recommended in flash flood prone areas, or for fish bearing perennial streams unless passage is provided in the main channel. Permeable fill can be used in areas where the road restricts ground water flow, causing drier conditions in downslope areas.

Considerations: When a multiple culvert array is used, the culvert spacing should imitate the natural flood plain so flows are not restricted to a narrow section of the meadow. Design culverts to carry 100-year storm events. Install all culverts at the same elevation to avoid headcutting at the lower ones. Culverts may require outlet *energy dissipaters (28)*. Fill heights should be kept to a minimum to reduce consolidation pressures on underlying soils. To reduce costs,

keep culverts short and minimize fill volume. In areas with large woody debris or significant bedload, adding an overtopping structure or *ford (24)*, will provide passage of water and debris. Design culverts to allow unrestricted passage for all life stages of amphibians, fish or small wildlife.

Potential Outcome/Benefits: Permeable fills can maintain and/or restore natural wet meadow hydrology, and result in maintained or restored wildlife habitat, vegetation diversity and water storage.

Alternate and Complementary Techniques: *Road relocation/realignment (11), bridges (29),* and *culverts (26)*. *Fords, low water crossings (24),* and over-topping structures can be combined with permeable fills.

Install culverts with the invert elevation at a higher elevation than the meadow elevation in order to promote seepage and infiltration

Culverts

Description: Culverts are used for roadway drainage and channel crossings. Culverts are made of a variety of materials, including corrugated metal pipe (CMP), concrete, and plastic. They can be round, box, or arch shaped. End sections placed on culverts control and enhance the entrance and exit hydraulic conditions.

Application: Culverts provide cross-drainage to a roadway ditch system or an existing channel. *Multiple culverts (25)* can help disperse flows at meadow crossings. Bottomless culverts at channel crossings simulate stream conditions and encourage aquatic organism and *fish passage (35)*; they are typically arch culverts with no bottom section.

Considerations: A culvert creates a hydrologic connection between the road and the landscape. Ditches and culverts increase the drainage density (channel network) of a watershed.

Sizing and spacing culverts require hydrologic studies. Dialogue between designers and resource specialists can prevent resource damage from improper culvert design. Too small a culvert can result in overtopping and failure of a road; too steep a culvert can result in erosion; too few culverts can result in both road failure and erosion. 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 (2)*, increase erosion, or alter floodplain characteristics. If *beavers (37)* are present, additional measures may be necessary to maintain drainage capacity. Wildlife passage increases as culvert size increases, so the largest culvert affordable should be considered.

Outcome/Benefits: Culverts control the flow path of roadway drainage and channels and keep the water separate from the roadway. Bottomless culverts maintain stream integrity, and facilitate aquatic and wildlife passage.

Alternate and Complementary Techniques: At channel crossings, *bridges (29)* provide similar benefits as culverts. However, *bridges (29)* provide the best structural passage for wildlife. *Outsloped (13)* roads and *dips (23)* may reduce the need for culverts. *Low-water crossings (24)* can replace or be used with culverts.

Culverts are often used with *energy dissipaters (28)*, *raised inlets (27)*, and *ditch treatments (22)*. *Permeable fills (25)* used to control small surface flows often rely on culverts to handle storm events.

Raised Culvert Inlets

Description: Culvert inlet elevations are raised by constructing a dike around the culvert or by installing a culvert elbow *(see photos below).*

Application: Raised culvert inlets installed on ephemeral channels keep water on the land longer and promote infiltration. These techniques are applicable in all ecoregions. Inlets can be installed onto new or existing installations. Locate these on low gradient stream systems, in large or small floodplains. They can create and enhance wetlands in a watershed.

Indicators include vertical instability such as head cutting and eroding banks in straight stretches, loss of meander patterns, lowered groundwater tables, and a change or loss of upstream riparian and wet meadow vegetation.

Prefabricated elbows and bands are inexpensive and easy to install. A variety of materials, including rock, timbers, concrete drop inlets, or multiplate culverts, succeed as dikes.

Considerations: Some results of raised culvert inlets may be:

- Creation of a wetland environment
- Reduced passage of fish, aquatic organisms and small animals
- Restricted transport of debris and bedload
- A fixed water level

Potential Outcome/Benefits: Increased riparian vegetation vigor and diversity, reduced flood flashiness, sediment basin creation above the culvert, raised water table and increased infiltration and reduced headcutting.

Alternate and Complementary Techniques: *Culvert arrays (25)* disperse flows over a broader area. Stop-log structures allow greater flexibility in mimicking natural hydroperiods. *Stream modifications (32), permeable fills (25),* and *reconnecting water bodies (33)* are alternatives.

Energy Dissipaters and Debris Racks

Description: Energy dissipaters and aprons, used at culvert inlets and outlets, reduce water velocities and prevent erosion. Dissipaters include riprap, vegetated ditches, concrete or steel baffles, and tiger teeth. An apron of coarse rock installed on a cut or fill slope can prevent erosion and undercutting at culvert outlets, and at other drainage outlets as shown here. Debris racks at culvert inlets can prevent clogging.

Lead out ditch with energy dissipater (Michigan)

Application: Energy dissipaters and aprons can protect steep slopes and erosive soils by reducing water velocity, dispersing flows and preventing channeling or undercutting at the culvert outlet. Dissipaters and aprons function on single or *multiple culverts (arrays) (25)* during storm and normal flow events.

Culverts experiencing frequent debris clogging or plugging may benefit from debris (trash) racks. Debris racks at culvert inlets deflect large woody debris and bedload from the channel before it enters and clogs the culvert.

Considerations: If racks become clogged, flows will overtop the road and may cause catastrophic failure. Install debris racks only when regular maintenance is possible. When passage of debris and bedload is necessary, debris racks are a common culvert treatment, but may not be the best long-term solution.

Potential Outcome/Benefits: Energy dissipaters and aprons can reduce water velocity and potential erosion. Debris racks deflect debris and bedload preventing culvert clogging or plugging.

Alternate and Complementary Techniques: *Low water crossings (24)* with "critical" dips that act as a safety valve during runoff events can provide some of the same benefits as debris racks. *Culvert arrays (25)* also disperse flows and energy. Entrance treatments such as headwalls, mitered inlets and flared culvert end treatments can complement the use of energy dissipaters.

Bridges

Description: Bridges provide safe and easy access for vehicles over naturally impassable features such as waterways, canyons or tidal areas. Bridges typically consist of spans, piers, and abutments.

Application: Bridges can be used to restore and maintain riparian function in ecosystems where roads have or could:

- Create *cutoff channels (33)*
- Interrupt stream flow
- Fragment *wildlife habitat (36)*
- Create *fish passage (35)* problems.

Other situations include:

- Flood prone areas
- Crossings with undersized culverts for flow and debris passage
- Channels with 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 (2)* during and after construction. The impact of a bridge depends upon the span length, height, and amount of fill required for the approaches. While it may be less expensive to minimize the span length, it increases the amount of fill material dumped in the crossing to build the approaches. The fill reduces the floodplain width and water carrying capacity of the channel. The fill can fragment wildlife habitat and reduce passage opportunities during high water. In a meandering channel system, a bridge is a fixed control point that reduces the natural ability of the channel to meander. This can cause greater than normal channel erosion upstream and downstream of the bridge. The concrete cantilever bridge above has minimal impact on the canyon below it. The fill approaches for the bridge in the picture below restrict natural channel processes.

Outcome/Benefits: Longer and higher bridges allow for the passage of larger runoff flows, greater bedload volumes, and bigger woody debris. Bridges provide much better passage across roads for fish and wildlife than any type of culvert, with high bridges and long spans the least restrictive.

Alternate and complementary Techniques: *bottomless culverts (26), temporary erosion control (12), paved approaches, low water crossings (24),* and *soil bioengineering (18).*

Surfacing Techniques

Description: Roadway surface treatments bind or seal roadway material. These treatments reduce dust, decrease erosion, and help maintain roadside vegetation, biological health and diversity.

Application: A surface treatment may be appropriate when dust becomes a driving hazard, compromises recreational experiences, degrades water quality, harms vegetation or aquatic organisms, or impairs air quality. If fine materials that bind larger particles are lost, rock is lost from the surface due to traffic wear, maintenance grading, and erosion.

Surface treatments include:

Native material surfaces are appropriate for low volume roads with stable soil resistant to erosion.

Gravel surfacing is used when native materials are not structurally strong enough to support traffic. This surface may minimize sediment transport. Imported material is placed over native subgrade.

Dust abatement reduces air-borne dust and binds aggregate particles to prevent aggregate loss.

Soil stabilization products reduce air-borne dust, strengthen road structure, and last longer (but cost more) than dust abatement. These products bind soil particles, creating a stable interlocking course.

Chip seals provide a skid resistant surface when wet and seal the surface from water penetration. An application of asphalt is followed immediately with aggregate and used on low to moderate volume roads.

Asphalt pavements are used on higher volume roads, and selectively such as bridge approaches, to reduce sediment deposition to water bodies. Asphalt paving is a surface course of aggregate coated and cemented together with asphalt cement, supported by an aggregate base course.

Considerations: Dust abatement requires one to two applications yearly. Soil stabilization reapplication varies. Chip seals last 3–6 years before requiring reapplication. Routine maintenance of asphalt pavement requires application of a seal coat; seal coat life expectancies range between 1 and 8 years.

Some dust abatement and soil stabilization products may have negative environmental or health impacts; refer to Material Safety Data Sheets before use. Some dust abatement products perform better in higher humidity.

Increasing the quality of the road surface may increase traffic speed, thereby creating wildlife passage concerns such as increased mortality.

Potential Outcome/Benefits: Surface treatments control dust emissions, provide stronger road structures, and create smoother riding surfaces. Reduced sediment in water bodies maintains biological health and diversity.

Alternate and Complementary Techniques: *Mobile rock crusher (31), outsloping (13).*

Mobile Rock Crushing/Rotor Trimmer

Description: These machines crush oversized waste rock into graded material suitable for road surfacing. They attach to a front-end loader.

Application: Sidecast or bermed waste rock on the roadway shoulder can be crushed into quality surfacing material. Crushers produce angular crushed rock, providing better interlock and reducing loss of *surfacing material (30)* from erosion or traffic.

Rotor Trimmer: The rotor trimmer uses its carbide tips to pull the rock out of the roadway and crush it. Unlike the mobile rock crusher, bedrock can be crushed and a windrow is not necessary.

Mobile Rock Crusher: The mobile rock crusher requires equipment to rip up the road, pull bermed material and waste rock from the edge of road, then windrow the material. The windrow consists of 50% fines and 50% rock. An average rock crush-er pass will reconstruct a 14-foot wide roadway with a 4-inch depth of crushed material.

(before)

Situations appropriate for crushers include where

1) Bedrock is present
2) Road prism is destroyed
3) Borrow pits are infeasible
4) Hauling rock is cost prohibitive
5) Oversized rock in road creates difficulty in blading
6) Roadside berms have oversized "waste rock"

Considerations: Material output is 2 inches and less *(see photo below)*. This rock diameter does not erode as easily as smaller material and allows water to disperse better.

Potential Outcome/Benefits: Road maintenance reconstruction costs using these crushers is generally 10% of the cost of traditional gravel road resurfacing. Crushed rock has more interlocking fragments that build a strong base which can be important where the existing road contributes sediment to the ecosystem or has a weak subbase.

Alternate and Complementary Techniques: Filter fabrics can separate poor sub-base material from clean crushed material, *outsloping (13), ditch treatment (22), surfacing materials (30).*

(after)

Stream Channel Modification Structures

Description: These techniques protect road embankments from channel scour and erosion. They can mitigate for loss or alteration of riparian vegetation, and restore riparian terrestrial and aquatic habitats.

Application: Roads are often constructed adjacent to river or stream channels and may serve as a source of sediment (surface erosion and road fill failure). Roads constructed adjacent to channels can influence channel meander pattern and geometry. This can straighten the channel, reduce channel complexity, cause loss or alteration of native riparian vegetation, and degrade terrestrial and/or aquatic habitats. In-channel structures can be installed to alter or modify channel flows either above or below channel crossing structures to improve *fish passage (35)*. This technique has application within each ecoregion in the country.

Indicators include the presence of road prism or embankment failures, undermined channel banks below the road, need for frequent high maintenance or reconstruction, change in channel classification type, change in native vegetation, change in terrestrial and/or aquatic habitat quantity and quality, and change in fish or wildlife habitat access.

Considerations: Install these structures at the lowest flow period of the year to reduce the amount of heavy equipment disturbance causing sedimentation and turbidity. These techniques are designed for small stream channels (2–3 order channels) and are not appropriate in large stream or river channels. Usually this technique is most effective in a series of in-channel and/or channel bank structures.

Potential Outcome/Benefits: In-channel and channel bank structures can reduce the higher maintenance or reconstruction costs resulting from road prism failures due to channel scour and erosion.

Alternate and Complementary Techniques: Use *temporary erosion reduction treatments (12)* as required. For bigger channels containing more flow and bedload, consider installing *log jam complexes (34)*. These structures can also be used as step-pools to augment *fish passage (35).*

Reconnecting Cutoff Water Bodies

Description: Culverts (26) and bridges (29) can reconnect side channels, ponds, wetlands and cut-off channel meanders within floodplains that have become isolated or cut off from the main channel due to the construction of a road prism.

Application: Roads constructed within the floodplain and adjacent to rivers or streams may isolate or cut off portions of the natural channel or wetland network. This can straighten the channel; increase water velocities, and cause loss or degradation of valuable aquatic and terrestrial riparian habitats. Structures can be installed within the road prism to create as many reconnections as needed, to meet one or more of the following resource objectives: (1) restore access and use of historic fish and wildlife habitats; (2) restore hydrology and significant aquatic habitat (an increase in channel meander and channel length or the amount of wetland surface area); (3) increase the channel or wetland diversity.

Indicators for use include (1) seasonal or year-round movement or migration of wildlife or fish species is impeded by the road; (2) a noticeable loss of fish and/or wildlife habitat (change in food, cover, and shelter); (3) the presence of non-native vegetation and /or animals.

Considerations: Reconnecting water bodies to active river and stream channels within floodplains could increase the risk for damage from high flow events, such as flood flows 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 those habitats could increase the incidents of human interactions with fish and/or wildlife species (disturbance, poaching, etc).

Potential Outcome/Benefits: Reconnecting floodplain water bodies can result in significant restoration of aquatic habitat quality and quantity, such as fish access to spawning or rearing habitat. Other benefits could be the long-term recovery of floodplain structure and function such as moderating effects of flood flows, increased channel or wetland diversity, and restored native riparian wetland vegetation.

Alternate and Complementary Techniques: *Low water crossings (24)* and *culvert variations (26), wildlife crossings (36), fish passage (35), beaver control (37),* and *vegetation restoration (17)*.

Log Jam Complexes

Description: Log jam complexes are multiple log structures placed in rivers and streams to protect channel banks, roadways and other adjacent features.

Application: Log jam complexes protect roadways adjacent to river channels by emulating natural river processes. Log jam complexes are usually placed in series or in combinations. These structures are suitable for larger channels, 3rd order or higher. Engineered log jams are one type of log jam complex and can have up to 500 wood pieces.

Log jam structures can: 1) stabilize channel banks and protect roads using native materials; 2) deflect and catch large woody debris in transport; 3) promote establishment of vegetated riparian areas such as channel banks and in-channel riparian islands; 4) improve and create new fish habitats; 5) restore and maintain natural river system characteristics.

Considerations: Install log jam complexes at the lowest flow period of the year to reduce disturbance to the riparian area by heavy equipment. Use sediment reduction treatments as necessary. Use techniques to keep fish away from the construction area. Consider the proximity of these structures and the potential risk to other public and private property located down stream before and during project implementation.

Potential Outcome/Benefits: Benefits provided by engineered log jams include: 1) initiation of channel scour and deposition around the structures; 2) retention of woody debris in transport within the river system; 3) increase in channel complexity such as meander pattern and geometry; 4) restoration and improvement of aquatic and terrestrial habitats.

Alternate and Complementary Techniques: Complementary practices include *revegetation (17), soil bioengineering (18)* and *channel modification (32)* structures.

Fish Passage

Description: The primary objective of fish passage is to provide unrestricted passage for adult and juvenile fish across roads or other barriers. Fish passage structures can be designed to allow other aquatic organisms, such as salamanders, to cross.

Application: Many existing roads were originally constructed without full consideration for adult and juvenile fish passage upstream and downstream of road/channel crossing structures, primarily culverts. Direct field inventories, or 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. *Bridges (29)*, bottomless arch culverts, larger full pipe culverts or box *culverts (26)* can restore unrestricted fish passage at these sites.

Considerations: Structure type (such as bridges, or open bottomless arched culverts), length, width, and installation grade is determined by stream and site surveys. The Forest Service's FishXing software can assist in this determination. Fish and fish habitat surveys are needed before and after project implementation. Size and design of the fish passage structure needs to consider the swimming speed capabilities of target fish species. Structure type partially depends on various flow regimes. Install structures at the lowest flow period of the year to reduce the amount of heavy equipment disturbance, sedimentation and turbidity. If fish adults or juveniles are present in the immediate construction area, use techniques to keep fish out of the area. Wherever possible, structures should be designed to accommodate all aquatic organisms and wildlife at the site.

Pretreatment: fish passage barrier at small culvert site.

Potential Outcome/Benefits: Unrestricted fish passage can significantly increase fish access to spawning and rearing habitats. Increased habitat access and utilization can significantly increase fish production. Other benefits of these structures could be more efficient passage of high flows and bedload, and an increase in channel complexity (channel meander and geometry). If *crossings for wildlife (36)* are also considered, the ecological integrity of the drainage can be maintained.

Alternate and Complementary Techniques: *Low water crossings (24) (fords), culvert variations (26), bridges (29), channel modifications (32), cut-off channels (33), beaver control (37),* and *vegetation restoration (17).*

Posttreatment: Larger, sunken culvert with step-pool structure installed at culvert outlet.

Wildlife Crossings

Description: Roads are often constructed near streams, riparian areas, and floodplains that serve as travel corridors for wildlife. Roads contribute to vehicle-caused mortality and reduced habitat connectivity. Wildlife crossing structures such as large *culverts (26)*, *bridges (29)* and overpasses are effective in reducing wildlife/vehicle collisions and restoring habitat connectivity.

Application: Numerous techniques have been used effectively across all ecoregions for all types of wildlife. Slotted-drain culverts (below) facilitate amphibian crossings by allowing sunlight and air exchange. Bridges that span entire riparian areas at floodprone width instead of just the active stream channel width allow larger wildlife species such as deer and bear to pass safely under roads. In areas where road modifications are not possible or are ineffective at reducing wildlife casualties, seasonal road closures may be necessary. As traffic volume and speed increases, structure complexity and size needs to increase.

Indicators for wildlife crossings are: (1) high rate of wildlife/vehicle collisions; (2) presence of important habitat connectivity zones; (3) disturbance of sensitive wildlife habitats.

Considerations: High bridges are the most effective type of wildlife crossing structure, especially if they provide unsubmerged areas along the stream. Directional fencing is often necessary to encourage wildlife to use constructed crossings. Water conveyance structures can be designed or retrofitted to allow wildlife passage. These include bottomless culverts, bridges, and livestock crossings. Warning signs alone are usually ineffective. Although road modifications facilitate wildlife crossings, wildlife movements will still be restricted and some mortality will occur. Where possible, road closures are a more effective treatment.

Potential Outcome/Benefits: Decreased wildlife mortality, decreased vehicle damage, protection or maintenance of existing habitat use, increased habitat connectivity.

Alternate and Complementary Techniques: *Road relocation/realignment (11),* road decommissioning, *bridges (29), controlled public access (10), fish passage (35).*

Beaver Pond Structures

Description: Roads passing through riparian and wetland areas may act as dikes or dams impeding water flow. Beavers are attracted to this ponded water because they can impound water with little additional work by simply blocking or plugging culverts. Several water control structures, such as beaver pond levelers, have been developed to facilitate water movement through beaver dams and 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: These structures maintain wetland habitat created by beavers and lower the water level of these ponds, reducing the risk of road erosion. Beavers search for leaks along the road berm or embankment and detect leaks 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 (1) beavers dam culverts and other road outlet structures; (2) the road prism is saturated; (3) beavers cause road erosion caused by beaver ponds built above the culvert inlet.

Considerations: Beaver pond leveler structures maintain ponded water levels above road/channel crossings during normal flow conditions. They are typically not designed to transport runoff from large storm events. Major roads should also contain nearby spillway areas to transport high flows (floods) across roads.

Potential Outcome/Benefits: Expected benefits include (1) maintaining fish and wildlife habitat created by beaver ponds; (2) reducing damage to adjacent roads, (3) maintaining floodwater storage; (4) maintaining the water purification functions of beaver ponds.

Alternate and Complementary Techniques: Beaver dam removal, beaver trapping, *road relocation/realignment (11)*, *bridges (29)*, *roadway dips (23)*, *low water crossings (24)* such as *fords (24)*, and *fish passage structures (35)*.

Wetland Maintenance

Description: Roads located near riparian areas and wetlands may contain culverts that alter the natural hydrography of these water bodies. These *culvert (26)* placements often set the water level either above or below natural levels. Most wetlands have seasonally fluctuating water tables allowing plants and animals to fulfill their annual life cycle requirements. Certain wetland maintenance techniques, such as stop-log structures, maintain water levels of wetlands located upstream from roads, simulating the natural hydrology throughout the year. Habitat for native fish, wildlife, and plant species can be maintained and restored by this technique.

Application: These structures are commonly used along most of the diked, dammed and drained river floodplains across the U.S. to restore and maintain wetland functions where hydrology has been altered and is no longer capable of functioning naturally. Structures such as stop-log structures have application on most forest and rangeland ecosystems, especially where roads traverse wetlands and marshes that naturally have seasonal variations in water levels. Depending upon the debris-loading situation at each site, different types of stop-log structures (as shown in these photos) can be used to reduce or prevent the plugging of culvert inlets.

Indicators for use include: (1) existing wetland crossings; (2) the presence of tree mortality; (3) change in vegetative species composition

Considerations: Traditional stop-log structures should not be used alone, or where fish or aquatic invertebrate passage is a management objective. Stop-log structures can be modified to allow increased *fish passage (35)*, but complementary fish passage structures are preferred. Consider traffic and roadbed loads when choosing among available corrugated metal pipe and reinforced concrete pipe structures. Maintaining the seasonal and annual desired water levels for forested wetlands and freshwater marshes will vary according to resource and road management objectives in each ecoregion.

Potential Outcome/Benefits: More diverse and natural plant community, and maintained or restored habitat for fish and wildlife species.

Alternate and Complementary Techniques: *Fish passage (35)* structures, radial gates, screw gates, *raised culvert inlets (27)* and weirs can be used in place of stop-log structures, but these are either more expensive or do not allow as precise water level manipulations.

THIS PAGE IS BLANK

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Lincoln, Nebraska
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah
Laramie, Wyoming

*Station Headquarters, Natural Resources Research Center, 2150 Centre Avenue, Building A, Fort Collins, CO 80526

Federal Recycling Program Printed on Recycled Paper