

Riparian Area Enhancement Through Road Design and Maintenance

Russell A. LaFayette^{1,4}, John R. Pruitt^{2,4}, and William D. Zeedyk^{3,4}

Abstract.—Traditional road location, design, construction, and maintenance have generally had adverse effects on riparian areas. Road locations, drainage methods, and maintenance practices have resulted in a net loss of both acreage and related values in riparian areas, particularly in the arid and semi-arid portions of the West. Results of these activities include drainage of riparian ecosystems, reduced site productivity, loss of fish and wildlife habitat, reduced base flows with increased peak flows, gully development, and accelerated downstream sedimentation. Recent changes in management philosophy and activities are reversing this trend by using road design and maintenance to rehabilitate riparian areas and restore their productivity. Methods being used to accomplish these goals include road obliteration, road relocation, modified culvert designs, raised culvert inlets, modified bridge and ford designs, flow dispersal, stilling basins, and more frequent and effective ditch management. Results have been dramatic, with nearly 100 acres (405 hectares) of degraded riparian area in the USDA Forest Service Southwestern Region started on the road to recovery over the past five years. Transportation system management is becoming an effective tool in the rehabilitation of riparian areas across the Southwestern Region.

INTRODUCTION

The Southwestern Region of the USDA Forest Service encompasses roughly 22.5 million acres (9.1 million hectares) in 11 National Forests and Grasslands on 64 Ranger Districts across Arizona, New Mexico, and western Oklahoma and Texas. Riparian areas and related wetlands occupy approximately 1 percent of this area, but they receive a disproportionate amount of use in relation to their size. Due to limited water in the arid and semi-arid Southwest, riparian areas have become the focal point of activities since their attributes include water, shade, productive soils, gentle topography, and many related values.

For many historical and topographic reasons, roads have often been located adjacent to water bodies and cross them frequently. Traditional road location, design, construction, and maintenance activities have had considerable negative impact on riparian areas across the Southwest. Many of these impacts were unintentional and simply followed long-held engineering training and practice. Modern managers have begun to realize the extent and magnitude of these impacts on riparian areas and their related values. Successful efforts are underway to prevent further losses and restore many areas to productivity.

This paper has several main objectives: (1) present a historical perspective on road-related impacts on riparian areas in the Southwest; (2) discuss how these impacts were recognized and analyzed; (3) list typical problems associated with road/riparian conflicts; (4) present suggested solutions, and methods to avoid

¹ *Riparian Area Manager.*

² *Riparian Area Manager, Director of Engineering (retired).*

³ *Director of Wildlife and Fisheries (retired)*

⁴ *USDA Forest Service, Southwestern Region,*

future problems or correct existing ones; and (5) discuss program progress to date and likely future accomplishments.

Accomplishing changes in road management to benefit riparian area resources requires those involved to be open to new and emerging approaches to road and water management (Figure 1). Traditional approaches to design, philosophy, and policy worked to collect, concentrate and discharge water. Water was viewed as a liability. Designs were single purpose, with an uncompromising and indifferent view toward related resource values.

Newer thinking views water as an asset. Designs are multi-purpose and multi-valued. Water is detained on site. Flow is dispersed and spread through the area in natural patterns where it can benefit a wide range of resources and users.

DEFINITIONS

The Forest Service Manual section FSM 2526.05 (USDA, 1986, 1991) defines riparian areas, including wetlands, as we use these terms throughout this paper. Riparian Areas are comprised of two ecosystems: riparian and aquatic. The Aquatic Ecosystem includes the stream channel, lake, or estuary bed;

water; biotic communities; and the habitat features that occur therein. The Riparian Ecosystem is comprised of terrestrial ecosystems characterized by hydric soils and plant species dependent on the water table (saturated zone) and/or its capillary fringe.

Wet Meadows are meadows having low velocity surface and subsurface flows. Channels are typically poorly defined or nonexistent. Vegetation is dominated by riparian-dependant species. Xeric species are confined to adjacent uplands or drier inclusions within the meadow.

HISTORICAL PERSPECTIVE

Water has long been a limited resource in the arid and semi-arid West. Riparian areas have always comprised a small portion of the Southwestern landscape. Even prior to the arrival of European immigrants, riparian areas probably involved less than 2 percent of the total land area. Recent reports indicate that, on a statewide basis, approximately 50 percent of the original acreage of riparian areas (including wetlands) in the Southwest have been lost or significantly degraded (U.S. GAO, 1988; Dahl, 1990, p. 6). Human activities have caused changes in watershed condition, hydrologic function, and soil productivity, which subsequently increased runoff, erosion, and sedimentation. These activities include but are not limited to: timber harvest; domestic livestock grazing; placer mining; water management activities such as diversions, dams, flood control, irrigation, drainage of wetlands, channelization, phreatophyte control; and road construction and maintenance.

Road construction and maintenance have been major contributors to riparian area losses over the years. Reasons for this are rooted in historical patterns of travel and commerce in the West. Old wagon routes tended to follow stream corridors since they usually offered many advantages over other routes. Stream bottoms had more gentle terrain, offered water and forage for horses and other livestock, housed fish and game for food supplies, and provided wood for fires and building materials.

Early roads and highways followed these old established routes along stream bottoms, where construction was usually easier and less expensive. Drainage and maintenance practices were designed to move water away from the road to keep the road surface and subsurface dry. Infrequent large drainage structures, augmented with extensive ditch net-

Design Approaches

Old/Traditional

Collect Water
Concentrate Flow
Direct Flow
Drain/Discharge Water
Accelerate Flow

New/Emerging

Control/Manage Base Level
Disperse/Spread Flow
Detain Water On Site
Slow Flow

Philosophical/Policy Approaches

Old/Traditional

Water Viewed As Liability
Single Purpose Oriented
Uncompromising
Narrow Scope
Indifferent

New/Emerging

Water Viewed As Asset
Multi-purpose Oriented
Compromising
Broad Scope
Nurturing/Concerned

Figure 1. Approaches to road/water management.

works, were preferred over numerous small structures to save effort and expense. Maintenance practices commonly routed water and sediments from the road surface and ditches directly into stream courses for rapid removal. This benefitted the road, but commonly caused unintentional harm to other resources by fostering extensive gully development and erosion of riparian areas.

Western water laws of prior appropriation required that water be diverted from the stream and put to a "beneficial" use. Until recently, water left in the stream was not considered "beneficial" in most western states. Little concern existed for fish passage or wildlife habitat. Water quality was not important in dry streams. Road-related recreation use along roads near streams further disturbed banks and riparian areas.

Over several centuries of habitation by European immigrants, riparian areas in poor condition and de-watered meadows with deep gullies became a common sight. Most people then and today have come to accept these conditions as "normal" and have no vision of what the land can and should look like. Until recently, little thought had been given or action taken to correct the situation.

PROBLEM RECOGNITION

Recognizing and becoming aware of a problem requires a willingness to see an existing situation from a different perspective. This calls for an open mind and a change in attitude and philosophy about the situation. Eventually, observant and concerned professionals began to notice the nature and magnitude of riparian area losses related to road construction and maintenance. These effects include: (1) riparian areas de-watered due to lowered channel bed nick points and gully formation and advance; (2) plant composition changed, with a shift from riparian dependant plants to drier and less productive upland species; (3) accelerated runoff caused increased flood peaks and related damages; (4) base flows decreased in volume and duration, causing streams to dry up earlier in the year; (5) perennial streams reduced to non-perennial flow; (6) increased channel bed and bank erosion; (7) eroded soil increased downstream sedimentation; (8) reduced habitat for riparian dependant wildlife species; (9) rapid movement of water off the land to water storage facilities at lower and hotter elevations increased water losses through higher evaporation rates; (10) improper road drain-

age led to higher road maintenance costs; (11) compromised safety of forest users from abnormal flooding; and (12) Forest facilities endangered by higher flood frequencies and magnitudes (DeBano and Schmidt 1989).

These effects were recognized first by professionals who's programs were most directly effected by riparian area losses: wildlife and watershed managers. Spurred by the concerns of these individuals, several on-the-ground managers began to experiment with different ways to improve road management in riparian areas. Their work provided good examples for others to observe, evaluate, and emulate. The staff of the Apache-Sitgreaves, Cibola, Gila, and Prescott National Forests (NF) took the lead in this arena and continue to lead the agency in developing these innovative road management practices.

The Regional Office staff is working to with the Forests to reduce the impact of roads on riparian areas. Together they are developing and implementing programs to reduce the impacts of current and future roads as well as actively use road management as a tool to rehabilitate areas damaged by past actions. This knowledge is beginning to spread to other Regions and agencies across the country.

PROBLEM ANALYSIS

Within the Southwestern Region the Forest Service manages approximately 53,000 miles (85,277 kilometers) of roads. The Region constructs an average of 60 to 70 miles (96.5 to 112.6 kilometers) of new road each year and reconstructs another 350 to 400 miles (563.1 to 643.6 kilometers). At the same time, nearly 1,000 miles (1,609 kilometers) are temporarily closed or permanently obliterated annually. This level of activity presents many opportunities to remedy riparian losses caused by previous road management activities.

In an effort to learn which methods worked best in different situations, several fact-finding visits were made to the lead Forests during 1989, 1990 and 1991. A team comprised of Directors and specialists from Watershed and Air Management, Wildlife and Fisheries Management, Engineering, and Range Management visited a wide variety of sites on these Forests. Similar trips were then made to other Forests to observe current practices and encourage the use and acceptance of successful modern road management methods. These trips consisted of a brief in-office presentation of concerns and ideas, followed

by visits to an array of suitable field sites, and a close-out meeting to discuss observations and opportunities for future work. The response on these trips was highly positive and encouraging, and many excellent ideas emerged.

Several basic categories of problems were observed and analyzed. These included: (1) wet meadow crossings and adjacent road locations; (2) routine stream crossings, including culverts, fords, and bridges; (3) road alignment on the landscape; and (4) road drainage, such as ditches, dips, and water bars. The team summarized and described findings, and developed a series of slides and line drawings to illustrate typical areas of concern, successful remedial methods, and ways to recognize opportunities for employing these techniques.

Problem Statements and Solution Proposals

The observational information collected during the Region-wide analysis of road design and location was used to develop problem statements and solutions for a variety of field situations. These situations include: roads and wet meadows, stream crossings (e.g. culverts, low water crossings, and bridges), road location and alignment, and road drainage. Also, many recommendations developed were based on information presented by Heede (1980) and DeBano and Schmidt (1989).

Roads and Wet Meadows

Problem Statement

In their natural condition, wet meadows typically have dispersed surface and subsurface flows at low velocities. The resulting areas are characterized by riparian obligate species present in the meadows with the more xeric species, which cannot tolerate wet conditions, confined to drier upland slopes or inclusions. Roads often violate this natural landscape feature by crossing the wet meadows or closely paralleling them (Figure 2). As a result, a road and its drainage structures tend to cut off dispersed water flow into the meadow, or concentrate flows and increase velocities through specific structures. Drainage structures are commonly excavated to set on "mineral" soil, which is below the natural grade of the meadow. This results in gully formation above and below the road. The concentrated flows cause chan-

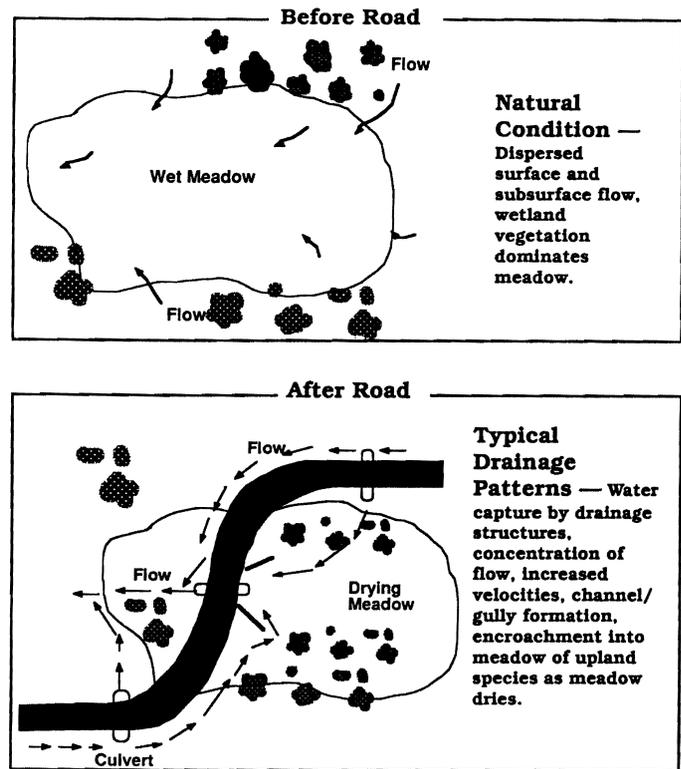


Figure 2. Typical water management scenario for roads and wet meadows.

nel downcutting, and gully erosion inevitably follows. The gullying gradually dries out the meadow as the channel deepens. The loss of a permanent water table by gullying leads to the encroachment of upland plant species into the formerly wet meadow, changing the vegetation composition, diversity, and productivity.

Solutions

The best solution to the adverse effect of roads on wet meadows is to avoid crossing them altogether. Select alternative routes at higher elevations that minimize the effects of road construction on the meadow. When it is not possible to avoid crossing the meadow, use construction methods that have minimal impact on the area (Figures 3-4). Preferable locations are to cross either below (Figures 5-6) or above (Figures 7-8) the meadow. Also, whenever possible, take advantage of local geologic features by crossing at natural pinch points, at grade, and at right angles to the flow direction in order to minimize impacts.

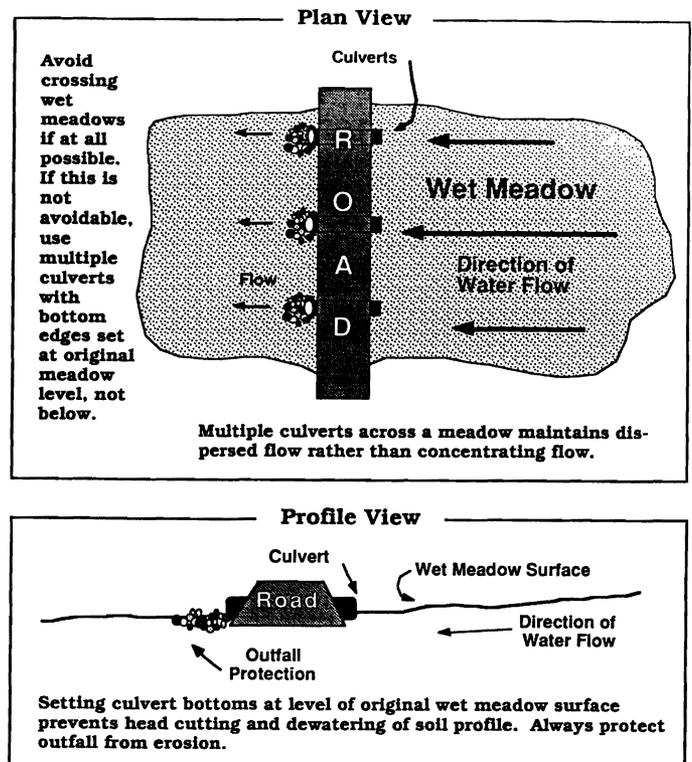
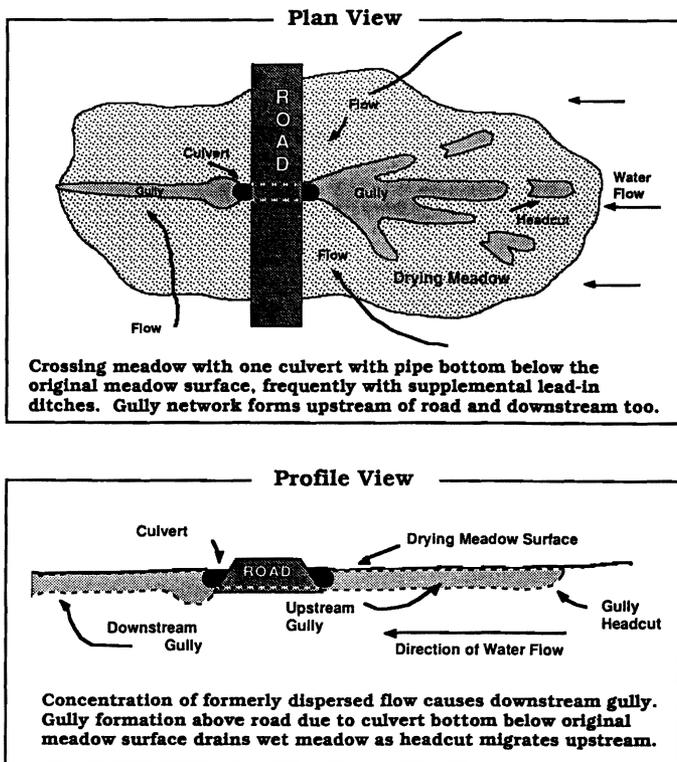


Figure 3. Road crossing through a wet meadow — improper method.

Figure 4. Road crossing through a wet meadow — proper method.

Stream Crossings

Problem Statement

The most common forms of stream crossings are culverts, low water crossings, and bridges. Some problems are common to all, while others are specific to the type of stream crossing.

Several mistakes are commonly made when installing culverts. First, when installing culverts, a few large culverts have usually been preferred to numerous small ones because the installation effort and costs are less for fewer large culverts. This presents a problem since directing all the flow through one opening concentrates energy, increases velocities, and accelerates erosion upstream and downstream of the crossing. Also, culverts are commonly placed with the culvert bottom excavated down to mineral

soil, usually below the natural grade of the stream bottom. This practice keeps the road prism dry and provides excellent bedding for the pipe, but can lead to both upstream and downstream channel degradation. The culvert outfall is commonly unprotected and creates a scour hole, which lowers the channel and results in drying of the surrounding riparian areas. In the upstream direction, side channel downcutting may occur and initiate upstream gully systems. Also, the sediment lost by both upstream and downstream erosion can affect downstream water quality. In addition, culverts that are too long, too steep, or having outfalls too high may impede fish passage.

Low water crossings (fords), when set below the natural grade, can also cause channel degradation both upstream and downstream from the structure. Failure to include a cutoff wall and splash apron in

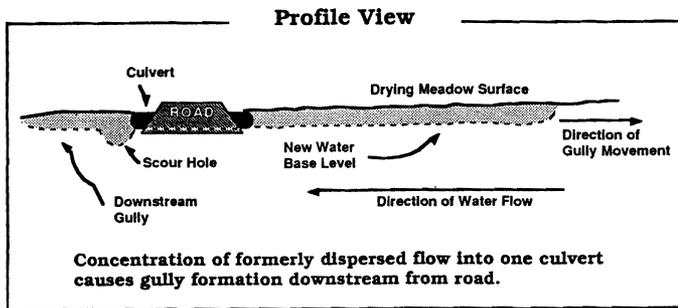
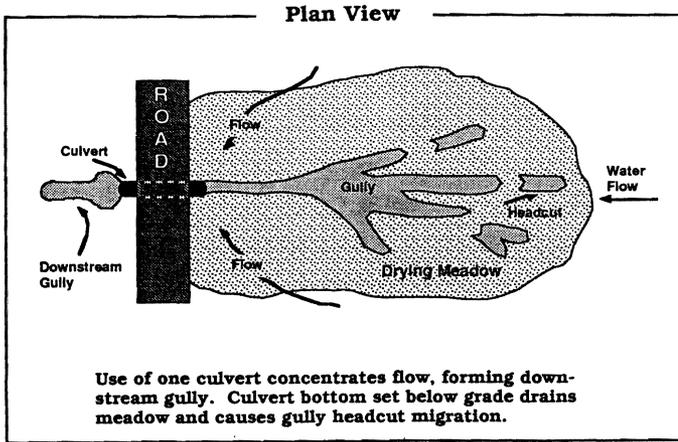


Figure 5. Road crossing through a wet meadow — improper method.

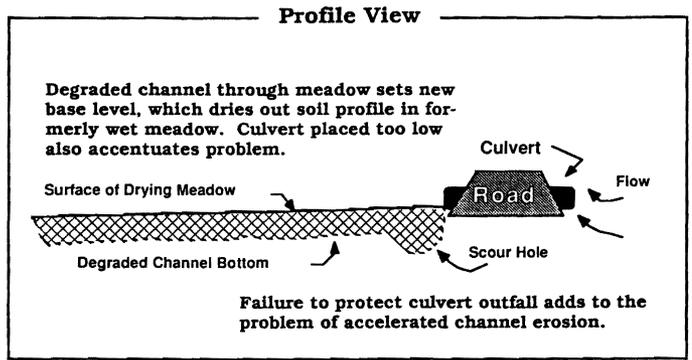
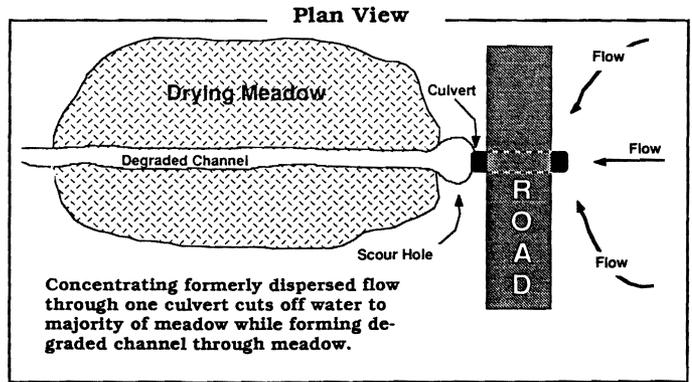


Figure 7. Road crossing through a wet meadow — improper method.

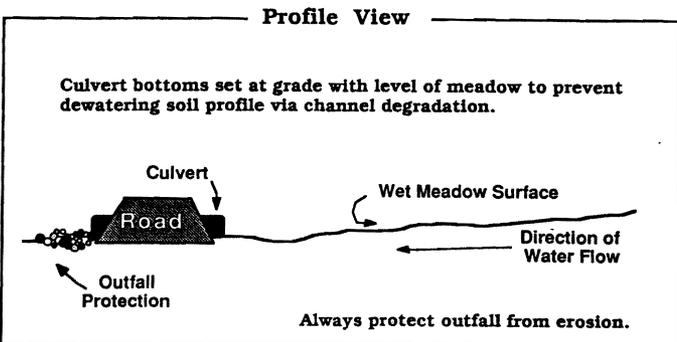
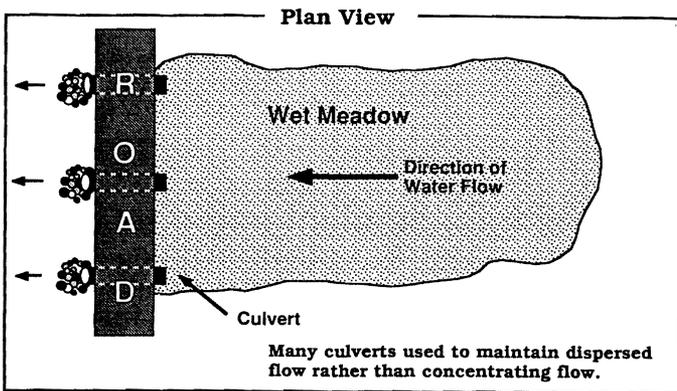


Figure 6. Road crossing through a wet meadow — proper method.

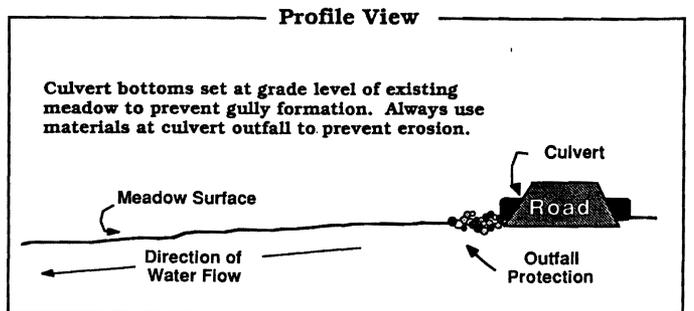
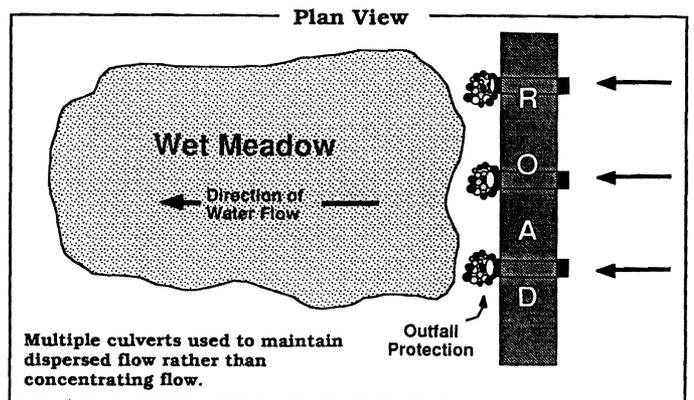


Figure 8. Road crossing through a wet meadow — proper method.

the design commonly results in formation of a scour hole and eddies below the structure. This undermines the crossing, resulting in high maintenance and eventual failure of the crossing.

Two common mistakes occur when constructing bridges. First, the opening is made too small to pass design flows. This reduces flow velocities above the bridge, which results in upstream aggradation. Also, the water passing through the structure accelerates, causing degradation of reaches below the bridge. The second common problem associated with bridges involves construction at an angle to the natural flow of the stream. This forces the water to impact the bank above the bridge and exit at an angle below it. A related problem is caused by channelizing the stream to align it with the bridge rather than aligning the bridge with the stream. Undersized openings and improper alignment endanger the structure and the riparian areas near it. The eroded soil generated as a result to improper alignment can also affect downstream water quality.

Solutions

Mitigating the effects of different kinds of stream crossings share some solutions. Others are unique to each structure type.

The number, location, alignment, and elevation of inlets are important considerations when installing culverts for road crossing. When the streamflow is not naturally concentrated into a single channel, as in a meadow, cienaga, or braided or wide channel, use multiple smaller culverts placed over the width of the affected area to spread the flow energy rather than using one large culvert that concentrates flow. Elevation of inlets are important when installing culverts. Where new construction or reconstruction allows choice in location of culverts, place the bottom of the culvert at the natural level of the channel. If proper bedding is a problem, excavate and refill to the natural level of the channel. Where previous channel degradation has occurred and restoration of the natural channel is the goal, place the culvert at the bottom at the desired channel elevation. This will allow sediments to aggrade the bed back to the original level (Figure 9). This may require more fill but the benefits to riparian resources will justify the additional cost.

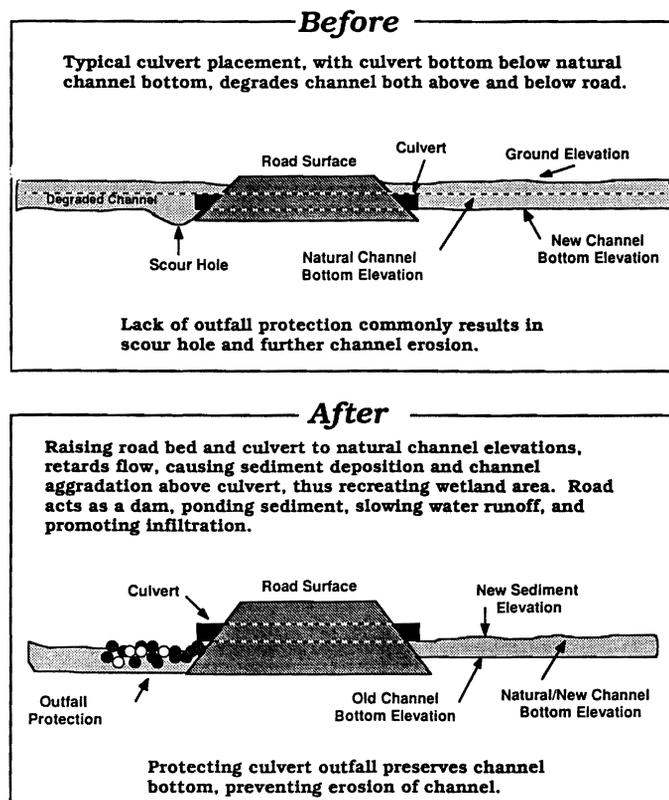


Figure 9. Raising culvert elevation to recreate wet area.

Where existing culverts cannot be changed, and aggradation of the channel is desired, construct an upstream dike to raise the water/sediment level and then drop the water safely to the existing culvert level. Construct upstream dikes of soil, rock, metal, concrete, wood or other suitable materials (Figures 10-11). Use caution in design to assure the new water/sediment elevation is less than the road surface elevation.

Another technique for raising the upstream end of a culvert involves attaching a 45 - 90 degree elbow with the elbow inlet at the desired stream bottom level (Figure 11). Provide sufficient freeboard on the fill to avoid overtopping the road. Culvert elbows also change the characteristics of how water enters the culvert, reducing its capacity under high flow conditions.

Align culverts with stream direction and gradient to assure that sediment passes through the culvert rather than accumulating inside it. When fish passage is necessary, make sure culvert openings will allow passage, especially at outfalls.

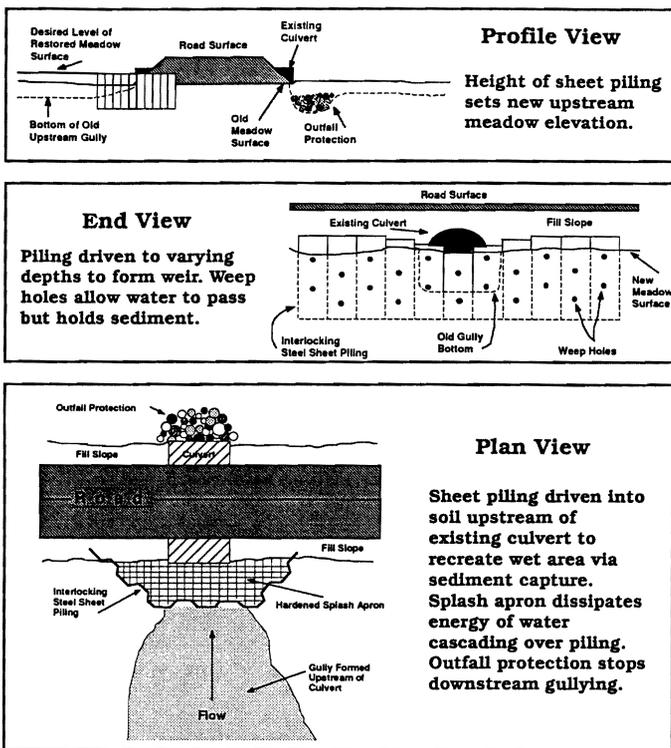


Figure 10. Using interlocking steel sheet piling upstream of an existing culvert to recreate wet area.

Special considerations when constructing low water crossings include maintaining the natural grade, installation of cut-off walls, providing sufficient channel capacity, and using "French" drains. The construction of "French" drains, which is rock sandwiched between layers of geotextile (Figure 12), allows water to pass through the road prism and at the same time keeps the road surface dry. They may be used alone or in conjunction with a culvert or dip designed to pass large runoff events.

Place crossing surfaces at the grade of the natural channel to maintain the current channel or facilitate aggradation of a degraded channel. The low water crossing should extend far enough up the stream banks to keep high flow events from eroding the ends of the structure. Install a cut-off wall at the downstream edge of the road surface to prevent undermining the structure. Construct a splash apron at natural channel gradients downstream of the cut-off wall to dissipate flow energies passing over the structure, thus avoiding erosion and eddies that could undermine the crossing (Figure 13).

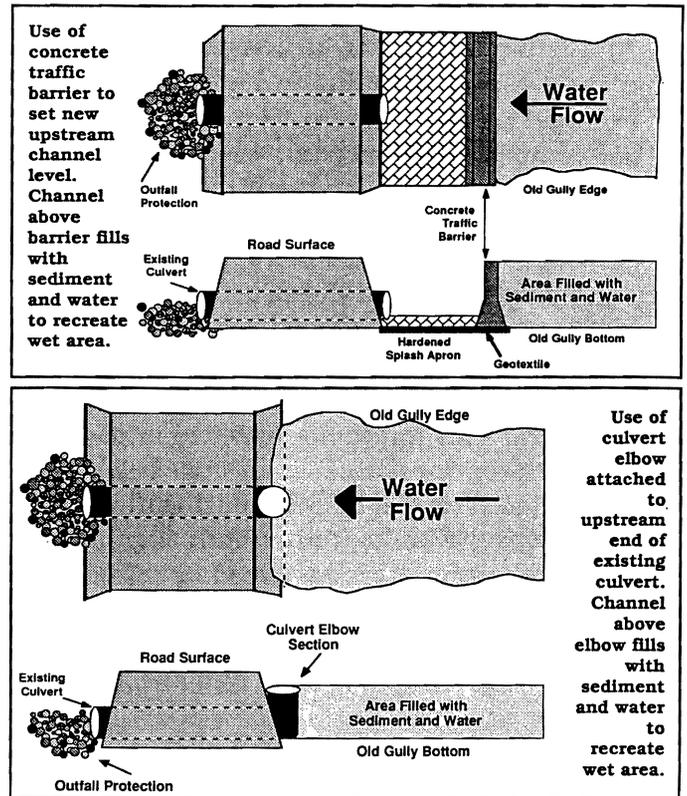


Figure 11. Modifying culvert inlet to recreate wet area.

Two important considerations when using bridges include flow capacity and an alignment with the stream channel. Construct the bridge opening sufficiently large to pass expected volumes without constricting flow. Avoid the temptation to construct a smaller opening to save initial costs. Future maintenance costs and damage to other resources may outweigh the higher initial cost of construction. The construction of secondary relief structures, such as dips or "sacrifice" bridge approaches are recommended. Build the bridge at right angles to flow. Avoid building bridges on curved stream reaches when possible.

Road Location and Alignment

Problem Statement

Many roads in the Southwest tend to closely follow and frequently cross streams and riparian areas because of the historical reasons discussed ear-

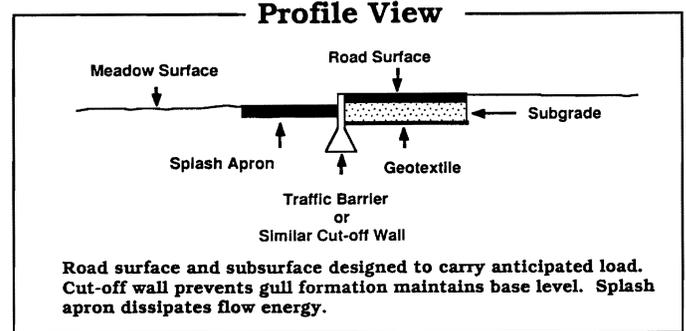
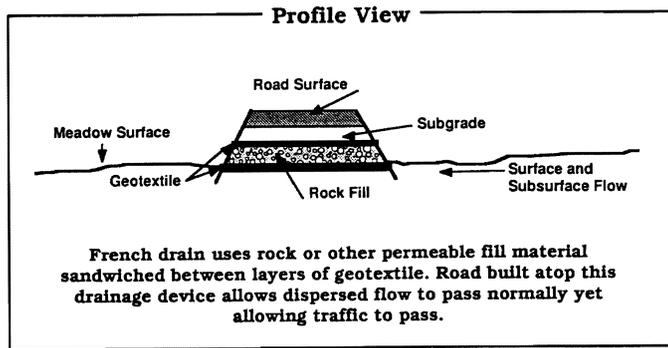
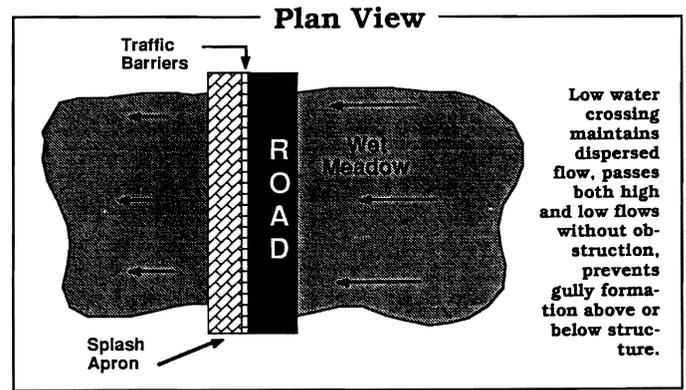
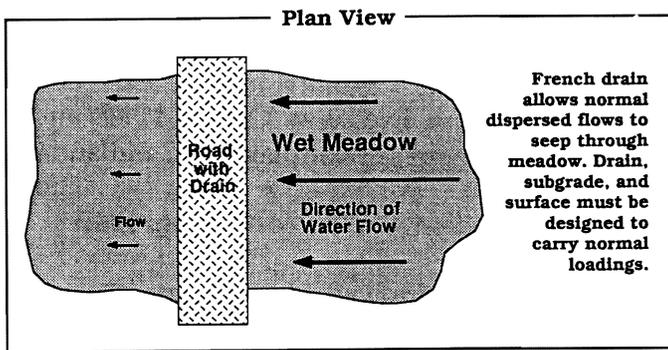


Figure 12. Use of french drain to cross wet area.

Figure 13. Use of low water crossing (fort) across wet area.

lier. Roads in riparian areas can take up a significant portion of the total area, replacing natural vegetation with an impermeable surface. This increases runoff and flood peaks while passing sediment and other pollutants into the stream. Locations often cut off or shorten stream meanders. This steepens channel gradient, increases stream power, and causes erosion and downstream sedimentation. Roads cut through alluvial fans may intercept and concentrate surface and subsurface runoff, with adverse effects downstream from the road.

Solutions

Keep roads completely out of the riparian areas whenever possible. Build roads on the ridges or sideslopes. While initial construction costs may be higher, long-term maintenance costs will be less and reduce damage to riparian resources. Minimize the number of crossings where they cannot be eliminated. Limiting crossing reduces potential problems and long-term expenses. Design and construct roads to detain or delay water and sediment upstream from the road. This reduces flow velocity, increases infil-

tration, and prolongs base flows below the road. Do not cut off or shorten stream meanders with crossings or road fill materials. Naturally occurring meanders are necessary to maintain an equilibrium gradient with the stream. Avoid building roads through alluvial fans. Provide drainage to mimic natural patterns where avoidance is impossible.

Road Drainage

Problem Statement

Drainage of water from roads, especially from ditch lines, can impact nearby riparian areas. Infrequent drainage allows water to travel for long distances in ditches, gaining velocity and sediment loads while reducing flow to meadows. Drainage outlets too close to channels can direct pollutant-laden water directly into the stream. Wing ditches and berms along roads frequently disrupt natural flow lines and concentrate flow where it causes erosion. Drainage outlets on fill materials commonly cause significant erosion. Unprotected culvert outlets cause scour and

additional sedimentation. Too frequent maintenance can remove erosion-resistant vegetation or rock armor, undermine stable banks, and increase erosion and sedimentation.

Solution

Where possible, use outsloped roads and rolling dips to avoid inside ditches. When ditch construction is limited to insloped roads, drain the water from the road frequently, avoiding flow concentrations in the ditch and at any single culvert. Protect drainage outlets against erosion by placing the outlet at the gradient of the channel bottom and installing energy dissipators at the outfall. Avoid placing outlets on fill material. Avoid directing accumulated ditch waters and sediment into streams. Turn ditch waters onto areas that will allow the water to infiltrate and sediment to settle out before reaching the stream. Construct stilling basins if necessary to provide these results. Maintain ditches and road surfaces at the minimum necessary to get the job done. Don't "over maintain" a road or "pull" ditches if they don't need it. Vegetation in the ditch can prove beneficial by stabilizing the ditch and cut slope, preventing erosion of both.

Program Advantages and Benefits

Managing roads with riparian area values in mind can yield a wide range of multiple benefits. Benefits include but are not limited to: (1) rewetting dewatered wetlands and re-creating former riparian areas; (2) limiting or reversing reductions in riparian acreage, resulting in an actual net increase in riparian areas in many instances as historic riparian areas are rehabilitated; (3) reducing flood peaks and related damages; (4) increasing base flow volume and duration; (5) limiting or stopping channel erosion and downstream sedimentation; (6) creating riparian areas using sediments trapped from uplands; (7) lengthening streamflow duration, sometimes returning once-perennial streams to perennial flow; (8) reducing water loss from evaporation in downstream reservoirs by storing it in the upstream soil profile; (9) increasing wildlife and fisheries habitat quality, quantity, and diversity; (10) increasing forage production for livestock and wildlife; (11) increasing recreation benefits and aesthetic values; (12) reducing road

maintenance costs; (13) turning water, which was formerly perceived as a liability, into an asset; and (14) complying with Executive Orders 11988 and 11990 on management of floodplains and wetlands.

Program Implementation and Progress

Many techniques are available to implement these new and revised ideas into everyday management, including: (1) design new roads using the concepts presented above; (2) reconstruct old roads using these concepts; (3) retrofit other roads during periodic maintenance, where appropriate and as opportunities allow; (4) use multiple funding from all benefiting resources; (5) train current and new employees to use these ideas through workshops, handbooks, videos, photo libraries, and related methods; (6) provide training to increase awareness of engineering personnel to other resource skills and needs; and (7) cross-train resource specialists to appreciate engineering skills and needs.

Progress to date is very encouraging. A wide variety of measures have improved nearly 1,000 acres (404.7 hectares) of riparian area across the Southwestern Region over the past several years. Particular success has occurred on the Luna and Reserve Ranger Districts of the Gila NF, Alpine and Springerville Ranger Districts of the Apache-Sitgreaves NF, and Mt. Taylor Ranger District of the Cibola NF. Some of the most notable examples are found on the Alpine, Luna, and Mt. Taylor Ranger Districts.

Planned reconstruction of nearly 60 miles (96.54 kilometers) of Forest Roads 49 and 50 in the Zuni Mountain section of the Mt. Taylor District near Grants, NM, will provide a showcase for demonstrating methods to protect and enhance riparian areas using modern road management concepts. Initial survey and design efforts show that an estimated 2,000 acres (809.4 hectares) of riparian area can be rehabilitated using a wide variety of proven and evolving technologies. Scientists from the Rocky Mountain Forest and Range Experiment Station are working with the project designers to establish research studies for evaluating changes in areas affected by the new road project. Expected changes include: extent and depth of water tables; soil moisture and productivity; water yield and timing, vegetation density, composition, and yield; sediment deposition; and wildlife use.

The added cost incurred from incorporating these riparian management concepts in the construction, reconstruction, and maintenance of roads is usually marginal. Retrofitting existing structures can be accomplished using simple materials and District and/or volunteer labor in many instances. One prime example on the Apache-Sitgreaves NF involves raising the inlet of a culvert by building an upstream structure using railroad ties, rock, and grout. Installation was done by volunteers over a weekend. The structure is capturing sediment and slowing runoff on an estimated 70 acres (28.3 hectares) of riparian area. Since the total cost of materials for the project was only \$700, costs for the work were a minimal \$10/acre (\$25 per hectare)! Other similar examples demonstrate that effective structures need not be large or expensive. Small, well-implemented designs are often less labor-intensive and require less future maintenance than large, elaborate measures.

SUMMARY AND CONCLUSION

For many reasons over many years, road location, design, construction, and maintenance have commonly proven detrimental to riparian areas and related resources, reducing acreages and multiple values. We now realize that many opportunities exist to regain lost acreages and values. Since many recommended techniques are relatively small and simple, costs for most design adjustments are inexpensive. Accumulated multiple benefits derived in most cases easily outweigh any additional costs. Technology to accomplish these goals already exists and continues to evolve today. Little research and development is needed to implement many of these practices; how-

ever, some research will be helpful in defining rates and kinds of benefits derived. Awareness and enthusiasm provide the keys to success in managing our road systems to enhance riparian areas and related benefits.

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