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Managing Roads for Wet Meadow Ecosystem Recovery

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16. Abstract

Riparian and watershed restoration and enhancement has gained the spotlight in recent years. Effective restoratin techniques are not often well understood. The Forest Service began a program of watershed restoration about 10 years ago. The focus of this effort was to "keep the water on the mountain" and as a result improve riparian habitat.

The objective of this project is to publish a riparian restoration guide which will be used as a reference document for use in understanding wet meadow functions, identifyng treatment opportunities, planning and implementing new or remedial treatments, and monitoring results.

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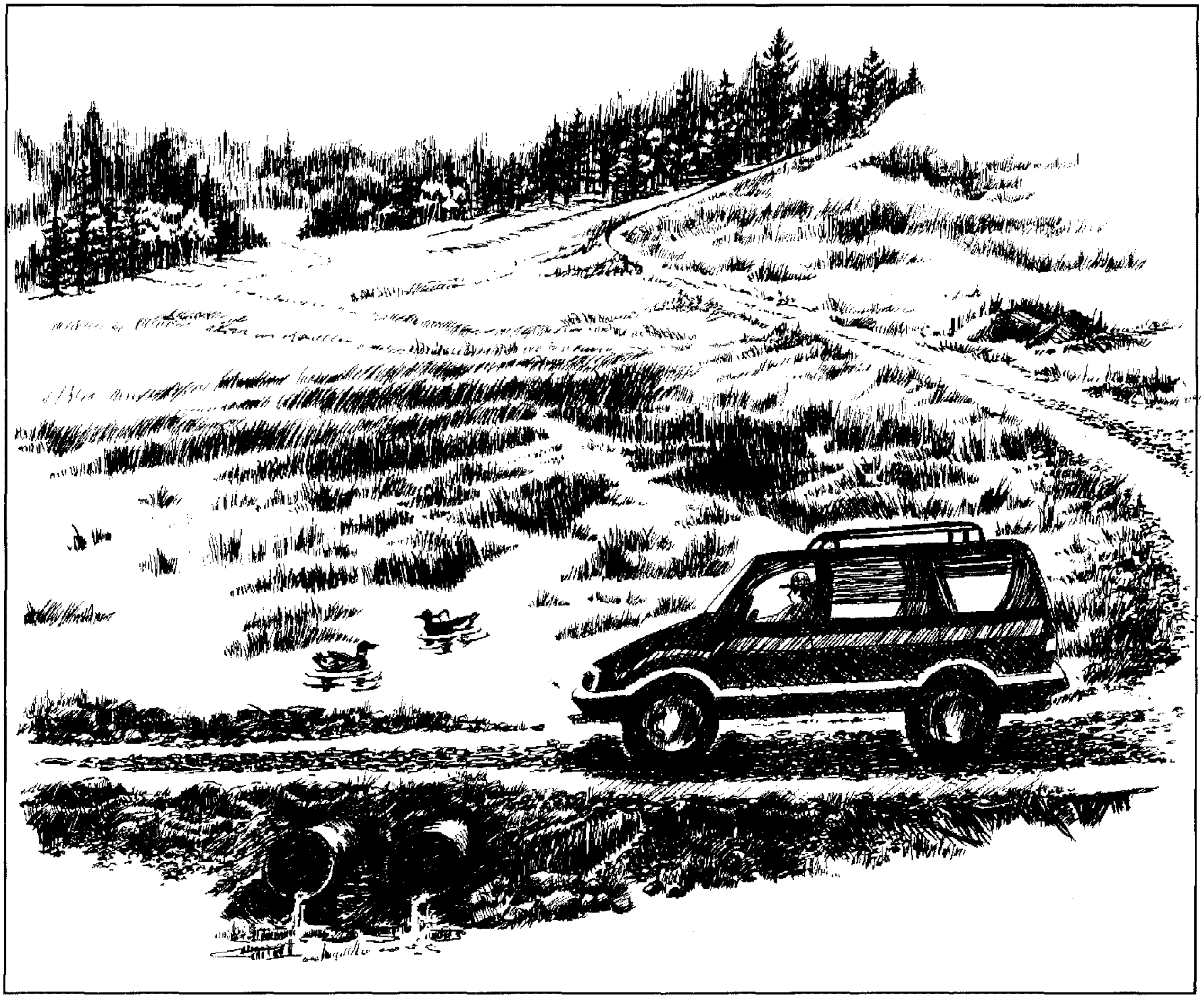
June 1995 William D. Zeedyk
Sandia Park, New Mexico

Managing Roads for Wet Meadow Ecosystem Recovery



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Credits

Gene Zeedyk: Frontispiece, Figures 33, 39.
Bill Zeedyk: Figures 1–21, 23, 26–32, 34–36, 38, 40, 42, 43, 47, 49–55.
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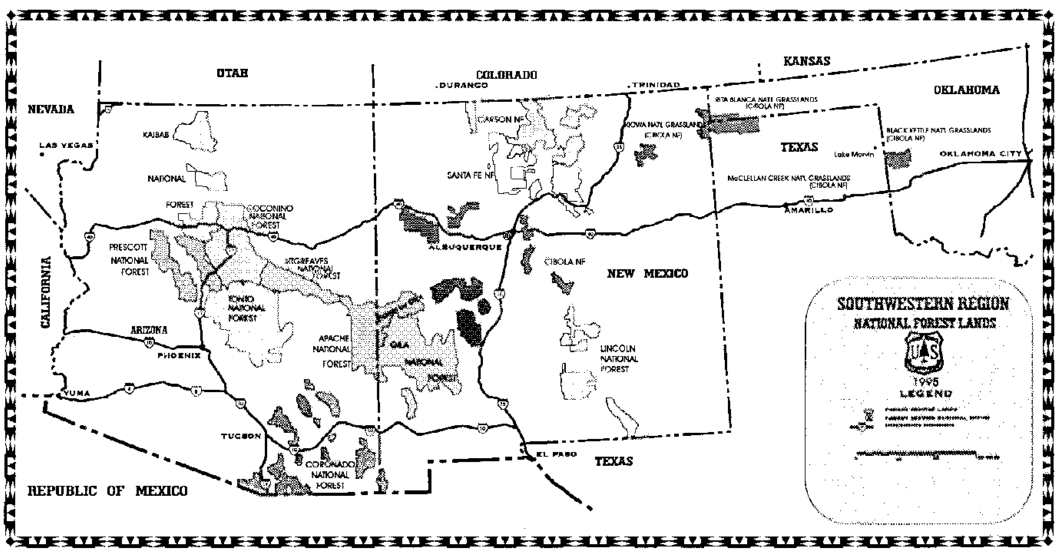
Introduction

Wet meadow ecosystems are among the most productive of all Southwestern ecosystems, but many have been impacted by an ever-expanding network of roads. Occurring on all National Forests of Arizona and New Mexico (Map 1), wet meadows sustain a great variety of ecological functions benefiting society and the natural world. Many have already been lost or impaired by human development. Fortunately, a greater sensitivity to natural processes by land and resource managers has motivated an emerging cadre of professionals to explore innovative ways for managing roads for wet meadow protection and recovery.

Surrounded by dense forests and arid mountain grasslands, wet meadows beckon visitors to stop and enjoy their beauty (Figure 1). Wet meadows provide food, water and cover for wildlife and forage for livestock. And while providing many benefits for mankind, wet meadows sustain a great variety of hydrologic and ecologic functions vital to ecosystem integrity. These functions include flood abatement, sediment retention, groundwater recharge, nutrient capture, and plant and animal diversity—natural functions of great importance to our burgeoning human populations.

People have used meadows for millennia. Native Americans gathered wild plants, hunted animals, raised crops and worshiped amidst these fertile wetlands. European settlers, first Hispanics then Anglos, grazed their cattle, sheep, burros and horses on the lush meadow grasses, and built communities where water and forage were readily available (Figure 2). Early access for settlement was by footpath, game and cattle trails. Soon, footpaths and trails were replaced by wagon roads and wagon roads became haul roads and highways. Some early roads skirted the edges of meadows where the going was easy, while others cut through



Map 1. National Forest System lands of the Southwestern Region.

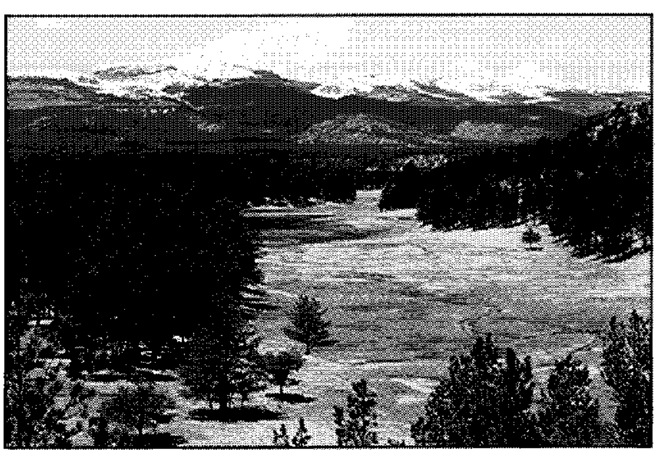


Figure 1. Surrounded by forests and grasslands, wet meadows beckon visitors to enjoy their beauty.

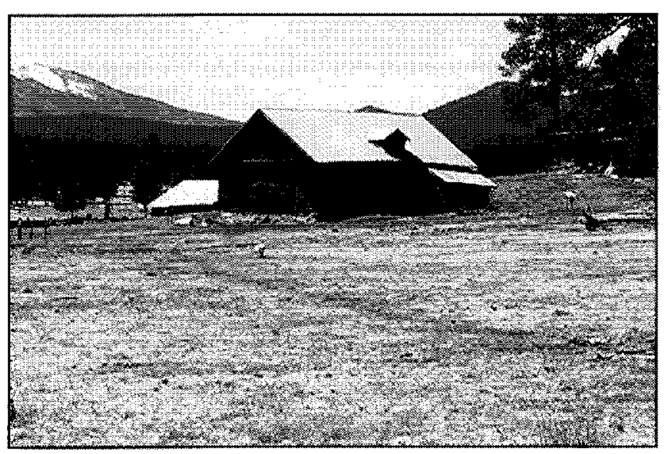


Figure 2. Early settlers built communities where forage and water were easily available.

their centers, crisscrossing streams and rivers and initiating the first spreading waves of erosion. Unfortunately, newer, more modern roads often hewed to the original routes, even when less destructive ways were readily available. As road systems expanded with the advent of modern construction equipment, impacts on wetlands became increasingly severe.

This is not to suggest that wetlands were deliberately destroyed, but only that these valuable assets were not recognized for their real worth. Roads were needed and good engineering practice required, and still requires that surface and groundwater flows be diverted and drained away from road surfaces and embankments. The goal of road construction was to deliver traffic safely from one point to another as cheaply as possible. Water was seen as a liability and drainage was expedient.

Today that view is changing. It has become not only feasible, but desirable to accommodate ecosystem values in construction and maintenance operations, while still achieving the goal of safe, speedy and economical travel. Methods are evolving for the effective protection and restoration of wetlands threatened or damaged by road building.

Across the Southwest an estimated 35 percent of wetlands present at the advent of European settlement has been lost, according to the National Wetlands Inventory (Dahl, T.E. 1990). As wetlands continue to disappear, or were degraded, those remaining in National Forest ownership, mainly wet meadows, become increasingly more valuable. The most valuable attributes of wet meadows occurring on the National Forests are: 1) clean, high quality waters relatively free from industrial, municipal and agricultural pollutants; 2) public ownership with management dedicated to public purposes, and 3) relatively intact communities of native plant and animal species.

Place names and townsites suggesting the high importance of wet meadow locations to early settlers dot the map—Hay Lake, Dry Lake, Laguna Seca, Mud Lake, Rice Park, Elk Meadows, Post Office Flat, Round Cienega and Centerfire Bog. Unfortunately, many of these historic sites have been seriously degraded. Crisscrossed by roads, drained for agriculture, trampled, compacted and eroded, many wet meadows have lost much of their inherent productivity.

Today, a new philosophy of road management, evolving in concert with broader public support for sustainable ecosystem management, is discovering and acting upon newly recognized opportunities for wet meadow restoration regardless of the causes of degradation (LaFayette et al, 1992). Changes in road construction and maintenance practices have produced remarkable recovery of degraded sites. By modifying channel crossings, relocating or realigning critical road segments, and modifying surface drainage features, engineers have reduced or eliminated road related wet meadow impacts at many sites while bringing about substantial recovery in ecosystem function. Examples are now in place and functioning on all National Forests in the Southwestern Region. The effectiveness of pilot treatments is being monitored and a second generation of treatments is emerging.

Pilot projects were first installed incidental to routine road maintenance or reconstruction activities beginning about 1986. A few were also completed by volunteer organizations as citizen conservation projects. Upon interpreting initial results, a second generation of treatments was implemented with the reconstruction of Forest Road 480 on Mount Taylor Ranger District, Cibola National Forest, New Mexico, and at many locations on the Apache-Sitgreaves National Forests, Arizona. Improved designs were being installed beginning in 1995 in the reconstruction of Forest Roads 49 and 50, Cibola National Forest, by the Federal Highway Administration (Figure 3). Potential benefits from this project include the projected recovery of up to 2,000 acres of historic wet meadow and riparian habitats.

Meadow restoration is quickly rewarded by improved environmental conditions and expanded ecosystem function. But economic benefits also accrue.

Economic benefits are realized in the form of reduced road maintenance costs, flood damages averted, increased forage yields, extended reservoir life, and re-

Figure 3. Improved designs are being installed in the reconstruction of Forest Road 49, Cibola National Forest, by the Federal Highway Administration.

duced cost of maintaining irrigation systems. Other benefits include increased fisheries and recreational values as stream flows become more dependable.

The changing roles of resource managers, engineers and transportation system planners are clear. First, professionalism requires a heightened awareness of the direct relationship between road management practices and ecosystem sustainability. Managers must learn to recognize degraded sites. Next, an inventory of restoration opportunities is needed for integration with ongoing or planned construction, maintenance and ecosystem investment projects.

Training is needed in the use of appropriate treatment measures. Funding of planned projects must be secured from appropriate internal sources or from outside parties through cooperative agreement or by donation. Finally, a public outreach effort is needed to inform the public of the need for, and the benefits to be derived from, activities of this sort.

The purpose of this handbook is to provide a reference document for use in understanding wet meadow functions, identifying treatment opportunities, planning and implementing new or remedial treatments, and monitoring results.

I. Wet Meadow Characteristics and Functions

Definition

Wet meadows (Figure 4) are riparian grasslands having low velocity surface and subsurface flows (Table 1). Stream channels are typically poorly defined, interrupted or nonexistent unless incised by recent erosion. Vegetation is dominated by wetland obligate species, principally grasses, sedges and rushes. A variety of wetland dependent fauna may be present. Soils are hydric.

For the purpose of this publication, the term wet meadow spans a continuum of plant communities and hydrologic conditions including wet meadows, cienegas and playa habitats. A broad representation of wet meadow communities is included in recognition of the vital role these habitats play in local, regional and continental ecosystems. Although this book is directed primarily at open-basin drainages, wet meadows and cienegas, a discussion of playa basins is included if road management considerations might be relevant to protection and management of playa habitats.

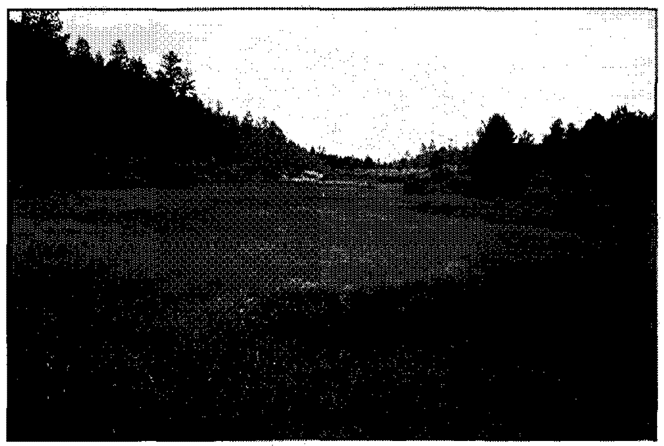


Figure 4. Wet meadows are riparian grasslands having low velocity surface and subsurface flows.

Table 1. Typical Characteristics of Southwestern Wet Meadow, Cienega and Playa Habitats

	Wet Meadow	Cienega	Playa
Basin Form	Open	Open	Closed
Principal Water Source	Channel Discharge Alluvial Groundwater	Deep Groundwater	Channel Discharge Overland Flow
Flow Regime	Riverine, Frequently Flooded by Annual Snowmelt and Storm Events	Relatively constant. Flooded only by overland flows.	Not Applicable
Flow Velocities	Low to high surface Low subsurface	Low surface and subsurface.	Ponded
Soil Profile	Banded. Fine to loamy surface. Sandy-gravelly subsurface on cobble or rubble.	Deep, fine, highly organic, mineralized.	Very deep silts and clays with clay pan.
Aeration	Seasonally variable from aerobic to anaerobic.	Surface aerobic, subsurface anaerobic.	Surface poorly aerobic. Subsurface anaerobic.
Saturation	Seasonally variable from saturated to drained.	Perennially saturated.	Usually saturated except during drought cycles.
Vegetation	Wetland obligate and faculative grasses, grass-like plants and forbs; scattered upland plants.	Wetland obligate grasses, grasslike plants, some shrubs and forbs.	Submergent and emergent wetland obligates (cattail, rushes, bullrush, pondweeds).
Principal Moisture Loss	Downchannel flow Evapotranspiration.	Downchannel flow Evapotranspiration	Evapotranspiration

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Wet meadows are wetlands within the purview of the National Wetlands Inventory in that: wet meadows are perennially or seasonally inundated for 7 or more consecutive days during the growing season, soils are hydric, and vegetation is dominated by wetland obligate or wetland facultative species. For a complete list of species, see "National List of Plant Species That Occur in Wetlands: Southwest" (Region 7) (Reed, P.B. 1988). For a list of wet meadow indicator plants, see Appendix A.

Within the context of USDA Forest Service Southwestern Region's Riparian Area Survey and Evaluation System, a wet meadow might be viewed as a landform comprised of the aquatic zone and the riparian zone superimposed. The aquatic zone is that portion of the meadow that is wetted by ephemeral, intermittent or perennial surface flow. The riparian zone is that portion wetted by the capillary fringe of the water table and within the rooting depth of riparian dependent plant species.

Characteristics

Wet meadows exist as open-basin wetlands in contrast with playas, which are closed. The water table beneath a wet meadow fluctuates continually, rising and falling with incoming runoff events and as alluvial storage is gained or lost primarily to downchannel flow.

Soil moisture is gained from on-site precipitation, channel flow, overbank and overland flow and groundwater discharge (Figure 5). Moisture is lost to evapotranspiration, downchannel runoff and groundwater recharge. Because of frequent flushing events and edaphic factors, soil pH, salinity and alkalinity remain typically low. In contrast, salinity and alkalinity tend to increase in playa basins where dissolved salts accumulate continually as moisture is lost mainly to evapotranspiration. Depending upon channel characteristics and surface features, ephemeral, intermittent or perennial pools may occupy wet meadow sites and develop plant communities representative of more aquatic environments.

Figure 5. Moisture is gained primarily as overbank flow.

Characteristic wet meadow plants are dependent upon basin discharge or groundwater flow for soil moisture and cannot survive on direct precipitation alone. In the Southwest, basin discharges are generated primarily by snowmelt or monsoonal storm events (Figure 6). Unless sustained by groundwater discharge, water tables beneath wet meadows are in constant flux, rising and falling in response to the volume, intensity, timing and duration of discharges from the contributing watershed.

Figure 6. In the southwest, basin discharges are generated primarily by snowmelt and monsoonal storm events.

As the water table rises and falls, the availability of free oxygen changes rapidly. While in flowing waters may be well oxygenated, free oxygen is quickly exhausted from subsurface levels by chemical oxidation/reduction processes. As the water table drops, air reenters subsurface levels through soil macropores only to be expelled again with the next rise in the water table. With each rise and fall of the water table, soil moisture conditions vary back and forth from aerobic (well oxygenated) to anaerobic (non-oxygenated). Plants characteristic of wet meadow sites, therefore, must be evolutionarily adapted to survival under alternating periods of aerobic and anaerobic soil moisture conditions. In contrast, upland plants which may invade degraded wetlands are not adapted to survive in anaerobic conditions.

Plant nutrients tend to be readily available in wet meadow soils for two reasons: First, dissolved nutrients continually arrive in groundwater and in runoff from upslope sources. Secondly, nutrients are also supplied in runoff as cations attached to, or abhering to, clay particles and organic matter suspended in the water column. Therefore, plant nutrients are continually resupplied, although not necessarily in the proper balance for optimum plant growth. Among plant nutrients, nitrogen tends to be most abundant following snowmelt whereas available phosphorous may be in constant shortage.

With abundant nutrients and available soil moisture, plant production is high. In fact, biomass production from wet meadow sites may be as much as twenty-five times that of adjacent uplands. Conversely, due to cooler soil temperatures and deficient oxygen supplies, organic decay proceeds more slowly in wet meadow soils than on adjacent slopes. Because production exceeds decomposition, organic material tends to accumulate in wetland sites as evidenced by accumulating litter, black or grayish soil color, and high humus content (Figure 7).

Figure 7. Organic production exceeds decomposition as evidenced by undecomposed litter, soil color and high humus content.

Wet meadow soils develop on fluvial deposits, that is, sediments deposited by running water. Therefore, soil profiles usually exhibit banded patterns of randomly intermingled layers of coarse and fine grained particles. Layers of sand or gravel may be sandwiched between layers of silt or clay, but surface layers are usually composed of silt and clay deposits with subsurface layers of sand, gravel or cobble. The arrangement of sediment deposits may determine the rate of subsurface flows percolating through a wetland. Clay layers inhibit gravitational flow but expedite capillarial, whereas the reverse is true of sands and gravels. Soil depths can be surprisingly thin, a condition that increases the vulnerability of wet meadows to erosional disturbances.

Soils derived mainly from basalt, volcanic ash, limestone, siltstone or shale normally have high proportions of fine-textured silts and clays in the soil profile, whereas soils derived from granite, sandstone or conglomerate formations normally contain higher proportions of coarse-textured particles. If damaged by erosion or compaction, deep, fine-textured wet meadow soils may be more difficult to resaturate than soils composed of intermingled layers of coarse and fine-textured deposits.

High elevation meadows have cooler soil temperatures, more precipitation, lower rates of evapotranspiration and shorter growing seasons than meadows at lower elevations. Water tables are more likely to be near the surface and channels tend to include more numerous reaches of intermittent or perennial flow. Conversely, wet meadows at lower elevations are characterized by longer growing seasons, warmer soil temperatures, increased evapotranspiration and more radical fluctuations in the water table. Therefore, erosional processes initiated by road related or other impacts are more likely to convert wet meadows at lower elevations from hydric to xeric condition. A rapid fluctuation in water table is not true for cienegas, which, by definition, are sustained primarily by groundwater flows and remain saturated throughout.

Hydrologic Functions

Wet meadows perform a variety of hydrologic functions operating through physical, chemical and biological processes. Primary among these functions are flow dispersal and energy dissipation, sediment detention, toxicant retention, groundwater discharge, groundwater recharge, and downchannel runoff. These functions are performed primarily through the processes of infiltration, percolation and evapotranspiration. The remaining functions are primarily ecological and are discussed below.

Hydrologic functions of wet meadows are vital to achieving one of the two purposes for which the National Forests were originally established under the Organic Administration Act of 1897, that is, the purpose of "securing favorable conditions of water flow." The capacity of wet meadows to perform various hydrologic functions depends upon a number of variables such as basin size relative to meadow size, topographic position in the watershed, depth and composition of sediment deposits, valley slope gradient, landscape form, surface roughness, and the composition and vigor of dominant vegetation. Hydrologic functions of wet meadow ecosystems are governed by a water budget and a sediment budget (DeBano and Schmidt 1989). Water is deposited into the water budget as on-site precipitation, as incoming channel flow, overbank flow, overland flow from adjacent slopes, and groundwater discharge. Water is "saved" in the budget as surface and subsurface storage, and lost or "spent" as downchannel runoff, evapotranspiration and groundwater recharge.

Continuing with the analogy by DeBano and Schmidt, sediments in the sediment budget are deposited from bedload, filtered from turbid runoff, or transformed from dissolved minerals in runoff and from groundwater flows. Sediments accumulate in a "sediment bank account" to be withdrawn by erosion. Unlike the water budget which performs like a checking account experiencing a continuing flow of deposits and withdrawals, the sediment budget performs more like a savings account with spasmodic deposits and withdrawals in response to major storm events.

With time, sediment deposits deepen and the surface area of a meadow expands to occupy the physical confines of the landform available. Coarser, heavy particles drop out of the bedload first, as runoff velocities slow, and are deposited at the head or upstream end of a meadow as the meadow expands, but may be resorted later by subsequent runoff events. Finer materials tend to be deposited downstream or toward the outer margins of the landform where runoff velocities slacken; thus, as deposits deepen, late arriving finer materials come to overlay earlier, coarser deposits. As the meadow surface rises, stream gradient is reduced, stream velocity decreases and the channel becomes more sinuous, meandering back and forth across the meadow. Additional sediments may entirely obliterate the channel, depending upon available stream energy as compared with sediment loading. The height and density of wetland vegetation directly affect the rate of sediment deposition by reducing runoff velocities and trapping sediments.

Eventually an equilibrium is reached in which sediments aggrading on the surface of a meadow are balanced by losses to erosion. Whenever sediment deposition exceeds erosion, a meadow expands; when erosion, due to the loss of vegetation or as the result of severe storm events exceeds deposition, the meadow degrades.

With time and a vigorous plant community, sediment accumulations begin to march upslope on steeper and steeper gradients rendering the entire system vulnerable to calamitous erosion following disturbances, such as road construction or overgrazing. Cienegas developing on steep slopes are particularly vulnerable to erosion due to fine-textured soils, and the high velocity flows that result if protective cover is removed (DeBano and Schmidt 1989).

When the rate of erosion exceeds deposition, the ability of a meadow to detain and store water diminishes and it begins to dry. As a meadow dries, the dense stands of riparian vegetation decrease, exposing the fine-textured soils to erosion. As channel incision and gully formation worsen, periodic surface flooding no longer occurs and riparian vegetation disappears leaving only remnant areas of formerly hydric soils as evidence of site potential.

Playas differ from wet meadows in losing water primarily to evapotranspiration rather than downchannel runoff. Consequently, sediments and minerals continually accumulate in playa basins. Fine grained particles may accumulate to relatively great depths and a clay pan may develop that inhibits percolation, thus groundwater recharge from playa basins may be negligible in comparison with that from wet meadows.

Infiltration and percolation are the processes by which meadow soils are wetted. Infiltration occurs when moisture penetrates the soil surface, with the rate of infiltration depending upon surface porosity. Compaction by trampling inhibits infiltration, but in-

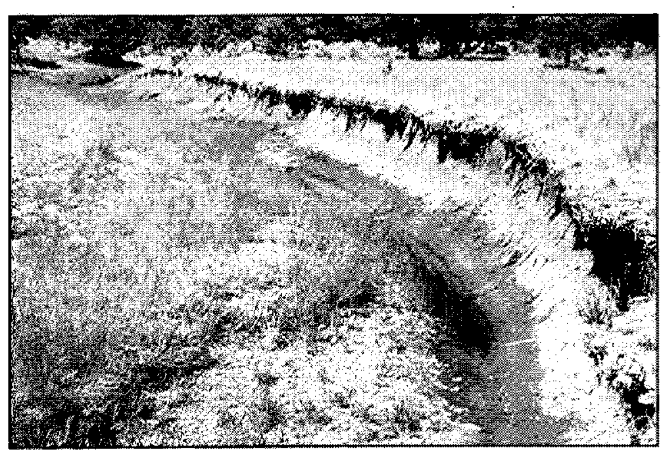

Figure 8. Capillary forces are most powerful in clay soils but particles must be premoistened for water to be wicked through the soil profile.

creased soil porosity resulting from penetration by the fibrous roots of grasses and sedges and activities of burrowing animals enhance it.

Percolation is the process whereby water moves through the soil profile and is the product of two forces: gravity and capillary action. Gravity draws water downward through soil pores. But capillary action draws water both vertically and horizontally, that is, in any direction depending upon the force of capillary tension between soil micropores. Thus gravitational percolation moves water more quickly through coarse-textured soils but more slowly through fine-textured soils. The opposite is true for capillarial percolation. Capillary forces are most powerful in clay soils, but the particles must be premoistened, like the fibers of a sponge, for waters to be wicked rapidly through the soil profile, as shown in Figure 8 on the preceding page. If soils are prewetted, capillary force can even wick water over low ridges on the meadow surface and from adjacent uplands, but it cannot wick water across gaps in the meadow surface. Gaps in the surface are barriers to capillary flow. Erosion gullies are serious barriers to capillary flow and once dry, gully walls are difficult to resaturate.

Ecological Functions

The ecological functions of wet meadows can be broadly divided between environmental modification and organic production (Figure 9). Ecological functions are manifest as the diversity and abundance of vegetation, nutrient removal, terrestrial diversity and abundance, aquatic diversity and abundance, and community diversity. The function of nutrient export is both hydrologic and ecologic. Ecological functions are carried out mainly through biological processes of photosynthesis, transpiration, propagation, herbivory, carnivory and microbial decomposition operating

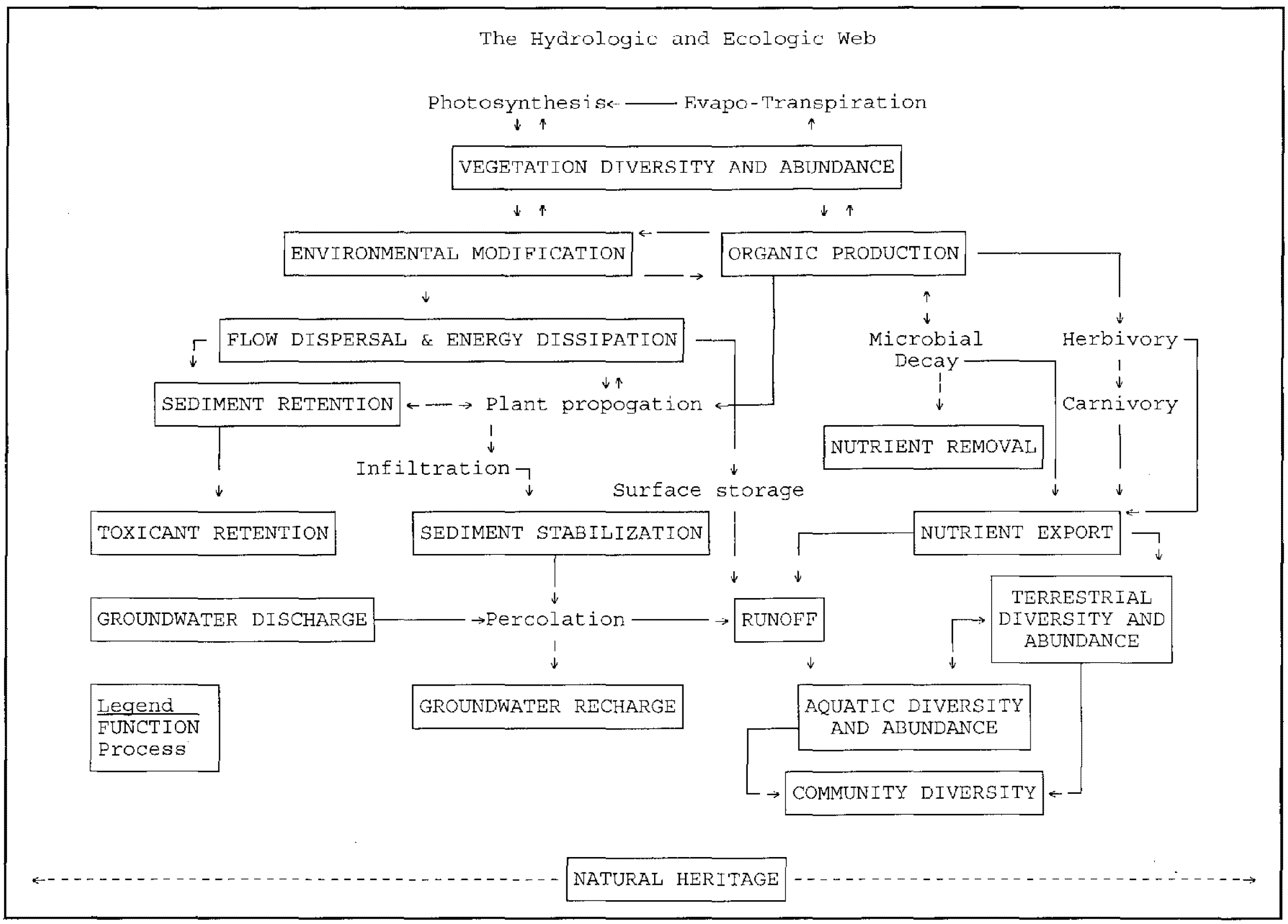

Figure 9. Ecosystem functions of wet meadows.

Figure 10. Biological processes affect the hydrologic environment by moderating runoff velocities.

through the growth, dispersal and decay of plants and the activities of animals.

Without biological modification of the hydrologic environment, wet meadows would not exist. Biological processes affect the hydrologic environment by moderating runoff velocities and the rates of sediment movement and nutrient transport (Figure 10). Wetland plants slow runoff, trap and retain sediments, and transform dissolved nutrients into organic compounds. By slowing and dispersing runoff, riparian plants facilitate infiltration and temporarily detain surface waters. Accumulated surface and subsurface moisture further stimulates plant growth, density and vigor. By propagation through seeds and other propagules, wetland plants, especially sedges, colonize freshly deposited sediments, as shown in Figure 11. Their roots bind sediments in place where chemical processes help to stabilize sedimentary deposits. Sediments accumulate until the geomorphic limits of

Figure 11. Riparian plants, especially sedges, colonize freshly deposited sediments.

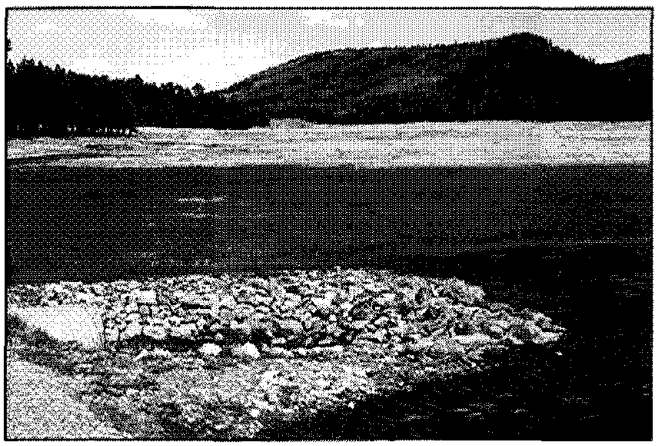

Figure 12. Zones or bands of vegetation shift position as hydric soils develop.

Figure 13. Herbivorous animals are attracted to the succulent, palatable and nutritious forage that grows in wet meadows.

the site are fully occupied, at which point deposition and erosion come into approximate balance.

In addition to stabilizing sediments, the fibrous roots of grasses and grasslike plants keep soils porous, which facilitates infiltration and percolation. Infiltration through the fibrous root systems of grasses and sedges is known to be more rapid than through the dendritic root systems of woody plants. Grasses and sedges also provide habitats for burrowing vertebrate and invertebrate animals, e.g., pocket gophers, voles, ants and crickets, further improving soil porosity.

As biomass accumulates, an increasing diversity of microhabitats evolve in response to subtle differences in soil texture, flooding regimes, soil temperature, aeration, compaction and other variables. For this reason, wet meadow vegetation takes on a zonated appearance reflecting the relative dominance of variously adapted plant species. Zones or bands shift position over time and rapid shifts are obvious at recently restored sites in response to the development or redevelopment of hydric soils (Figure 12).

Organic production is high on wet meadow sites, ranging upward to 5,500 pounds per acre per year, as compared with more xeric upland sites with as little as 200 pounds. Herbivorous animals are attracted to the rich forage base where growth is rapid and forage is succulent, palatable and nutritious (Figure 13). While populations of herbivorous vertebrates such as livestock, deer, elk and pocket gophers may be more apparent, populations of herbivorous invertebrates, such as ants and grasshoppers, may comprise the larger total biomass (Figure 14). An abundance of prey attracts a variety of carnivorous animals ranging from spiders to bats, shrews to eagles. Some vertebrates, especially birds, alter their role in the food chain through the seasons to take advantage of the shifting abundance and nutritional quality of available foods and to satisfy their own nutritional requirements.

For example, adult Merriam's wild turkeys utilize meadows in early spring in search of new plant growth (herbivory). Later, hen turkeys with broods bring their young to the same meadows to feed upon grasshoppers and spiders (carnivory). Waterfowl alter their role in the food chain to meet changing dietary requirements depending on physiological needs of the season. Female cinnamon teal, for example, may consume a high proportion of invertebrate larvae in preparation for nesting while their mates glean sedge

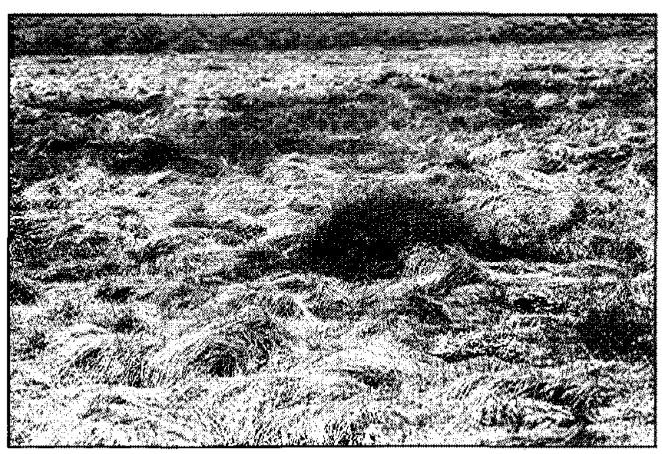

Figure 14. Large herbivorous animals may be more apparent but herbivorous invertebrates can comprise the larger biomass. An ant mound at a wet meadow, Cibola National Forest.

seeds or other plant parts from the meadow (Gammonley 1995). Omnivorous species, such as bears, coyotes and common ravens, regularly frequent wet meadows and consume a wide range of plant and animal foods. The combined activities of many highly mobile species transport significant quantities of nutrients off site. Thus the ecosystem function of maintaining terrestrial diversity and abundance is sustained. Wet meadows are key components in far broader ecosystems.

Concurrent with nutrient export by vertebrate species, decompositional processes carried out by microbial plants and animals reduce plant materials and animal feces to basic organic compounds and chemical elements. Such materials may be chemically altered and bound with minerals in the soil or become dissolved in subsurface flows to be flushed from the system as runoff supporting aquatic life further downstream. Other plant and animal materials may fall or be washed directly into stream channels, providing a food base for aquatic life. In this way, meadows fulfill an ecologic function of sustaining aquatic diversity and abundance. Interaction between the terrestrial and aquatic communities creates the total biotic community or diversity characteristic of an area.

This tangled web of hydrologic and ecologic functions is displayed in Figure 9, but many aspects are closely related and difficult to distinguish. Wet meadow ecosystems do not possess easily definable limits. Ecological threads radiate outward linking meadow communities with forests and prairies, rivers and wetlands, near and far. Migrating waterfowl, raptors, shorebirds, and songbirds which stop to feed or rest for a day or week at a secluded meadow, may continue onward to breed in the subarctic tundra or winter on the pampas of South America.

Feedback is important to wetland function. Feedback loops are represented in Figure 9 by double-headed arrows indicating the magnification of a function or process with an increase in the related function. For example, total photosynthetic activity will increase with an increase in plant diversity and abundance. Likewise, as base flows increase with increasing bank storage capacity, aquatic diversity increases, further modifying the nature and timing of runoff events, such as occurs when willows or beavers colonize a wetland.

Healthy wet meadow ecosystems make vitally important and timeless contributions to the natural heritage of Southwestern National Forests. But the ecological function of wet meadows can be artificially limited by human impacts such as drainage of surface or subsurface flows, diversion of in-channel and overland flows, groundwater depletion, accelerated erosion, the introduction of coarse-textured overburden from off-site sources, and soil compaction by vehicles, trampling by wild ungulates, livestock and humans.

Distribution

Wet meadow ecosystems exist where channel obstructions or a change in slope gradients have resulted from seismic uplift, or where intruded volcanic dikes, extruded lava flows, ash flows, glacial moraines, alluvial fans or rockslides resist erosion and induce sediment deposition. Wet meadows may sometimes develop on stream terraces or on floodplains receiving runoff from lower-order side channels. Some have developed on former Pleistocene lake beds, along the margins of playa basins, and in valleys long subjected to beaver activity.

The most extensive wet meadow systems on National Forests of the Southwest can be found in association with extruded basalt flows such as those found on Anderson Mesa of the Coconino National Forest, in the White Mountains of the Apache National Forest, on the Taos Plateau surrounding San Antonio Mountain on the Carson National Forest, and in the Jemez Mountains of the Santa Fe National Forest. Isolated wet meadows associated with regional uplift occur in the Sangre de Cristo, Sandia, Manzano, and Sacramento Mountains of New Mexico, and along the Mogollon Rim and in the Juniper Mountains of the Prescott National Forest, Arizona. In the Zuni Mountains of New Mexico, wet meadows owe their existence to seismic uplift, extruded lava flows and rockslides. The Spur Lake Basin near Luna, New Mexico, is a former Pleistocene lake bed supporting an extensive, but highly degraded, wet meadow ecosystem.

Wet Meadow Values

Paraphrasing from Adamus (Adamus et al., 1991), wet meadow values relate to those wetland attributes society finds valuable whether or not these are important to the integrity of the wetland itself.

Because wet meadows are a subset of wetlands, values that apply to wetlands in general apply to wet meadows specifically, but it is difficult to compile a set of values unique to wet meadows alone.

Broad values applying to wetlands include: 1) reduced flood intensities and frequencies, resulting in reduced damage and economic losses; 2) increased sediment retention resulting in less rapid sedimentation of reservoirs, irrigation systems and water works; 3) improved water quality benefiting fisheries, recreation, municipal, industrial and agricultural uses of downstream waters (Figure 15); 4) aquifer recharge resulting in cheaper pumping costs and extended longevity of investments reliant on groundwater sources; 5) base flow augmentation benefiting fisheries, recreational and other dependent uses (Figure 16); and 6) other values related to natural heritage functions such as habitats for sensitive species, and scientific, educational, cultural and religious benefits.

Values specific to wet meadow locations (Figure 17) and attributes include:

- Key habitats for adapted wildlife which nest or feed in wet meadow or playa habitats.
- Courtship and prenesting conditioning habitats for migratory waterfowl, shorebirds and songbirds.
- Habitat for threatened, endangered and sensitive species.
- High yields of succulent, palatable and nutritious forage important to livestock and native wildlife such as elk, mule deer and antelope (locally).
- Reliable and dependable forage sources in times of local or widespread drought.
- Focal settings for wetland specific recreational activities including nature study, photography, birding, fishing and hunting.

Figure 15. Wetlands remove suspended sediments from runoff, improving water quality.

- Traditional settings for cultural, religious or spiritual observances of community or individual importance.
- Scenic diversity and relief for recreational users and travelers in forested landscapes.
- Pastoral settings for passive recreational pursuits, e.g., camping, picnicking, hiking and biking.

Figure 16. Base flow augmentation benefits fisheries, recreational and other uses of streams flowing through wetlands.

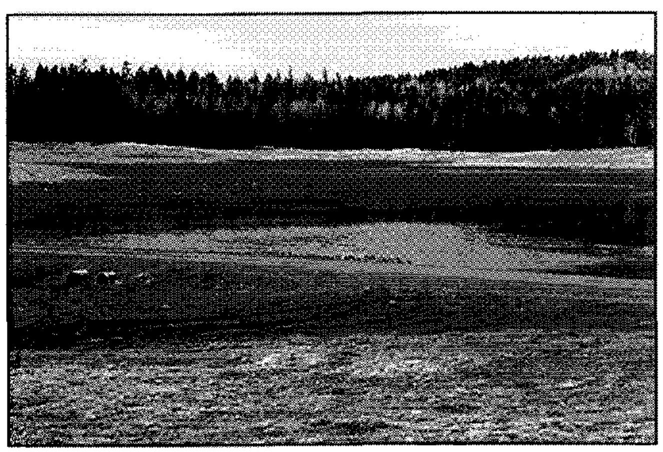

Figure 17. Wet meadows provide waterfowl habitat, livestock forage, water storage, recreational and other values to society.

II. Road Related Impacts and Opportunities for Restoration

Scope

The Forest Service maintains about one mile of road per 400 acres of National Forest land in the Southwestern Region, or about 52,000 miles on 22,000,000 acres, including about 6,500 miles of roads designated as suitable for use by low-clearance vehicles and passenger cars.

State and county governments manage many additional miles under easement, cooperative agreements or special use permit. Presently, the Forest Service is building few new roads but the states, counties, Federal Highway Administration, and private entities continue with construction activities.

There is continued expansion, in some areas, in the mileage of unauthorized 2-track roads, many of which directly affect wet meadow ecosystems since open meadows offer the easiest routes of travel. On the other hand, many sensitive areas have been successfully closed to off-road travel, a practice which protects some wetlands.

What proportion of the total transportation system crosses or affects wet meadows and riparian areas is unknown, but travel routes do tend to follow stream courses and there seems to be a bias toward selecting open meadow environments as travelways. The nature of meadow impacts ranges from slight to severe, for until recently, wetland impacts were rarely considered in the routing or construction of roadways.

Figure 18. An unimproved ford at "S.A." Creek, near Luna, New Mexico, lowered the nickpoint, initiating headcutting in the upstream meadow.

Effects

Road construction can directly affect wet meadow hydrology and suppress biotic productivity by:

- Converting productive wetland to barren road surfaces and facilities.
- Constraining and diverting surface and subsurface flows.
- Dewatering wetlands.
- Concentrating and accelerating runoff.
- Creating a source of toxic pollution.
- Increasing sediment loading.
- Intercepting groundwater flows.

Roads can indirectly affect wet meadows by:

- Increasing/decreasing channel gradients and runoff velocities.
- Accelerating soil erosion and the loss of soil nutrients.
- Dewatering wetland sites.
- Triggering site conversion from wetland to upland species.
- Reducing organic production and forage yields.
- Impairing habitat effectiveness for wildlife.
- Degrading water quality.

Figure 19. Headcutting initiated by the ford, shown in Figure 18, has proceeded about 120 yards in 16 years.

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- Reducing base flows, increasing peak flood flows and flood frequencies.
- Reducing groundwater recharge.

Road management practices that most commonly damage wet meadow ecosystems involve:

- Building and maintaining roads on wet meadow locations instead of using suitable alternative locations or alignments.
- Installing channel crossings below gradient, a practice which results in accelerated runoff, erosion and channel incision, as shown in Figures 19, 20, 21, and 22.
- Installing in-meadow road ditches and drainage works below meadow surfaces, resulting in rill and gully erosion and surface drying (Figures 23 and 24 on the following pages).
- Constructing upslope road ditches and cross drainage structures in a manner which diverts and concentrates overland flows leading to erosion and desiccation of meadow soils.
- Intercepting and diverting groundwater away from cienegas and wet meadow sites.
- Neglecting to maintain cross drains and ditch systems, leading to concentrated runoff, accelerated velocities, erosion and sedimentation of wetlands.
- Conducting unnecessary ditch maintenance activities which increase sedimentation of wetlands and riparian areas.
- Surfacing roads with aggregates inappropriate to the site, slope or traffic loads, thus generating avoidable sedimentation.
- Borrowing gravel and fill materials from stream channels and meadow surfaces thus damaging the hydrologic function of meadows.

Figure 25 depicts common wet meadow impacts resulting from drainage structures.

Figure 20. The first wave of headcutting removes fine-textured surface soils, creating a gully and lowering the water table.

Figure 21. The second wave of headcutting removes coarse-textured subsoils, increasing the depth of gully entrenchment.

Figure 22. The combination of overgrazing and an overly deep culvert has caused erosion of this meadow.

Figure 23. An in-meadow roadside ditch intercepts surface and subsurface flows.

Opportunities for Restoration and Recovery

Opportunities for protecting and restoring wet meadow ecosystems while carrying out road construction and maintenance activities exist throughout the Southwest. Fortunately, treatments need not be complex or costly. The challenge seems to be in recognizing road related restoration opportunities and having the skills and flexibility to take advantage of them.

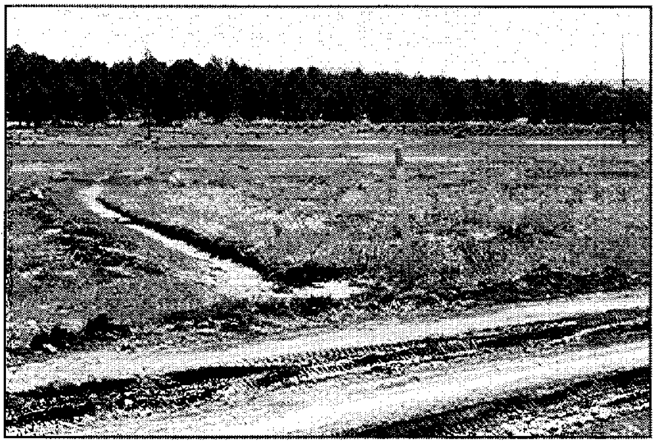

Figure 24. Lead-out ditches divert surface runoff and capture subsurface flows, lowering the water table.

Road construction does not, of itself, restore wet meadow habitats and the promise of restoration should seldom be used as the justification for construction activities. Other means are available. However, in the construction/reconstruction process, it is often quite feasible and highly desirable to incorporate emerging philosophies, methods and treatments for wet meadow protection and restoration into road planning and implementation processes. Some measure of riparian and wetland recovery can often be achieved through appropriate modification of construction and maintenance practices whether the degraded condition of affected wetland sites is primarily due to road related impacts or to some other disturbance. To be truly effective, and not merely substitute a new set of problems for the existing set, project objectives, design, and treatment activities must be clearly thought out in terms of locally specific hydrologic and ecologic realities of the site in question. Such an approach would not only avert future wetland degradation, but also provide realistic opportunities and expectations

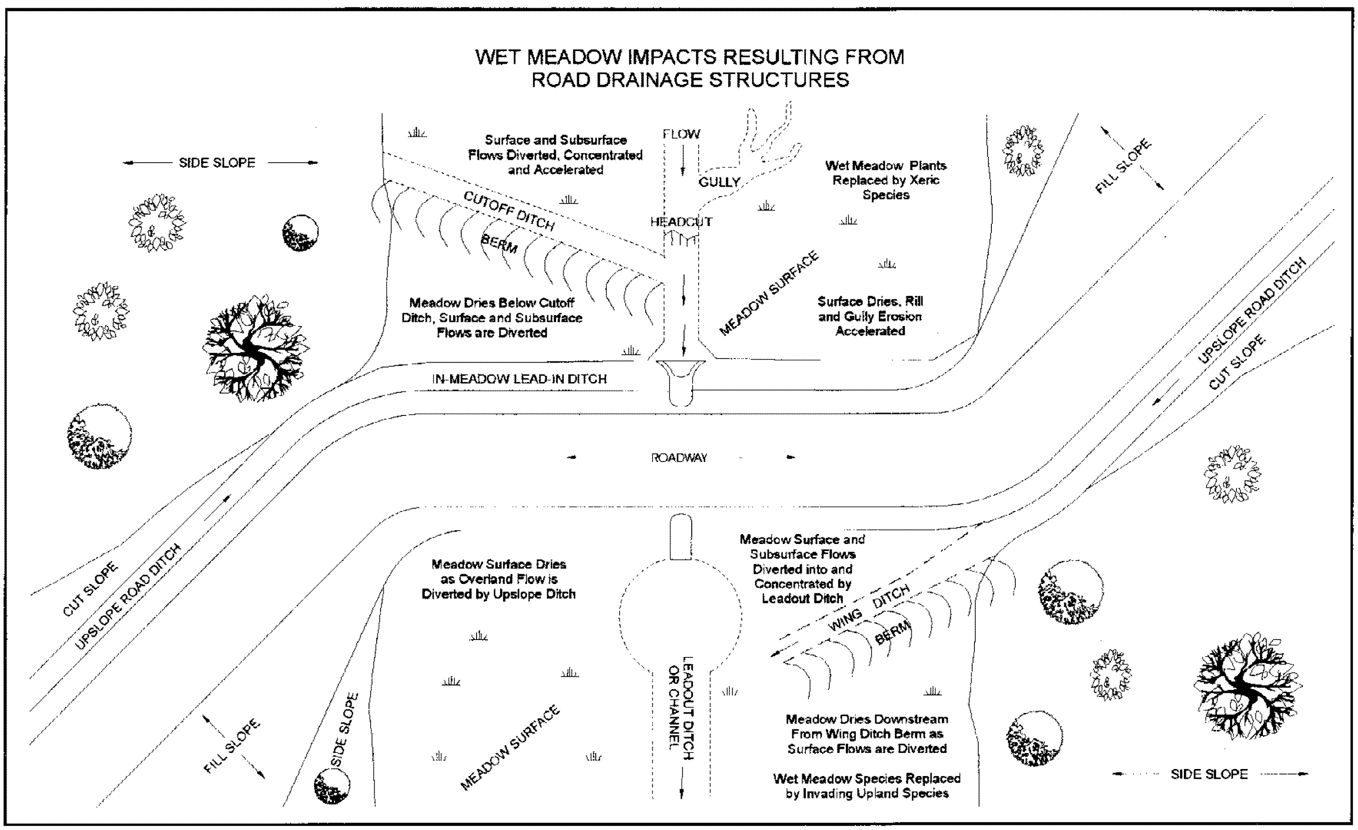

Figure 25. Typical wet meadow impacts resulting from improper road drainage structures.

for the restoration of damaged sites and, at least, avoid further deterioration.

While Forest Service road construction and reconstruction programs have been greatly reduced, some work continues (Figure 26). New roads are being built across National Forest lands by Federal, state, county and private agencies with ample opportunity for agency review of planned activities. Reconstruction and maintenance of existing roads continues and provides many opportunities for treatment of affected wetland and riparian areas as shown in Figure 27. Occasionally, emergency situations such as floods and fires offer a one-time opportunity to repair long standing riparian problems, but usually, under enabling funding authorizations, only replacement of existing facilities is allowed.

Figure 26. Construction of Forest Road 49, Cibola National Forest, provided an opportunity to install a reconstructed stream channel at Agua Fria Creek.

In addition to publicly funded programs, a host of volunteer conservation organizations such as Ducks Unlimited and Rocky Mountain Elk Foundation stand ready to assist worthwhile projects with funding and expertise (Figure 28). Businesses making use of National Forest road systems may also be willing to contribute time, money or machinery to ecosystem recovery for reasons of their own.

Most road related riparian restoration projects are directed toward restoring flows or raising the water table. But other site specific goals may be important such as diverting sediments away from playa basins, redirecting intercepted groundwater flows through wet meadows or cienegas, or improving seclusion for wetland dependent wildlife.

Figure 27. This earth fill berm was installed during routine road maintenance activities, Apache-Sitgreaves National Forests.

Obviously, road construction and reconstruction projects offer greater flexibility and more powerful options for meadow restoration than do maintenance projects. Usually, more funding is available and there is greater leeway in the choice of design, material, location and standards. But even on a day-to-day basis, routine road maintenance activities still present many opportunities for wetlands protection and recovery.

Restoration successes accomplished through construction or reconstruction projects have included relocating road corridors away from impacted wetlands; realigning roads to cross meadows on different locations or alignments; raising channel gradients to their historic elevations at crossings; installing permeable rock fills and multiple-culvert arrays at crossings to

Figure 28. This encased rock berm was constructed by a volunteer youth group at Round Cienega, Apache-Sitgreaves National Forests.

disperse flows across moisture-deprived, degraded wetlands, and; obliterating unwanted or obsolete travelways. There are innumerable remaining opportunities for applying similar treatments in the restoration of damaged and degraded wetland ecosystems throughout the Southwest and beyond.

Meadow recovery accomplished through routine maintenance has included projects such as the installation of drop inlet structures that effectively raised the inlet elevation of culverts, and the installation of additional cross drains to restore overland flow to downstream meadow surfaces. Unimproved fords have been replaced with properly elevated culverts or improved fords to raise depressed water tables. Meadow damaging unimproved roads and travelways have been closed or obliterated. Modification of long established maintenance procedures has put an end, on some National Forests, to the unnecessary, if sometimes customary practice, of pulling or blading well vegetated ditch systems. In some cases, diverted groundwater flows have been redirected and dispersed across cienegas and meadows. If maintenance standards, procedures and practices were rigorously reviewed, many opportunities for wet meadow recovery might be revealed.

III. Desired Future Condition

A desired future condition for wet meadow ecosystems affected by roads is one in which hydrologic and ecologic functions have been restored and can be maintained through socially and economically acceptable management practices (Figure 29).

Restored Sites

On restored sites, most or all of the following attributes will be evident:

- Flood energies are dissipated and surface runoff is well dispersed across the site during runoff events.
- A diversity of wetland obligate forbs, grasses and grasslike species dominate the site; a minor component of wetland obligate woody plants may be present.
- Upland plants, if present, comprise only a minor component of plant composition.
- A diverse community of riparian obligate and riparian faculative vertebrate and invertebrate fauna occupies the site.
- There is little or no active rill or gully erosion or headcutting; all channels are hydrologically stable.
- The water table occupies the natural topographic limits of the site and fluctuates in rhythm with hydrologic events occurring within the basin; hydric soils prevail.
- Organic production exceeds decomposition.
- Downchannel runoff is sustained by in-meadow storage.

Figure 29. Flanigan Meadow, Gila National Forest, exhibits the desired future condition of a wetland restored, in part, through road management treatments.

- Temporarily or permanently pooled surface waters collect in depressions on the meadow surface and are occupied by aquatic plants and animals in season.

Recovering Sites

For sites in a recovering condition, the following attributes may be present:

- Flood flows are dissipated and the area periodically saturated during runoff events is expanding.
- Fine grained sediments and organic debris are accumulating in gullies and channels and on the meadow surface; incised channels have been stabilized.
- The diversity and vigor of wetland obligate vegetation is increasing and site occupancy is expanding.
- An increasing diversity and abundance of riparian obligate vertebrate and invertebrate species is present.
- Upland plants characteristic of more xeric sites are decadent or disappearing.
- The water table is rising and its capillary zone is expanding; formerly hydric soils are recovering.
- There is an accumulating biomass of dead, partially decayed vegetation.
- Incised channels and gullies are stabilizing.
- Downchannel base flows are increasing in volume and permanence.
- Pooled surface waters may be present.

IV. How Meadows Heal

Wet meadows can heal when remedial treatments reverse the downward spiral in ecologic and hydrologic condition characterized by the following indicators:

- An incised channel with active headward erosion, i.e. headcutting;
- An eroding soil surface marked by sheet, rill or gully erosion;
- A lowered water table and receding capillary zone;
- Surface drying accompanied by the loss of formerly hydric soils;
- Declining populations of wetland plant species;
- Increasing or encroaching populations of upland plant species, and;
- The disappearance of wetland obligate fauna.

Restoration begins when available soil moisture increases and the duration of moisture availability is extended sufficiently to meet the minimum seasonal growth requirements of locally adapted wetland plants, especially sedges and rushes. If these two objectives—increasing soil moisture levels and extended growing season availability—can be achieved, other management objectives including sediment capture and erosion control will follow as the direct result of vegetative response to improved soil moisture conditions.

Basically, there are three approaches to increasing soil moisture levels and extending the duration of soil moisture availability: 1) impounding seasonal runoff; 2) dispersing seasonal runoff across the meadow surface, and 3) increasing subsurface flows. It is not necessary to inundate the site. In fact, for open basin wetlands, except groundwater fed cienegas, the goal is merely to re-establish a cycle of seasonal wetting and drying typical of the landform under management. In order to re-establish a typical wetting cycle, ephemeral or perennial surface ponding may be used as a means to an end, but any ponding effects will likely be transitory over the long term. Many wildlife and aesthetic benefits may be realized during the interim.

Various methods for achieving wet meadow ecosystem recovery are described in the following chapters. Except for those designed to increase the efficacy of buffer and filtration zones, all function by dispersing or temporarily impounding surface and subsurface flows.

Dispersing runoff, especially annual snowmelt events, across the surface of degraded systems seems to be more effective than impounding flow. Dispersal of surface flows has the beneficial effect of increasing both gravitational and capillarial percolation across the landform, whereas impoundment increases mainly capillary action along the margins of the impounded area unless the floodplain is inundated.

Water can be dispersed over the surface of a meadow by relocating or revamping ditch systems and cross drains, or by installing permeable rock fill embankments, for instance. Runoff can be impounded by raising culverts or culvert inlet elevations and by installing fords or low water crossings. Subsurface flows in areas below road crossings can be increased or dispersed by using road culverts, fords, permeable fills, and ditch modifications.

Dispersed Surface Flows

When surface flows are properly dispersed, existing vegetation quickly responds to the improved moisture regime. Soil moisture increases and its seasonal availability is extended. Plant densities and vigor increase and organic matter is added to the soil. Fine sediments, organic debris, and soil nutrients are filtered and captured from each new runoff event. Plant roots penetrate the soil and improve infiltration and percolation. Remnant populations, seeds and propagules of wetland plants respond to improved soil moisture conditions depending upon the degree of soil saturation. Recovery begins and spreads outward from the area first wetted.

When an area is first wetted, upland plants occupying the site display a burst of vigor, as shown in Figures 30 and 31 on the following page, but as soils become more saturated, roots of upland plants begin to die in the anaerobic environment. As soil aeration deteriorates, the plants lose vigor, become chlorotic and eventually die. Until upland plant species are replaced by invading wetland vegetation, a period of patchy cover may ensue. The rate of reinvasion will depend upon various characteristics of the new flooding regime, extent of flooding, rates of infiltration and percolation, and the availability of seeds and plant propagules and other factors. Most important of these other factors is the re-establishment of a contiguous, unbroken capillary zone within the rooting depth of native wetland species. Once re-established, a contiguous capillary zone can wick each new runoff event across and throughout the treated area, thereby dispersing water to the entire wetland community.

Figure 30. A wet meadow downstream from a raised culvert installed September 1992, Agua Media Creek, Cibola National Forest.

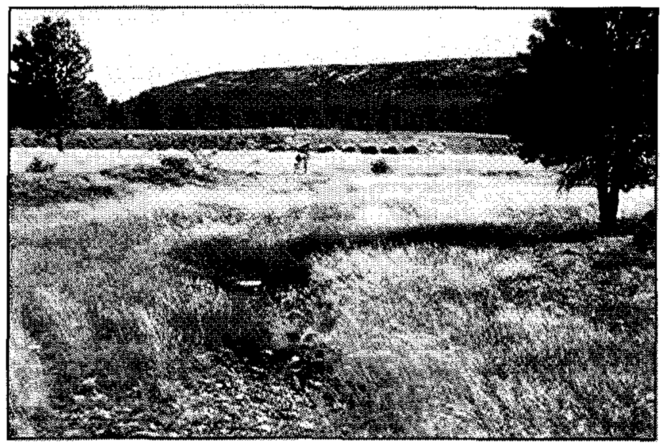

Figure 31. The same meadow as Figure 30, one year later. Note vigorous response of wetland faculative and upland species.

Various factors can delay or prevent the development of a contiguous capillary zone. These factors can include discontinuities in soil texture or breaks in the continuity of surface and subsurface soils such as gullies, ditches and former stream channels.

Decadence and mortality of upland plants proceed at varying rates by species. Usually gramma grasses and rabbitbrush, for example, fade quickly, but Kentucky bluegrass and ponderosa pine may persist for some time. Kentucky bluegrass and common dandelion, for example, are species that are somewhat adapted to moist soils but which do not compete well with invading wetland obligate grasses, sedges and rushes. Ponderosa pine will persist for some time if some portion of a tree's spreading root system extends to well aerated soil.

At least three problems can impede wetland recovery when using treatments based upon dispersed surface flow:

1) Ditches, gullies or channels may deliver excessive amounts of coarse-textured sediments to the site, burying productive soils under a veneer of infertile deposits;

2) Runoff may be channeled into and concentrated by abandoned roadways, channels or ditches thus accelerating erosion and further degrading the site; and

3) Excess runoff or ponding may temporarily inhibit revegetation of some sites.

Figure 32. Sedges colonized this delta fan which formed upstream from a raised culvert.

When assessing the effects of restoration efforts, look for evidence of increasing soil moisture, a rising water table, reinvasion by wetland vegetation and decadence among upland plant species. Evidence of site impairment, as described above, may require followup treatment to correct the situation.

Impounded Runoff

The purpose of this discussion is to describe the recovery process associated with sediment accumulation where channel runoff is impounded or detained. Wetland characteristics can be restored by detaining runoff through the use of raised culverts, or some other practice that raises the base level of channels as shown in Figure 32 on the preceding page. Surface ponding will develop with the first and each subsequent runoff event. Wetting of channel banks and the channel bottom occurs and a delta bar, or wedge, of deposited sediments will begin to accumulate at the head of the ponded area. Vegetation quickly invades the wetted channel and deposited sediments (Figure 33a).

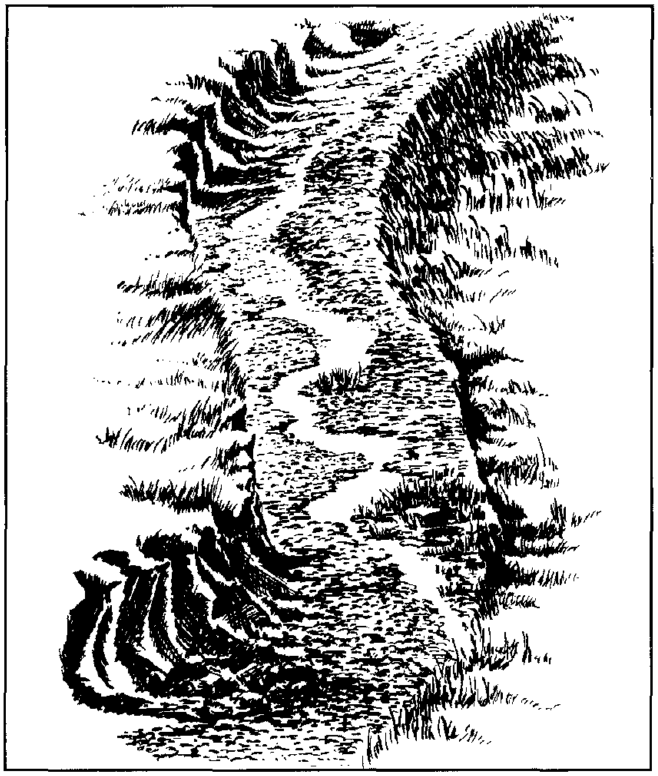

Figure 33a. Pretreatment condition, typical incised channel.

Each successive runoff event adds sediment, captured by expanding vegetation growth, to the delta. The vegetation increases channel roughness and, in effect, creates a new dam that will somewhat impound successive runoff events effectively slowing stream velocity and causing a new delta to form upstream of the first one (Figure 33b). The delta or bar is in turn invaded by aquatic vegetation. In this manner, the channel aggrades headward as a series of shallow pools. Channel banks are wetted to a greater and greater depth as new deltas evolve. With time the water table gradually rises and the capillary zone is reestablished, effectively rewetting formerly hydric soils and further stimulating the growth of wetland plants.

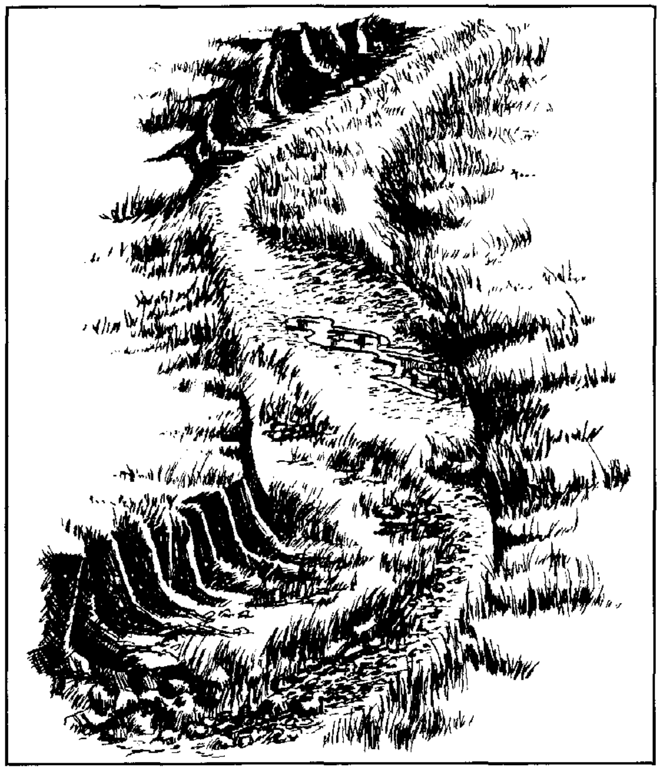

Figure 33b. Channel treatment reduces runoff velocities and initiates deposition of sediment fans which evolve into point bars as wetland vegetation stabilizes the accumulating sediments.

As the channel aggrades, slope gradient decreases causing runoff velocities to decrease. The channel widens in response, and becomes more sinuous in order to accommodate more or less the same volume of discharge moving at reduced velocity. Sediments washed from the widening channel are deposited on the channel bottom or on point bars. The point bars expand as more coarse-textured sediments erode from cutbanks (lateral erosion) only to be redeposited on the point bars, as shown in Figure 33c on the following page.

Riparian plants soon colonize the evolving point bars, and as surface roughness increases, more sediments will be captured by the vegetation, including increasing proportions of fine-textured silt, clay, and organic debris. Gradually, a sinuous, low banked meandering channel evolves to replace the straight, deeply incised, high banked original channel. As the channel aggrades, ensuing runoff events spill from the channel as overbank flow to wash across the old floodplain or form a new one (Figure 33d on the following page). Some overbank flow will be retained as bank storage

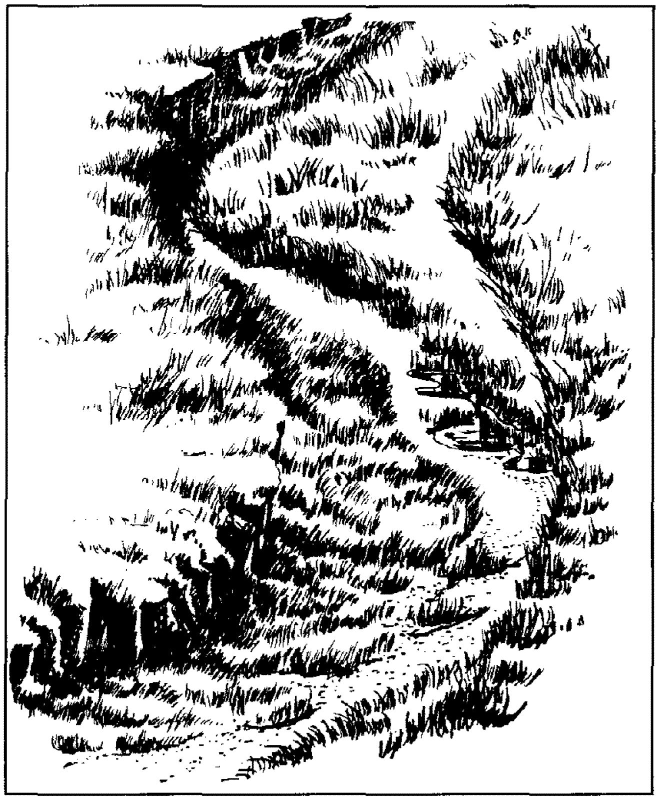

Figure 33c. Wetland vegetation further reduces runoff velocities, while capturing additional sediments that increase the height and size of point bars, initiating lateral erosion and meander formation.

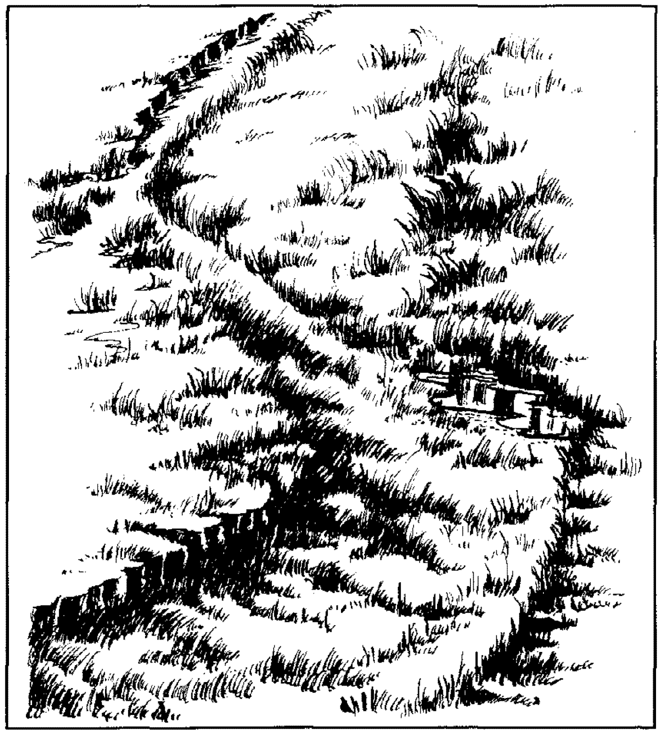

Figure 33d. Widening meanders yield bedload that raises the channel bottom and expands the size of point bars thereby reducing channel capacity and initiating overbank flooding.

or as surface ponding to stimulate wetland plants and to raise the shallow, alluvial water table (Figure 34). As the area of riparian plant growth expands, increasing quantities of silt and clay accumulate on the floodplain further expanding the saturated zone and the capacity for alluvial bank storage. The added stored moisture extends the duration of the wetted period as shown in Figure 35 on the following page.

Note that the reach of channel above a ponded area will tend to aggrade before the impoundment itself fills with sediments. Aggradation may happen quickly or take many years depending upon bedload characteristics, basin size, channel gradient, landform, the magnitude of storm events, and other conditions. Meanwhile, the ponded area will be colonized by submergent and emergent aquatic plants, creating habitat for aquatic fauna, forage and water for livestock, storage for downchannel base flow augmentation and aesthetic benefits.

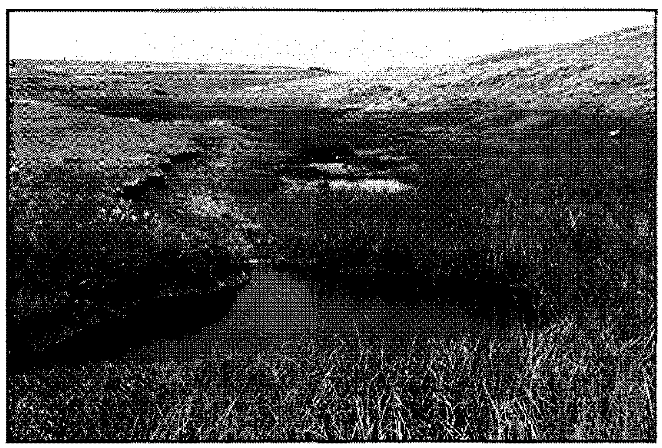

Figure 34. Aquatic vegetation increases the hydraulic roughness of newly developing sediment deposits.

Figure 35. Channel meanders expand as sediments add height to deltas and point bars. Burro Creek, Apache-Sitgreaves National Forests.

When reviewing restoration projects based on the impoundment concept, look for an initial response in the upstream channel. A series of newly developing delta shaped sediment fans should be apparent. The deltas should be revegetating with wetland plants and the channel should be aggrading and becoming more sinuous as point bars increase in area and height. Runoff events should spill across the historic or evolving floodplain with increasing frequency.

Dispersed Subsurface Flow

While it is easy to visualize an improvement in the dispersal of surface flow, it is more difficult to visualize a change in the dispersal of subsurface flows. Nevertheless, subsurface flows can, in fact, be increased in volume and rate of flow and better dispersed in time and space through the effect of raised culvert installations, raised inlets, ditch modifications, installation of raised fords, and modification of drainage works servicing alluvial fans, springs and seeps. Subsurface flows are dispersed by percolation through interbedded deposits of sand, gravel or cobble, by seepage along the interface between subsurface deposits and underlying bedrock formations, or as seepage through valley rubble.

A rapid recovery of wetland vegetation on sites downstream from modified road crossings has often been observed. While such recovery may be due, in part, to improved spatial distribution of flows, much of the observed increase in plant growth and diversity is believed due to the extended duration of subsurface flows and capillary wetting within the rooting depth of wetland vegetation (Figure 36). Surface soils are wetted by a rising water table and an expanded capillary zone.

When assessing the effects of modified road crossings and drainage systems, look for results attributable to improvement in the availability of dispersed subsurface flows.

Figure 36. Six years after installation of raised culverts, wet meadow vegetation is sustained by baseflow discharged from a treated wetland, Post Office Flat, Cibola National Forest.

V. New Construction and Reconstruction

Road construction and reconstruction activities can pose new threats to wet meadow ecosystem integrity or provide opportunities for the restoration of damaged sites as discussed in Chapter 2. The outcome will depend upon the skill, flexibility and attitude of planners and managers charged with project design and implementation responsibilities. When using road construction activities as an avenue to wetland restoration, planners should consider the potential effects of:

- Alternative road locations and alignments within the wetland landform.
- Alternative road locations and alignments on adjacent sideslopes.
- Channel crossings, locations, elevations, and form.
- Drainage works, including ditches, berms and cross drains.
- Road surfacing materials and applications.
- Sediment abatement practices and filtration zones.
- Buffer zones for improved wildlife habitat effectiveness.

For a summary of available treatments, see Table 2, "Treatment Synopsis: Wet Meadow Restoration Practices."

Table 2. Treatment Synopsis: Wet Meadow Restoration Practices

Application	Principles	Comments
Raised Culverts		
Existing or historic wet meadows with poorly defined or eroded channels.	Place culvert inlet at or slightly above meadow surface or at historic stream channel elevation if known.	When crossing a cienega or playa wetland, consider using a permeable fill as an alternative.
First and second order headwater watersheds preferred.	End haul materials from upland sources to fill the eroded channel or gullies to the elevation of the historic meadow surface. Compact fill.	Excessive bedload movement could bury remnant hydric soils under infertile sediments.
Applicable where the valley slope is < 4%. Channel slope < 2% preferred but acceptable on steeper slopes.	Do not borrow road fill or embankment materials from stream channel or meadow surface.	Consider the consequences of blocking fish passage even in intermittent stream situations.
Select a single pipe alternative when the objective is to maintain or create a single channel below the structure.	Use riprap or velocity checks to stabilize and disperse outfall. Avoid using lead in or lead out ditches.	
	Insure adequate freeboard.	

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Table 2. Treatment Synopsis: Wet Meadow Restoration Practices (continued)

Application	Principles	Comments
Multiple Raised Culvert Arrays		
Broader valleys, with higher discharge volumes, than raised culverts above. Cienegas and playa wetlands Applicable where the valley slope is < 4%. Channel slope < 2% preferred. Select a multiple pipe array when the objective is to disperse flood flows across the downstream floodplain and the use of a permeable fill is not possible.	Space pipes across the meadow surface. Use one, larger capacity, squashed pipe with inlet at desired channel elevation, and place smaller diameter pipes equally spaced across valley with inlets at floodplain level to accommodate and spread overbank (flood) flows. Insure adequate freeboard. Combined discharge capacity of multi-pipe array should be capable of passing design storm. Otherwise, same as raised culverts.	Multiple pipes spilling in close proximity can destabilize channel banks. Remove ditches, berms or channels which might interfere with or prevent proper function of the structure. Multiple pipe arrays can block fish passage. Use riprap or velocity checks to disperse outfall.
Culvert Retrofits, Raised Inlets[1]		
Existing or historic wet meadow sites with incised channels, upstream from the road. Valley slopes < 4% Channel slopes < 2% Sites with adequate freeboard. Use at sites with no potential for impacting improvements or private property interests. NOTE: The purpose of culvert retrofits is to expedite recovery of existing or historic wetlands by temporarily detaining runoff, retaining sediments, and restoring natural fluctuations in the water table, not to create permanent impoundments.	Use to raise the effective inlet of an existing culvert to the historic meadow surface or floodplain elevation. Maintain design storm capacity or provide flood relief capability. Maintain streaming flow into the pipe. Keep a shallow weir effect. Do not concentrate spill by using a notched weir edge. Protect the road prism from erosion by tamping fill materials and riprapping interface of structure with road embankment. Rock berms should not be used where channel slope exceeds 1%.	Piping caused by increased hydraulic head could undermine, soften or collapse road depending upon type of structure used and nature of embankment materials. Elbows increase the risk of piping more than other treatments. Debris clogging could block culvert inlet, but not likely in open meadow situations; use grates if needed. Frequent maintenance may be required when first installed to control seepage and erosion. Raised inlets provide an opportunity for creating small wetlands where none existed naturally. Check desirability and water rights constraints, if any. An alternative may be to remove the pipe and replace with permeable fill, especially at cienegas and spring seep locations. Drop inlet structures such as concrete traffic barriers and steel multiplate require the use of machinery which could compact wet meadow soils.

[1] *Includes elbow extensions, rock berms, tie and timber, concrete traffic barrier, multiplate arch, gabion baskets and similar treatments.*

Table 2. Treatment Synopsis: Wet Meadow Restoration Practices (continued)

Application	Principles	Comments
Permeable Fills		
Use at wet meadow sites with no defined channel or where the objective is to create a meadow with no channel; preferred for crossing cienegas and spring seeps. Valley slope < 2%, except cienegas of any slope. Use at sites with low velocity, well dispersed discharge. Use to protect playa wetlands from turbid runoff and prolong basin longevity.	Sandwich a layer of 2 to 6" rock, 12" deep between two layers of geo-textile separation fabric. Maintain 2% longitudinal grade across sandwich fill to sustain positive hydraulic head and reduce interstitial sediment deposition within the fill. Maintain adequate freeboard and use a culvert or dip with design storm capacity for emergency flood relief. Place lower layer of fabric on a smooth, graded base at historic meadow or cienega surface elevation.	Possibly vulnerable to damage by motor grader or snow plowing operations. Same sort of flood relief capability is advised except in very small watersheds or cienegas. Obliterate channels, berms and ditches above and below structure to assure well dispersed surface flows. For public safety, identify edges by marking with posts or deflectors as with culverts. The most aesthetically pleasing of all meadow treatments.
Fords, Low-Water Crossings		
Applicable in 1st to 4th order watersheds. Areas with low volume traffic preferred. Steep gradient channels in 1st-4th order watersheds with hard bottom sites, such as bedrock, boulders, or coarse gravel.	Armor edges with boulders or larger diameter riprap to prevent motor grader damage. Use fords on hard bottom or improved sites only; never on fine grained deposits. Make crossing as wide as possible to maintain a shallow weir edge; minimize eddying, while maintaining design discharge capacity. A splash apron is essential to prevent undercutting due to scour pool effect. Keep the crossing elevation lower than meadow surface. Tilt surface slightly downstream for self cleaning.	Suitable for raising water table from below; not suitable for dispersing flows across meadow surface. Eddying, end cutting, under cutting likely if not properly designed. Fords in incised channels have a high flash flood hazard. Warn public of hazards. The rapid accumulation of coarse bedload deposits could destabilize channel, but once a structure is firmly established, bedload movement should easily pass a properly designed ford. Possible fish barrier. Frequent, early maintenance is advised.

Table 2. Treatment Synopsis: Wet Meadow Restoration Practices (continued)

Application	Principles	Comments
Drainage Works, Ditches, Berms, Cross Drains		
(a) Upslope Ditches and Cross Drains	Return waters captured in upslope ditch to meadow surface promptly using closely spaced culverts or dips. Locate cross drains according to surface topography and vegetation; not according to mathematical spacing formulas. Install additional cross drains where needed. Do not route ditch runoff directly into natural channels. Use vegetated filter zones, sediment pits or settling ponds to capture sediments, moderate velocities. Protect outfalls with riprap or aprons to prevent scour and disperse runoff. Remove blockages regularly and keep cross drains functional.	Relate cross drain spacing to natural terrain features. Always use riprap or velocity checks below outfalls, to reduce erosion. Do not clean or disturb stable outfalls. Do not route runoff from cross drains into gullies, abandoned roadways, or ditches that might capture and concentrate flow. Road ditches paralleling meadow slope should be drained frequently to maintain soil moisture regime of meadow. Stop unnecessary cleaning or grooming of ditches! "Pull" only those reaches that are blocked and do not function properly.
(b) In-Meadow Ditches	Eliminate in-meadow ditch whenever possible. Relocate, realign or elevate road grade if necessary to reduce the need for ditches. If in-meadow ditches are unavoidable, use frequent cross drains and outlets to spread downstream flows. Avoid spilling ditch flows directly into main channel.	A high risk of headcutting erosion is always associated with interceptor ditches and berms. In-meadow ditches lower the water table; cause rill and gully erosion. Where the in-meadow road alignment parallels channel or valley slope, effective mitigation of an in-meadow ditch system is usually constrained by grade, and may be impossible to achieve.
(c) Cut-Off or Interceptor Ditches and Berms	Avoid or minimize use of cut-off ditches and berms. Elevate road surface and use raised culvert or permeable fill instead. When ditching is unavoidable, direct flows to the outer edges of the meadow and install culverts at edge rather than center of meadow. Disperse flows downstream of road.	

Table 2. Treatment Synopsis: Wet Meadow Restoration Practices (continued)

Application	Principles	Comments
(d) Lead-In, Lead-Out Ditches	Avoid or eliminate use of lead-in or lead-out ditches whenever possible. Replace lead-out ditches with velocity checks to disperse discharge flows across meadow surface.	Eliminate unnecessary cleaning of lead-out ditches. Cleaning is necessary only when back flows or sediment accumulations reduce culvert capacity. Lead-in, lead-out ditches induce headcutting by lowering the nick point and increasing runoff velocities.
(e) Lead-off Ditches on the Meadow Surface	Eliminate lead-off ditches and berms on the meadow surface. Contour lead-off ditches along the toe of sideslopes to escape road influence and terminate at meadow edge.	The combination of lead-off ditch and berm is highly damaging to wet meadows. Do not clean lead-off ditches unless blocked flows threaten the road itself; avoid unnecessary cleaning.
(7) Relocation/Realignment Consider relocating road segments that parallel the channel within the floodplain.	Select an alignment that crosses valley slope perpendicular to flow. Where feasible, relocate roads to achieve adequate filter and buffer zones for infiltration, sediment detention and wildlife security (habitat effectiveness). Sideslope locations are preferable to in-meadow routing. Where possible, locate roads out of meadows to avoid the need for in-meadow ditches.	If the continued use of an abandoned segment is anticipated, it may be preferable to stick with the present route. Possible stream capture by the abandoned segment presents a risk of gully formation unless preventative treatments are applied. Abandoned road segments may be difficult to obliterate or stabilize if incised beneath meadow surface; structural work is usually required to disperse flows across the meadow surface. Do not rely on revegetation alone.

Location and Alignment

Road construction affects both hydrologic and ecologic functions of wet meadows. This is true of roads that cross and roads that parallel wet meadow landforms, but the nature and extent of impact varies with location and alignment; potential impacts can be either beneficial or adverse with respect to existing conditions.

Hydrologic impacts are mainly associated, with intercepting, diverting, concentrating, accelerating, and dispersing surface and subsurface flows. Ecologic impacts are associated with changes in plant and animal community composition, biotic productivity, nutrient import/export, and habitat effectiveness.

The impacts of roads positioned within or adjacent to wet meadow landforms are more direct and perhaps

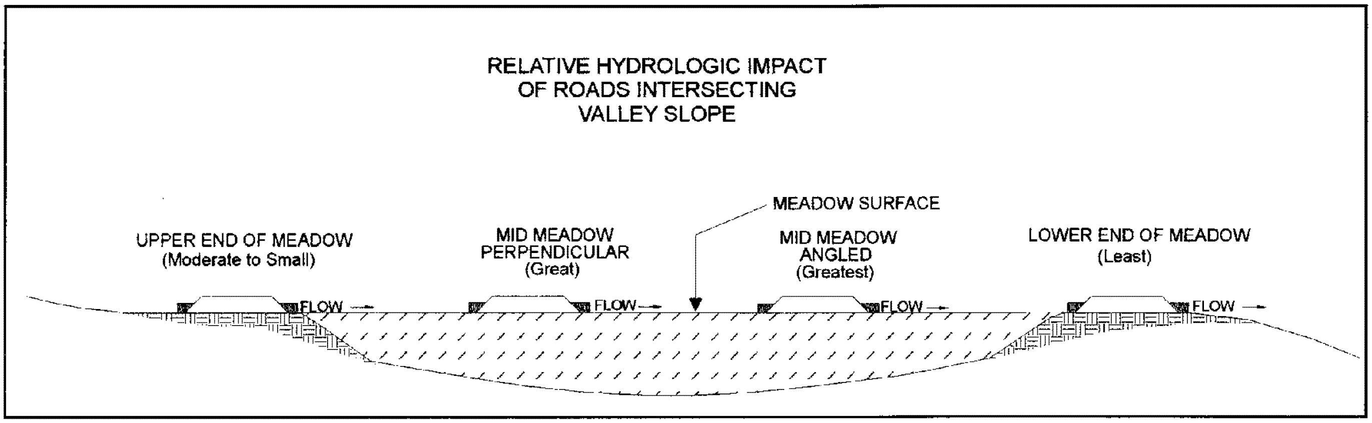

Figure 37. Relative hydrologic impact of roads intersecting valley slope.

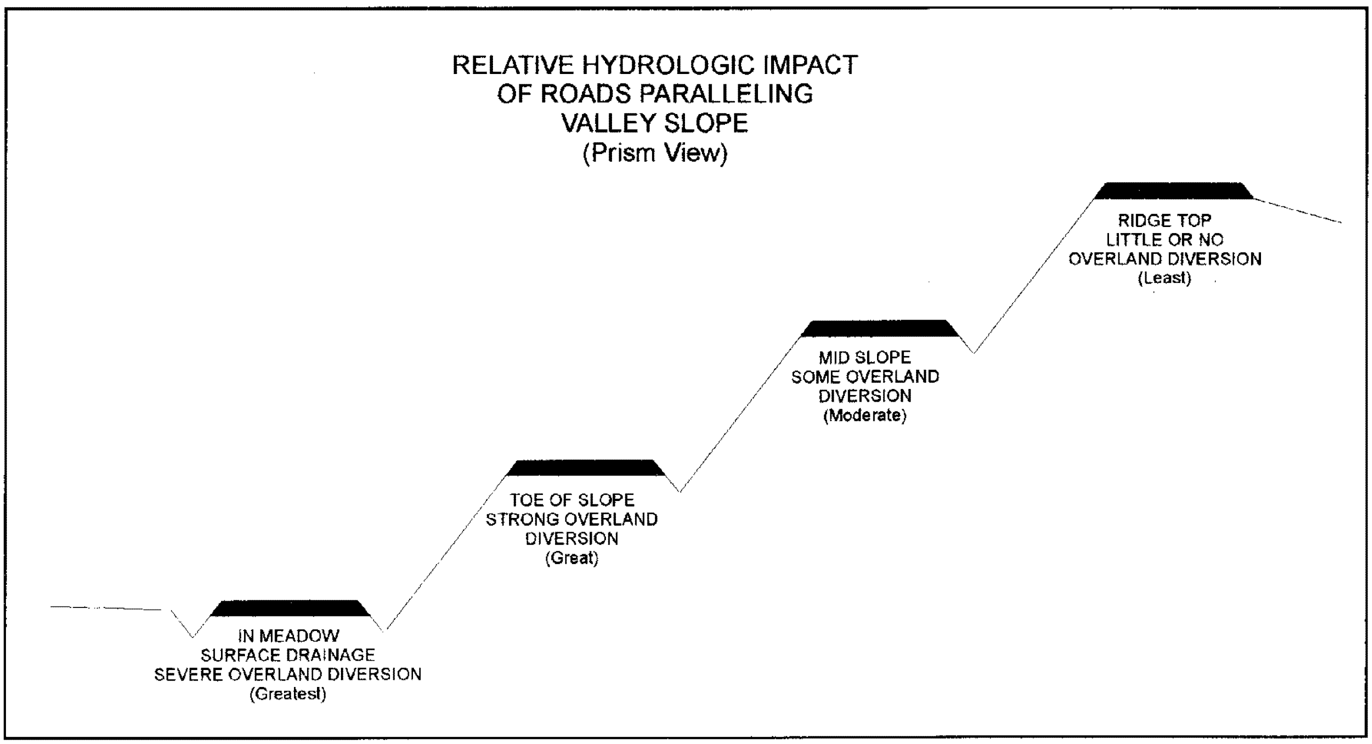

Figure 38. Relative hydrologic impact of roads paralleling valley slope.

more readily understood than those positioned upslope, or more distant, from the wetland itself. Still, potential problems can be transformed into opportunities with the right choice of road location, alignment and construction methods.

When positioning a road corridor across a wet meadow landform, essentially four options are presented unless constraints unrelated to topography apply. These options are: 1) the downstream periphery; 2) the upstream periphery; 3) an in-meadow location on an alignment perpendicular to valley slope and; 4) an in-meadow location diagonal with valley slope. The nature and extent of potential impacts will vary with the option selected, as shown in Figure 37 on the preceding page. For road corridors paralleling wet meadow landforms, again four basic options are presented: an in-meadow location aligned with valley slope, and lower slope, midslope and ridgetop locations, as shown in Figure 38 on the preceding page. Again the nature, extent and severity of potential wetland impacts will vary with location, alignment and construction details.

Addressing crossing options in the order presented above, crossing at the downstream periphery is preferred. Crossing at the downstream periphery usually permits crossing on the natural geological nickpoint that initiated formation of the wetland landform. Primary geologic nickpoints can be recognized normally as exposed bedrock, bouldery or rock rubble outcrops in the stream channel and usually define a break in valley slope. Secondary or former nickpoint locations, long buried under valley alluvium, may be visible if revealed by recent erosional events, and while marking a break in channel slope, have no affect on the present landform.

Some advantages of crossing a wetland at the primary nickpoint are: 1) The relationship of channel slope to valley slope can be readily determined from this point, and the appropriate channel slope can be re-established by setting the invert elevation of crossing structures accordingly; 2) Construction of in-meadow ditches and other supplementary road drainage structures can be avoided; 3) Downstream runoff can be dispersed using structures designed for and placed at the proper elevation and pattern of distribution to establish desired runoff characteristics; 4) A stable platform is afforded for the construction of embankments and placement of structures, and 5) Impacts to wildlife security, habitat effectiveness, scenic and other values can be reduced. Such advantages may or may not hold for mid-meadow crossings utilizing secondary nickpoint locations within the wetland landform.

If the downstream option is not feasible, crossing at the upstream periphery of a wet meadow landform can offer distinct advantages for wetland restoration: 1) the choice of crossing location and alignment can be more flexible than at the primary nickpoint; 2) depending on design characteristics of the road embankment and crossing structure, runoff can be very effectively dispersed over the downstream meadow, increasing surface and subsurface flows and enhancing infiltration and percolation; 3) the use of in-meadow ditches and drainage works can be avoided; and 4) impacts to wildlife security, habitat effectiveness, and scenic values can be lessened as compared with mid-meadow alignments.

If crossing at neither the upstream nor downstream periphery is feasible, and a mid-meadow location cannot be avoided, the recommendation is to cross on an alignment perpendicular to valley slope. In this situation, use stream crossing structures that can be aligned with the stream channel without channelizing or redirecting channel flows. Crossings perpendicular to valley slope reduce the need for in-meadow ditch systems, as compared with diagonal alignments, and therefore pose less potential impact on surface and subsurface flows. Where possible, choose an alignment that takes advantage of a secondary geological nickpoint.

Two advantages of mid-meadow locations having alignments perpendicular to valley slope are: 1) Channel gradient can be stabilized by constructing an artificial nickpoint set at the most advantageous elevation to initiate sediment deposition and aggradation; and 2) Wetland restoration downstream from the crossing point can be initiated or accelerated.

Disadvantages of mid-meadow crossings are that: 1) significant impacts to wildlife security, habitat effectiveness, scenic and related values may be unavoidable; 2) the use of in-meadow drainage works may be difficult to avoid; and 3) an appropriate alignment of the crossing structure with the existing stream channel may be difficult to establish without artificial channelization or relocation of the channel. (In some rare cases, it may be hydrologically and ecologically desirable to realign or relocate the existing channel.)

Finally, a mid-meadow crossing constructed diagonally with valley slope is inherently problematic and is not recommended. While some advantages may be as above, the disadvantages are usually more severe: 1) the use of in-meadow roadside ditches and secondary drainage works, such as cut-off, lead-in and lead-out ditches usually cannot be avoided; 2) road embankments tend to be longer, therefore wildlife and scenic values are usually more severely affected; and 3) artificial channelization and realignment of stream channels may be unavoidable to align culverts, bridges and embankments with channels. When avoidable, mid-meadow locations constructed on diagonal alignments should be rejected.

Presumably, the adverse hydrologic impacts of in-meadow alignments can be reduced by "floating" embankments across wetlands on geotextile separation fabric. In any case, embankment materials should be hauled from an upland borrow source and not excavated from an in-meadow or in-channel source that could lower the water table, or damage hydric soils.

Roads on terraces and sideslopes can contribute to meadow degradation by diverting and concentrating overland flows, and inducing channel incision and gully formation that lower water tables. By diverting overland flows away from wet meadow edges, roads can lower soil moisture, resulting in the loss of riparian vegetation and invasion by upland species (Figure 39). Channel incision triggered by concentrated flows from drainage systems drains subsurface moisture and lowers the water table with similar impacts on wetland vegetation. Finally, coarse-textured sediments flushed from road surfaces and construction zones can be deposited in thickening layers on the meadow surface, smothering plant growth.

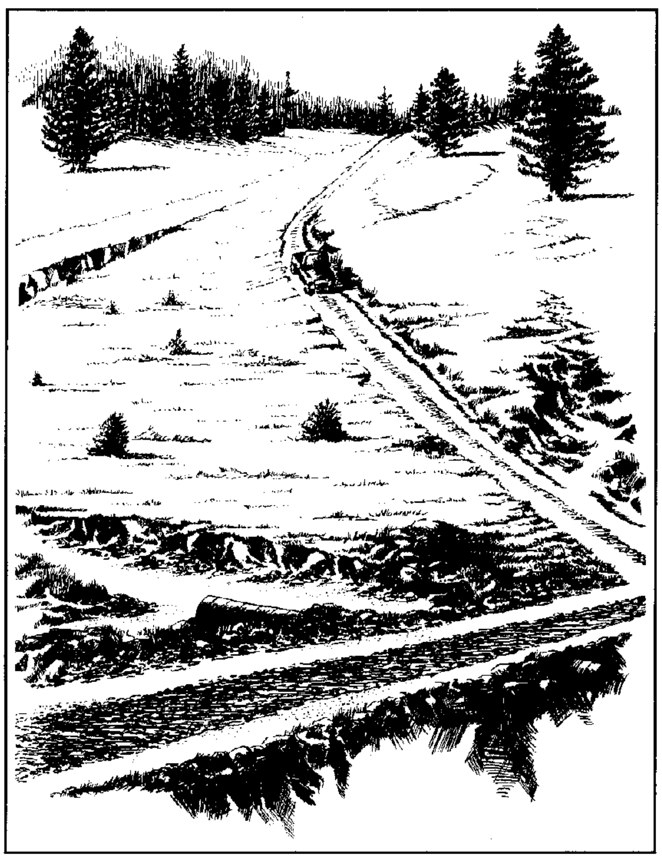

Figure 39. Diverting overland flows away from wet meadow edges can lower soil moisture, resulting in the loss of riparian vegetation.

Of the various meadow paralleling road alignments, an in-meadow location parallel with the valley slope is the most difficult to mitigate. The basic problem is that unless road embankments are well elevated, an in-meadow ditch must be constructed on either side of the road to assure adequate drainage. By necessity, such ditches lower the water table.

Special problems may be encountered with regard to road locations intersecting playa basins or cienegas because these wetland types are comprised primarily of fine-textured soils with high organic content and are especially vulnerable to erosion. When crossing a playa basin, the principal concerns are increased turbidity, the loss of playa soils by displacement and erosion, and increased wildlife disturbance. Roads built within the perennially wetted portion of playas are especially harmful. Adequate buffer and filtration zones are necessary to maintain habitat effectiveness and assure sediment capture. Special attention should be directed toward containing and dispersing ditch flows to control gullying.

Cienegas are especially sensitive to road construction because cienegas are sustained by groundwater discharge and, like playas, have fine-textured soils high in organic content but, unlike playas, often occur on steep gradients. Maintaining dispersed flow and preventing headward erosion are critical. Choosing a level road alignment contouring the slope offers the best opportunity for maintaining dispersed flows, whereas ascending alignments are more apt to capture and divert groundwater flows, induce erosion and damage cienegas by gully formation.

Dealing with Functional Wetland Ecosystems

Construction activities may affect wet meadow ecosystems which are essentially functioning properly. When this situation is encountered, every effort should be made to protect and preserve the existing hydrology of the site without modification or impairment. New structures should be designed and constructed with great care to maintain existing channel characteristics including shape, alignment and slope. If channels are

Figure 40. A multiple raised culvert complex 3 years after installation.

stable, stream channelization should be avoided, as should any attempt to lower or raise the stream crossing elevation in order to drain or impound the site. Stream crossings should be designed to disperse overbank flow across the downstream wetland in a pattern of flow and at surface velocities that replicate the existing pattern. Artificial confinement, concentration or acceleration of flows could seriously damage wetland soils and impair ecosystem function.

On the other hand, where obviously damaged wetlands, dysfunctional or unstable channels are involved, a careful evaluation of on-the-ground conditions could lead to the selection of one of the various restoration treatments described below.

Figure 41. The road embankment serves as a dike at this raised culvert installation.

Raised Culverts and Multiple Raised Culvert Installations

As the name implies, a raised culvert is a culvert installed with its inlet elevation at or slightly above the historic surface elevation of the affected meadow (Figure 40). Multiple-culvert installations are used where a single pipe of appropriate diameter is insufficient to pass the design storm discharge, or where it is desirable to disperse runoff across the wetland surface to re-establish an overbank flooding regime.

A raised culvert can be used to restore or establish the desired channel gradient, slow runoff and raise the water table which in turn stimulates native wetland vegetation, captures sediments, aggrades the channel and restores wetland functions within the affected landform. The road embankment itself serves as a dike facilitating the process (Figure 41). The purpose of a raised culvert is not to create a permanent impoundment, but to initiate a round of hydrologic and ecologic processes that will ultimately reclaim a damaged site (Figure 42). Ephemeral, intermittent or even perennial ponding may result and persist until sedimentation processes reclaim the affected area. Creating a permanent impoundment is not the objective.

A raised culvert is best used to restore wet meadows in geomorphic situations where stream channels are naturally poorly developed, discontiguous or interrupted. Such situations include small headwater watersheds drained by intermittent or ephemeral channels on shallow slope gradients with low discharge rates. If the active channel appears stable, then installing a raised culvert may not be appropriate to the situation. Conversely, if the channel is unstable and bedload originates primarily from within the wet meadow landform and its orderly transport is not critical to downstream channel stability, a raised culvert installation could be an appropriate technique for site restoration. Raised culverts probably should not be utilized where slope gradients exceed four percent, preferably less.

Installation of raised culverts may not be practical unless done in conjunction with new construction or reconstruction activities. An exception is the placement of culverts at crossings currently served by un-

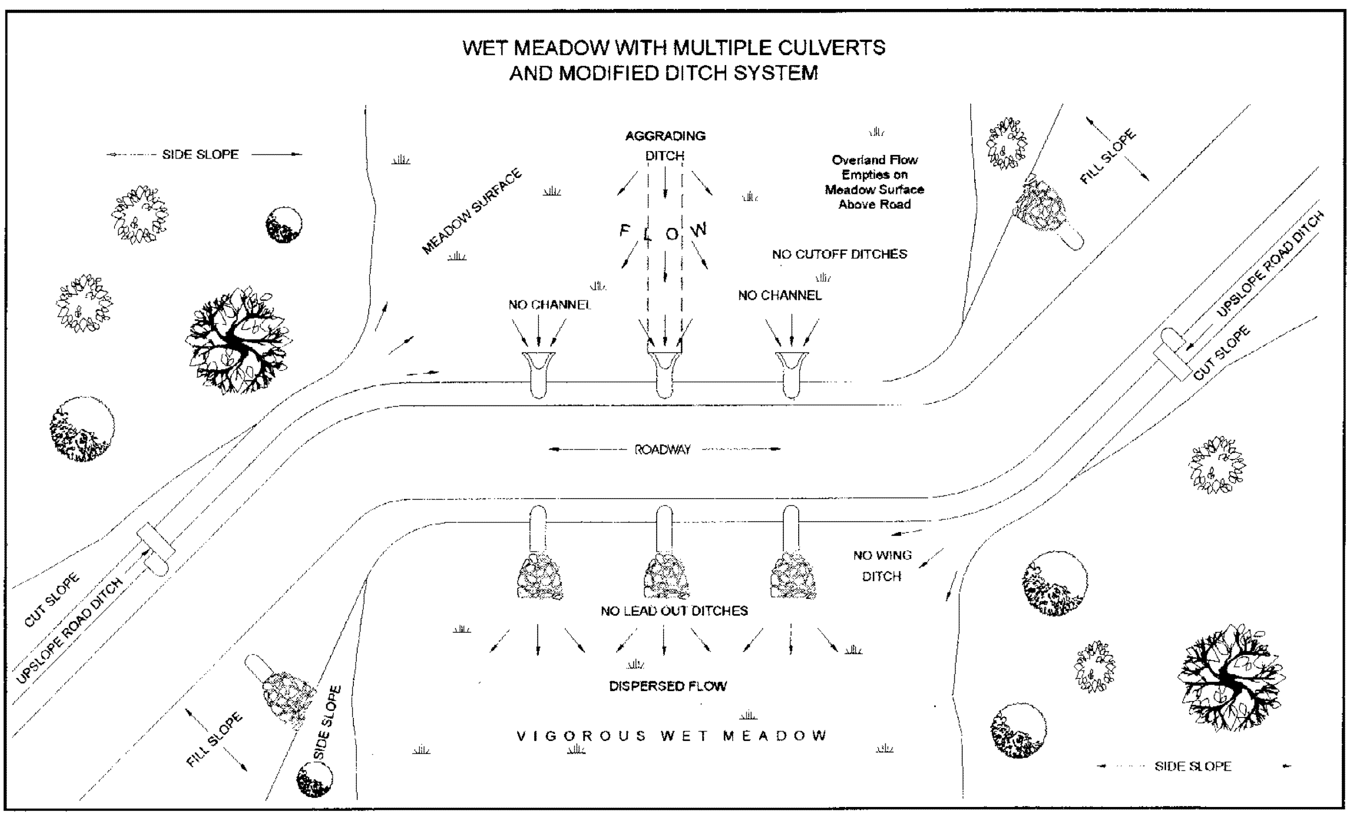

Figure 42. Typical Drawing: Wet meadow with multiple-culverts and modified ditch system.

improved fords (see Figure 18). Such improvements can be accomplished in the course of routine road maintenance operations or as direct investments in ecosystem management.

If a raised culvert installation is selected for site restoration and the channel has eroded below the historic meadow surface, the incised channel should be filled and compacted. Fill materials should be obtained from an upland borrow source and not from a pit excavated from the meadow itself. A pit will act as a sink drawing water from the surrounding wetland, frustrating the objective of meadow restoration.

The new pipe(s) should be placed with the inlet elevation at or slightly above the historic meadow surface. Placement above the meadow surface will control vortex eddying which could initiate gullying upstream from the structure. If a multiple pipe array is installed, spread the pipes equidistantly across the breadth of the meadow to disperse surface runoff. To create or maintain a flooding regime emulating natural overbank flows while maintaining a defined channel, install a central pipe having a capacity equal to bankfull discharge and flank it with pipes of smaller diameter with higher inlet elevations to accommodate overbank flows.

To comply with permitting requirements of Section 404 of the Clean Water Act, instream structures must not interfere with passage of migratory aquatic organisms. Therefore, fish passage should be considered in planning raised culvert installations. Intermittent, and even ephemeral streams, may sometimes provide important spawning or other seasonal habitats for migratory fish. However, in dealing with restoration of eroded wet meadows in upper headwater watersheds,

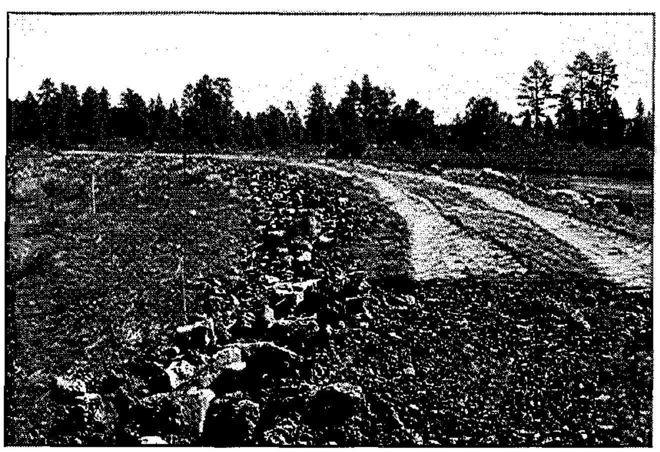

Figure 43. A permeable rock fill embankment under construction. Note placement of rock fill, separation fabric and embankment materials.

it is unlikely that situations affecting migratory fish passage will be encountered.

Culvert outfalls should be fitted with velocity checks or stilling basins. A stilling basin, which can be constructed of riprap or boulders, can serve as a device for dispersing surface flows across the downstream area. All ditches, berms, gullies and other surface irregularities which might concentrate or restrict flows should be removed or substantial damage to the wetland could result.

Raised culverts can be aesthetically offensive and pose a safety hazard if pipes are allowed to jut from the embankment. Pipes can be trimmed flush with the embankment to eliminate these problems.

Permeable Fill

The permeable fill is also known as permeable rock fill, rock embankment, rock fill embankment, French Drain and stabilized natural drainage. An old concept with new applications, the permeable fill is designed to disperse flow across the wetted surface of a wet meadow or cienega.

A permeable fill consists of a layer of coarse rock sandwiched between two layers of geotextile separation fabric extending across the width of the area to be wetted. A layer of fabric is placed on a prepared subgrade constructed at the natural surface elevation of the meadow. The subgrade should be tilted slightly down meadow in order to maintain positive hydraulic head through the structure. Rock from 2 to 6 inches in diameter is spread evenly to a depth of at least 1 foot across the fabric and a second layer of fabric is laid over the rock. An earthen embankment is then constructed on the rock fill bringing the entire structure to grade. Large rocks may be embedded within the edges of the embankment to reduce the chance of damage by future motor grading or snow plowing operations. For safety measures, such rocks should not protrude from the embankment, presenting a collision hazard.

Figure 43 shows a permeable rock fill embankment under construction at Capulin Canyon, Forest Road 49, Cibola National Forest. The structure is about 330 feet long and 28 feet wide at ground level, shown in Figure 44 on the following page. Constructed by the Federal Highway Administration, the structure is intended to bring about restoration of a 60-acre historic wetland which was intentionally drained by earlier road construction and maintenance operations. The site will be monitored to measure hydrologic and ecologic responses.

An overflow culvert, supported by a full length concrete cradle, was installed in the embankment to insure flood relief capability. The inlet elevation of the culvert corresponds with the top elevation of the rock fill so as to not interfere with the intended performance of the permeable fill.

Figure 45 displays a design for a stabilized natural drain without flood relief. Such structures have been installed at four sites on Cibola National Forest where there was little potential for flooding. If the capacity of a rock fill embankment to pass design storm discharge is in doubt, flood relief capability should be built into the structure. Figure 46 displays an untested design for a permeable fill with a flood relief culvert installed at ground level. The effective inlet elevation of the pipe is controlled by an external berm, placed at least twice the diameter of the pipe, upstream of the inlet.

One factor which could damage or interfere with the proper performance of a permeable fill is excessive sediment loading. For this reason, rock fill installations should be protected from coarse-textured sediments originating from road surfacing, ditches or gullies. Figure 47 displays a schematic diagram of a properly installed permeable fill embankment.

Permeable fill installations may be used to protect existing or restore historic wet meadow sites, and are recommended for use at cienegas and seeps where groundwater discharges are relatively constant and the need to maintain well dispersed surface flows is critical to site preservation or recovery.

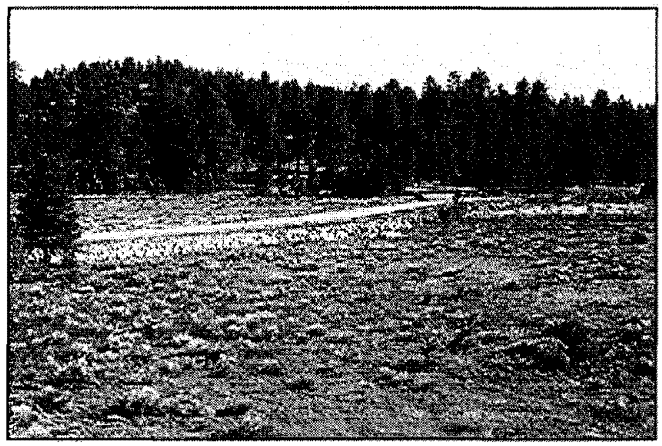

Figure 44. A completed permeable rock fill embankment, June 1995, Capulin Canyon, Cibola National Forest.

Permeable fill embankments are not recommended for sites having valley slopes steeper than two percent or for crossing channels with significant bedload movement. Any berms, ditches, gullies or other surface irregularities which might interfere with flow dispersal should be removed at time of construction.

Permeable fills blend very well with the natural landform and can be aesthetically pleasing once vegetation recovers from construction activities.

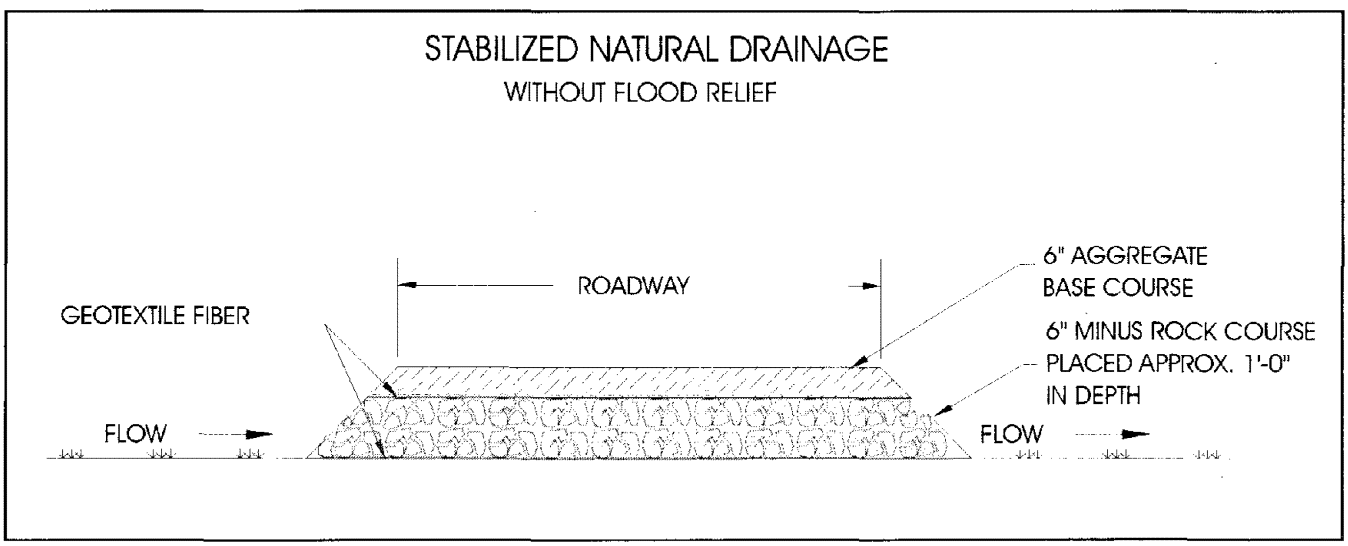

Figure 45. Typical Drawing: Stabilized natural drainage without flood relief.

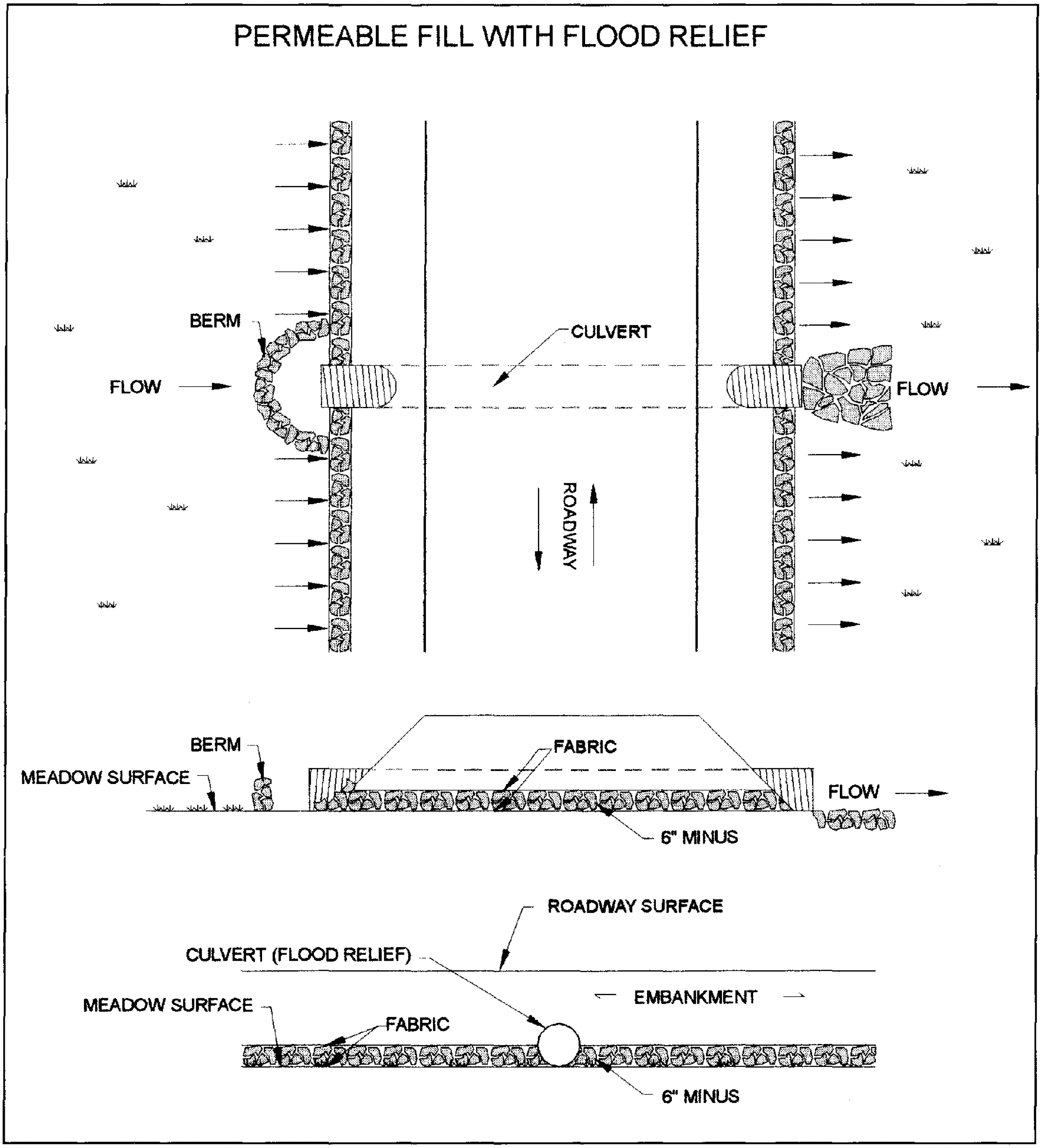

Figure 46. Typical Drawing: Permeable fill with flood relief.

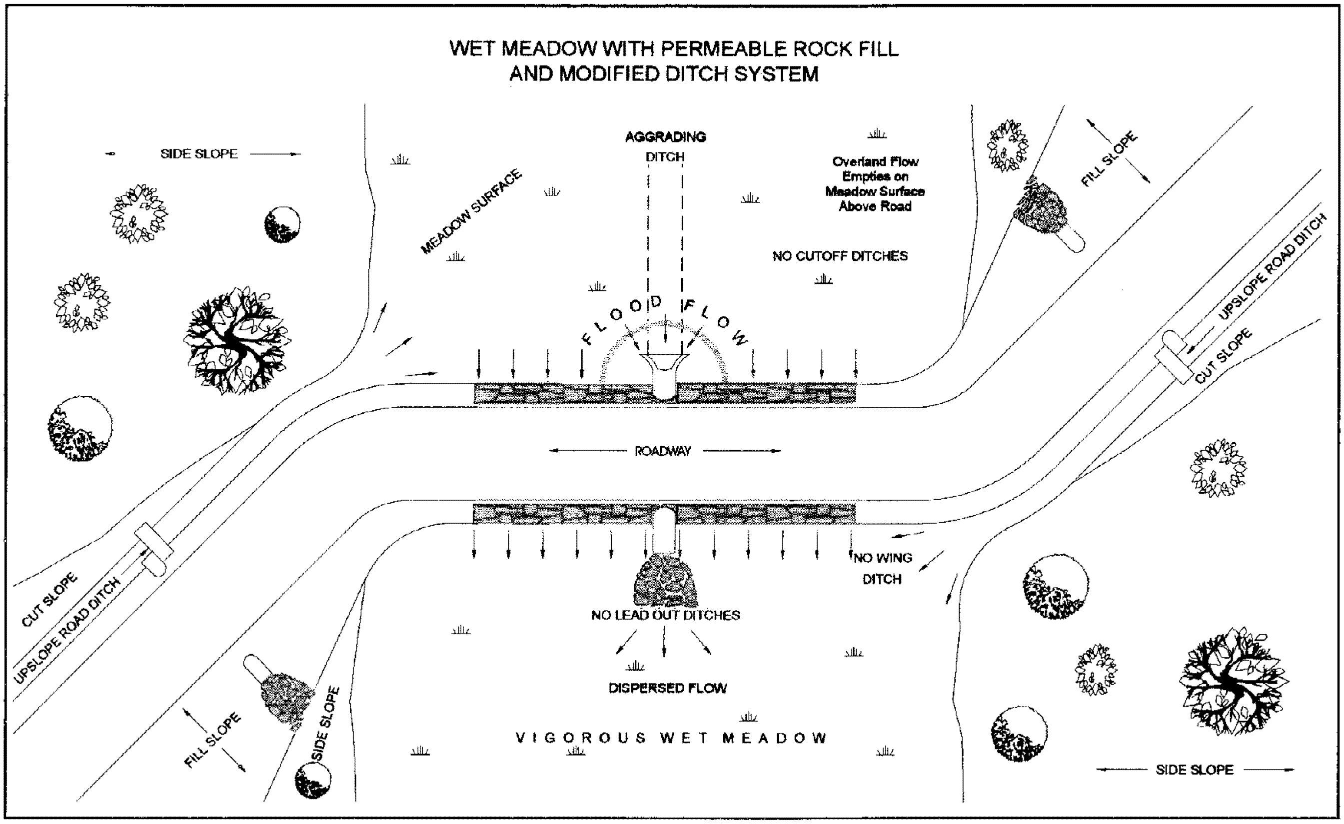

Figure 47. Typical Drawing: Wet meadow with permeable rock fill and modified ditch system.

Fords and Low Water Crossings

Improved fords and low water crossings installed at the appropriate channel elevation can be effective in restoring wet meadow sites. Since improved fords function by recharging the water table from below, success depends upon how well the design promotes flow interchange between channel flows and interbedded layers of coarse grained alluvium beneath the wetland surface. Channel flows seep into the alluvium through exposed deposits of interbedded sand and gravel. Fords are not appropriate for saturating meadow soils by means of overbank flooding because of hazards posed to public safety and the difficulty of controlling surface erosion. Fords are most appropriate for use in well defined, incised channels that carry significant bedload or debris that might obstruct culverts.

Features important to the satisfactory, long-term performance of improved fords include a proper weir elevation, adequate streambank protection to control end cutting, a splash apron to prevent scour pool formation, a cutoff wall to control seepage, and ample channel capacity to accommodate peak discharges without overbank flooding. Fords are usually installed on bedrock or valley rubble at sites characterized by coarse-textured sediments and steep gradients greater than four percent. For maximum effect in meadow restoration, place the weir elevation (road surface) at or above the apparent interface of fine-textured surface soils with the underlying beds of sand or gravel. Subsurface flows moving beneath fine surface soils should promote re-establishment of the capillary fringe essential to germination and growth of riparian vegetation.

Channel Reconstruction

Channel reconstruction is an innovative, if somewhat expensive, approach to restoring severely incised stream channels. The technique is highly technical and involves reshaping a stream channel by using costly earth moving equipment and sophisticated streambank and bed stabilization practices. The goal of channel reconstruction is to artificially re-establish interactive stream channel and floodplain functions having the characteristics and attributes of an undisturbed system. The appropriate geomorphological characteristics are mathematically generated, engineered and constructed to accommodate all runoff stages from base flow to overbank flooding. The premise is that if runoff can interact freely between the channel, the floodplain and alluvial storage while efficiently transporting bedload, the channel will maintain itself and wetland vegetation will flourish. Designing, planning, engineering, surveying, constructing, revegetating and monitoring such an undertaking is a job for experts, not laymen, and requires special training. Such projects should not be undertaken without thorough preparation.

At time of writing, only one channel reconstruction project had been attempted on Southwestern National Forests. This pilot project was under construction during the Summer of 1995 at Agua Fria Creek, Mount Taylor District, Cibola National Forest, New Mexico, by the Federal Highway Administration. The project was planned by Forest Service engineers and hydrologists, with expert consultation, and the full support and cooperation of the Federal Highway Administration.

The goal of this project is to resaturate up to 120 acres of former wet meadow or riparian soils dewatered by channel downcutting, presumably related to stream capture by primitive roads, as well as overgrazing and other disturbances including watershed degradation. Dewatering of the site had resulted in invasion by ponderosa pine, rabbitbrush, gramma grasses, cactus and other upland species. A remnant population of wetland plants survives upstream from the site and is expected to provide seeds and propagules for revegetation.

The option of channel reconstruction was selected to accommodate potentially high volumes of bedload, which, in fact, rendered other types of treatment infeasible. Preconstruction studies were completed before project initiation and progress will be systematically monitored to document and evaluate project results. It is still too early to evaluate project success or to recommend channel reconstruction for widespread application.

Road Surfacing

Road surfacing materials can affect the quality of runoff entering channels or flowing across meadow surfaces. Dissolved pollutants and suspended sediments are of concern, especially sediments. If road surfaces are steep, if surfacing aggregates contain high proportions of fine-textured particles, or if runoff is captured on road surfaces for appreciable distances, large quantities of sediment can be washed from roadways and deposited on adjacent meadow soils. Surface veneers of coarse sediment can smother wetland vegetation and convert productive soils into sterile outwash.

Various preventative treatments can be used during construction to avert this potential problem. To avoid trapping runoff on the road surface for long distances, techniques such as frequent grade reversals, crowning, maintaining an undulating road surface, or outsloping can be used, at least in the immediate vicinity of affected wetlands. To control sediment generation, surfacing aggregates containing larger sized particles or binding agents should be used for road segments near wetlands. Another option might be to pave the road or road segment causing the problem. Filter zones and sediment pits can be used to trap eroded surfacing materials.

Intercepted Runoff

Intercepted runoff, including runoff from overland flows and groundwater discharges, can significantly affect impacted wetlands. If concentrated and diverted at high velocities, intercepted runoff will erode and dewater meadow soils. Conversely, if runoff is properly routed and dispersed at low velocities, the added moisture can be important in resaturating hydric soils previously damaged by erosion.

Topics related to intercepted runoff are addressed under "Drainage Works; Re-routing Intercepted Runoff," Chapter 6.

VI. Remedial Treatments

Purpose

A variety of treatments has evolved for retrofitting existing facilities. Remedial treatments can be installed incidental to maintenance operations or directly as investments in ecosystem management. Some remedial treatments, such as culvert inlet modifications, lend themselves to completion by volunteer conservation organizations, local landowners or other interested parties.

Treatments described in this chapter are not panaceas for repairing damaged wetlands and should not be installed indiscriminately. But by being aware of the range of available practices and alert to opportunities, managers can use the methods described here to correct problems encountered on the ground and make steady progress toward the restoration of damaged wet meadow sites. Before treating a degraded site, proponents should carefully consider the individual situation and review available treatment alternatives. A misguided treatment could not only fail to accomplish project objectives, it could result in serious damage to resource values or improvements, including the road itself.

The first consideration is the purpose of the project. Is the project purpose that of restoring a degraded wet meadow site, or is it to create a new wetland where none existed previously? This determination is essential in examining questions related to water rights issues, Clean Water Act permitting requirements, endangered species obligations, and agency policies. An examination of site characteristics including soils, vegetation, land form, and other physical evidence should quickly establish whether or not the site is, in fact, an existing or historic wetland. For a discussion of relevant water rights issues, please see Appendix B.

In addition to legal and policy constraints, proponents should examine project feasibility in terms of channel morphology and flow characteristics, land ownership status, resource values, productivity, affected improvements, and any other factors which might argue for or against the project.

Remedial treatments can range from simple to very complex. For low standard roads, low channel gradients, and low volume discharges, simple retrofits such as raising a culvert inlet or modifying a ditch configuration might prove structurally sound and highly effective. Alternatively, for high standard roads and high volume flows, proposed treatments could prove complex, costly and quite risky.

Precautions

Regardless of treatment selection, structural design or materials used, certain precautions should be observed whenever planning or carrying out remedial treatments:

- Determine hydrologic characteristics of the site and design accordingly.
- Use methods and materials that protect road users from project-induced hazards, such as appropriate use of highway safety standards and warning devices.
- Accommodate public and private property interests.
- Consider any site specific technical problems having to do with structural integrity, flow characteristics, natural resource values or other site related functions or values.
- Be diligent and attentive to the smallest detail during the construction process. Running water is a powerful and relentless force that will exploit any flaw in design or workmanship to the future detriment of the project.
- Once begun, complete all construction promptly; unexpected flooding can prove disastrous.
- Minimize project-induced turbulence that could reduce the hydraulic capacity of the structure or induce erosion.
- Insure adequate freeboard or provide flood relief capacity.
- Protect the site against erosion from end cutting, piping, or undercutting of the structure or the road embankment.

Road Relocation

Relocating a short section of an existing road can be used to:

- Align a road corridor with a geological nickpoint in order to favor installation of a raised culvert or permeable fill;
- Modify or eliminate drainage works such as roadside ditches, lead-in and lead-out ditches, and cross drains;

- Eliminate stream channel encroachments or channelized stream reaches;

- Provide space for a filtration zone; or

- Establish a buffer zone to improve wildlife habitat effectiveness.

Relocating a road from the floodplain to an adjoining terrace, toe slope or ridgetop will result in the rapid recovery of wet meadow ecosystem functions if new facilities are properly constructed and drained. In situations where an in-meadow ditch system is essential to securing adequate road drainage, relocation may be the only feasible alternative for dispersing surface and subsurface flows, raising the water table, controlling excess sedimentation, or mitigating wildlife disturbances.

Raised Inlets for Retrofitting Existing Culverts

Many kinds of treatments have evolved for retrofitting or raising the inlets of existing culverts without incurring replacement costs. Successful treatments have ranged from simple rock berms and elbow extensions to installation of recycled concrete traffic barriers, steel piling and concrete dikes. Choosing an appropriate treatment depends upon such variables as discharge volumes, channel characteristics, valley slope gradient, nature of the road fill, road standard, available freeboard, accessibility and cost. Functional considerations include maintaining the hydraulic efficiency or capacity of culverts; the potential for piping; concern for public safety; and the class of traffic crossing the structure.

Encased Rock Berms as Inlet Treatments

An encased rock berm consists of a horseshoe-shaped layer of rock wrapped in a sausage-like casing of geotextile fabric and placed a few feet upstream of a culvert inlet (Figure 48). Rock berms are cheap, effective and simple to build; and are ideally suited for use in shallow channels incised into broad, gentle valleys. Rock berms should probably not be used at sites having a valley slope greater than two percent because higher flow velocities on steeper slopes could dislodge stones and damage the structure.

An important advantage of the encased rock berm is its permeability. A porous rock fill permits gradual inundation and drainage of an impounded area in synchrony with the natural flooding regimes characteristic of undisturbed wetland areas. Wet meadows restored using rock berms quickly develop patterns of vegetation reflecting the sensitivity of various wetland species to subtle differences in soil aeration, pH, soil temperatures, flooding regimens, and other variables characteristic of wetland sites.

To construct an encased rock berm, first clear away loose materials and smooth the site upstream of the culvert inlet (Figure 49). Spread a layer of geotextile fabric in front of the pipe and extending at least 20 feet upstream. Stack rock on the fabric in an arc encircling the inlet. The center of the arc should be from 6 to 10 feet from the pipe. Fold the remaining fabric back over the fill with the edge against the pipe(s). Add a final covering of rock to protect and conceal the fabric. For the covering layer, use larger rocks than were used for the fill, and create a smooth slope on the downstream side that will funnel streaming flows into the pipe with minimal turbulence. Finally, pile rocks higher along the interface with the road embankment to control end cutting. The weir edge, or lip of the rock berm, should be approximately level with the historic meadow surface or slightly above it.

Frequent maintenance is recommended soon after installation to assure prompt replacement of any rocks dislodged by erosion, ice flows, vandalism or trampling by large animals. With time, sediments and vegetation will bind the rocks together reducing the need for further maintenance. Installation costs have ranged from $200 to $500 per structure.

Figure 48. An encased rock berm, Round Cienega, Apache-Sitgreaves National Forests. Note exposed geotextile fabric, foreground.

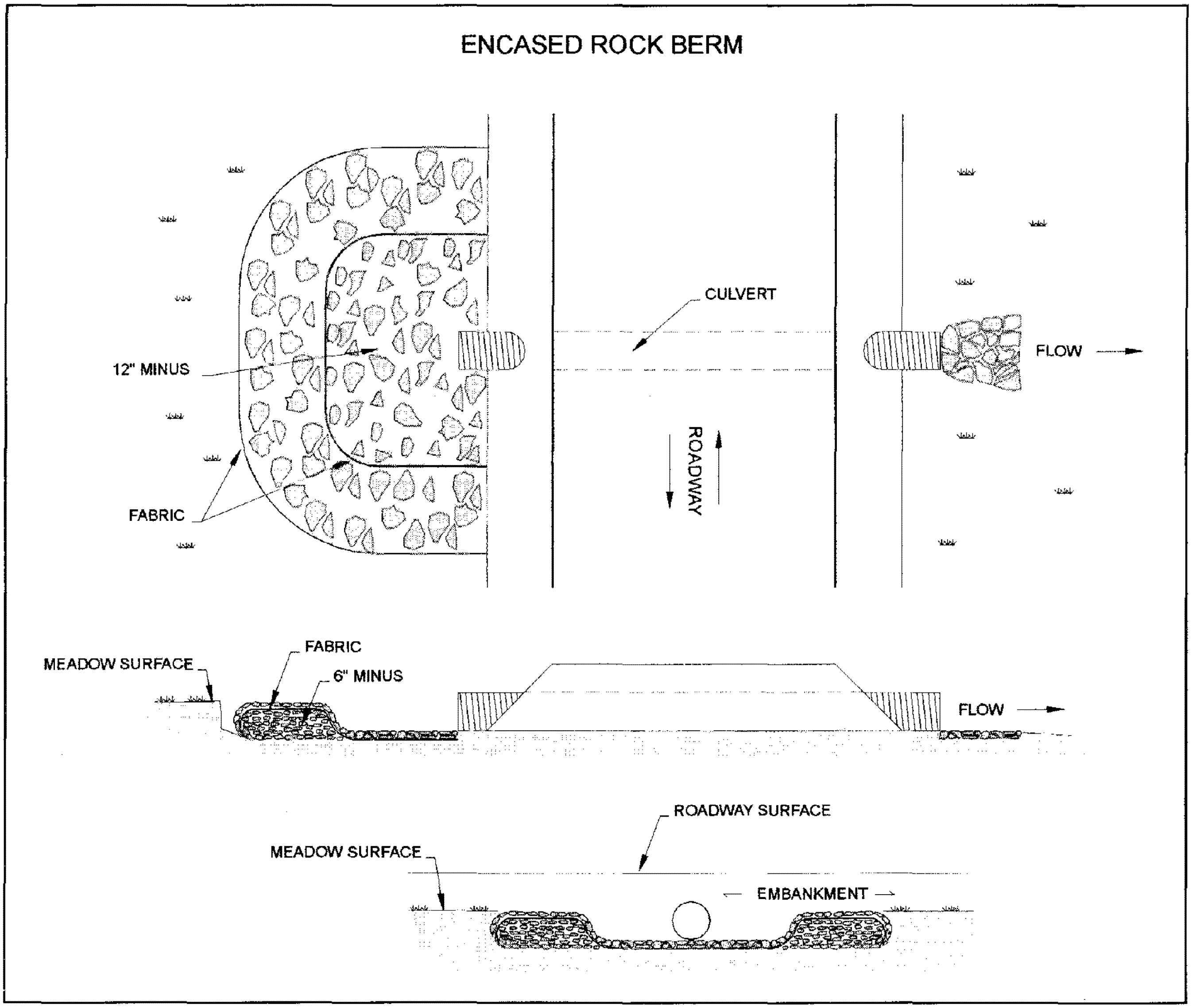

Figure 49. Typical Drawing: Encased rock berm.

Elbow Extensions

Elbow extensions, which are manufactured in standard diameters and in 45° and 90° angles, are readily available from construction supply firms. Extensions can be easily attached to corrugated metal or polyethylene pipe using simple sleeve-like adapters. Preparation involves cleaning fill dirt and debris away from the pipe and slipping the adapter into place. Depending upon diameter and weight, an elbow may need to be supported in position for proper alignment with the existing pipe.

Elbow extensions are suitable for pipes up to 30 inches in diameter and are simple to install. For larger diameters, anti-vortex baffles and debris grates are recommended to control hydraulically induced harmonic vibration and to prevent debris clogging. Such modifications are more difficult and expensive to design and install.

Some problems may be encountered in the use of elbow extensions. The bright, metallic finish may not be aesthetically acceptable in highly visible situations, but this objection can be mitigated by using black polyethylene extensions. A more important functional concern, however, is the potential reduction in hydraulic capacity that could render a culvert incapable of passing the design runoff. Reduction in capacity is related to turbulence generated at the apex of the elbow as flow changes direction from vertical to horizontal and loses velocity in the process. Right-angle elbows are less efficient than 45° elbows, but in small drainages, or, at crossings with adequate freeboard, loss of culvert capacity may be of no consequence (Figure 50). If in doubt, a 45° elbow may be more appropriate.

Another concern with elbow extensions is the risk of piping. Piping is the phenomenon which occurs when water seeps between the exterior surface of a culvert and the surrounding fill material (Figure 51). Piping is possible with any culvert installation or modification, but it is especially likely to occur where an elbow extension is fitted to an existing structure where the fill material is coarse grained or poorly compacted. Attaching an elbow will cause impounded water to stand against the culvert at the interface with the embankment. As hydraulic pressure increases against the fill material, so does the tendency for seepage. Depending upon the nature and composition of the road fill, piping may erode the embankment causing the roadway to collapse. Short of collapse, increased seepage could preclude any beneficial wetting of the treated site.

Road embankments built of tightly compacted, impermeable materials resist piping, whereas loosely compacted fills or fills composed of sand or gravel are prone to piping. An examination of nearby soil materials may yield some indication as to the type of materials used in the embankment and the likelihood of piping. If the potential for piping is of concern, a better alternative might be to use a drop inlet structure that does not impound water directly against the embankment.

In spite of potential drawbacks, there are many situations where elbow extensions function extremely well. Elbows are cheap, quick and convenient to use. Local engineering experience may provide some guidance as to where culvert extensions could be safely and effectively used (Figure 52). Installation costs can be as low as $125 per structure.

Figure 50. Forty-five degree elbow extensions are hydraulically more efficient than 90° elbows.

Figure 51.The potential effectiveness of these 90° elbows was negated by seepage piping through a loosely compacted embankment.

Figure 52. This right-angle elbow has been free from any problems associated with either piping or debris clogging for 7 years since installation, Forest Road 480, Cibola National Forest.

Tie and Timber Drop Inlets

Drop inlet structures can be fashioned of salt-treated timbers or railroad ties, although environmental concerns have been raised concerning the safety of salt-treated materials (Figure 53). Drop inlets are hydraulically efficient, durable, aesthetically neutral in appearance and not readily clogged, as shown in Figure 54. Drop inlets are suitable for shallow to steep gradients and high volume flows. Tie and timber structures are well suited to installation by volunteer work crews. Because impounded waters are not in direct contact with the outside surface of the culvert, a piping problem is less likely to develop than with elbows. When installing drop inlet structures, attempt to match the weir edge with historic meadow surface elevation as shown in Figure 55, or bankfull channel depth if the channel has not downcut. Although these structures are durable and hydraulically efficient, certain steps must be followed during construction to insure trouble free performance:

- Carefully prepare a smooth, firm and level seat or footing for the first tier of ties or install on compacted material. Place a layer of geotextile fabric under the entire structure with sufficient extra material left over to fold along the front and sides of the structure as additional tiers are laid.
- Key the ties (timbers) into the embankment at least 2 feet, offsetting more deeply with each additional tier. When backfilling around the ties, tamp firmly to prevent seepage and end cutting.
- Keep the weir edge, i.e. the top tier, broad and level. Do not cut a notch for concentrating flows. The objective is to maintain a thin, dispersed spill across the full width of the structure. This minimizes the erosive force of the falling water, while a notch has the opposite effect.
- Place the weir edge at least two times its height from the pipe inlet.
- Fashion a trough-shaped apron of concrete or rock to funnel flow smoothly into the culvert inlet. By insuring smooth, streaming flow rather

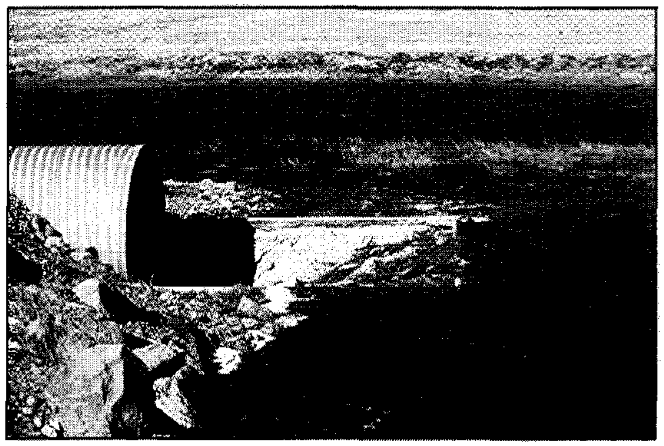

Figure 54. A drop inlet fashioned of railroad ties raised the inlet elevation by 32 inches. The concave concrete trough accelerates flow into the pipe for improved hydraulic efficiency.

Figure 53. A drop inlet built of salt-treated timbers. The top tier was later removed to extend the weir edge. Biscara Canyon, Carson National Forest.

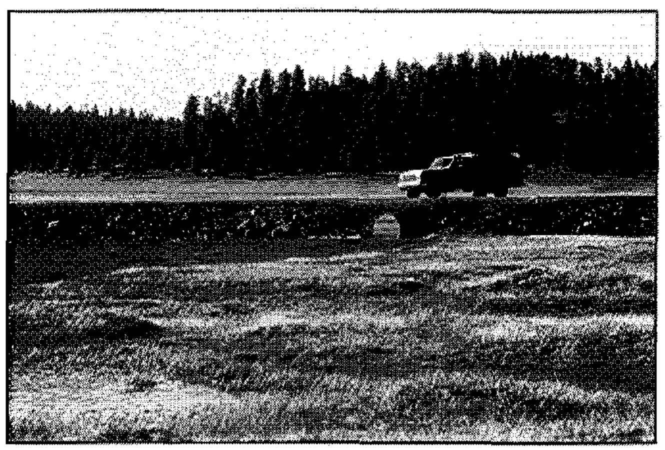

Figure 55. The weir elevation of this drop inlet (Figure 54) matches the historic meadow surface. Sierra Blanca Lake, Apache-Sitgreaves National Forests.

than turbulent flow, velocities accelerate and the full capacity of the culvert is preserved to accommodate the design runoff.

- Build a soil berm against the front or upstream edge and sides of the structure in order to keep the fabric in place and reduce seepage.
- Armor the embankment interface and seed disturbed soils for prompt revegetation of the site.
- Maintenance inspections should check for end cutting and debris clogging especially when first installed.

Skilled supervision is required to insure proper installation of tie and timber structures, but with adequate supervision, volunteer labor is well suited to projects of this type. Construction costs have ranged from $300 to $800 per structure.

Other Drop Inlet Designs

Efficient drop inlet structures can be constructed from a variety of materials and designs (Figure 56). Drop inlets have been built from new and recycled concrete traffic barriers, steel multiplate arch, gabion baskets, steel piling and other materials commensurate with channel size, discharge volumes and resource values at stake. Obviously, the taller the structure, the more substantial it should be. Because the force of falling water multiplies geometrically with increasing height and volume of flow, the technical difficulties involved in designing and building large structures must not be underestimated.

Some guidelines include the following:

- Excavate a smooth, solid base and install structures on firm mineral soil or rock fill.
- Key the structure into the road embankment and control seepage by firmly tamping all fill materials.
- Place the weir edge of the structure at least two times its vertical height horizontally from the culvert inlet to preserve hydraulic capacity of the pipe.
- Control turbulence by insuring smooth, streaming flow into the pipe.
- Use a wide, level weir edge to insure a thin, even spillover effect.

Timely maintenance is important in securing expected performance from retrofitted structures. Examine all structures soon after the first significant runoff event. Plug small leaks before they become big ones. Look for signs of unacceptable seepage or any evidence of damage to, or collapse of, the road embankment. Early maintenance can help to assure long-term satisfactory service from revamped structures. Again, skilled supervision is important to proper installation. Heavy equipment may be necessary. Costs have ranged from $300 to $3,000 per structure.

Figure 56. A drop inlet structure fashioned of steel multiplate arch, Apache-Sitgreaves National Forests.

Flood Relief/Emergency Spillways

When modifying stream crossings to restore wet meadow sites, it may be wise to provide emergency spillway capacity to accommodate unexpected flood events, even if not originally provided. All modifications described in this chapter, except ditch works and road relocations, function by temporarily impounding, detaining or dispersing flows, therefore, the potential for damage by peak runoff is always present, thus the case for flood relief.

Options for providing emergency spillway capacity are to:

- Construct a broad, level rock-hardened dip in the roadway at one end of the fill embankment. Once compacted by vehicular traffic, the dip should resist erosion from occasional flooding while serving as a low water ford, but if it fails, a dip can be easily repaired as compared with the expense of replacing an entire culvert installation destroyed by washout.
- Add overflow pipes having higher inlet elevations to accommodate peak flows.

- Install flood relief in the form of an overflow pipe or hardened dip in conjunction with any permeable fill installations.

Drainage Works; Rerouting Intercepted Runoff

Drainage works, i.e. ditches, berms and cross drains, are used to intercept, collect and divert runoff away from roads; runoff that is the lifeblood of meadows. Keeping roadways dry is a basic tenet of road construction and maintenance activities, but maintaining ecosystem function has, until recently, been an overlooked factor in the design, installation and upkeep of drainage works.

An examination of existing drainage works may reveal opportunities for securing favorable patterns of flow, without compromising the basic objective of keeping the road dry. Perhaps water trapped behind a berm could be dispersed across an impacted site, or a previously dewatered section of meadow rewetted without damaging the road. Perhaps a ditch could be relocated, a berm reshaped, or a cross drain added to restore normal hydrologic processes.

Minor modifications of existing drainage facilities, such as adding cross drains to disperse intercepted runoff, can produce amazing results in terms of improved wetlands hydrology. By observing runoff patterns during spring snowmelt or summer storm events, feasible opportunities for adjusting the location of cross drains, ditch outfalls, or berms, may be revealed, as shown in Figure 57.

Upslope Road Ditches

Upslope road ditches collect water from road surfaces, cutbanks, sideslopes and intercepted groundwater sources. As concentrated flow gains momentum and volume, its power to dislodge and transport sediment increases at an increasing rate. Recognizing this, ditch flows are routinely diverted through cross drains or lead-off ditches to minimize erosion of ditch banks,

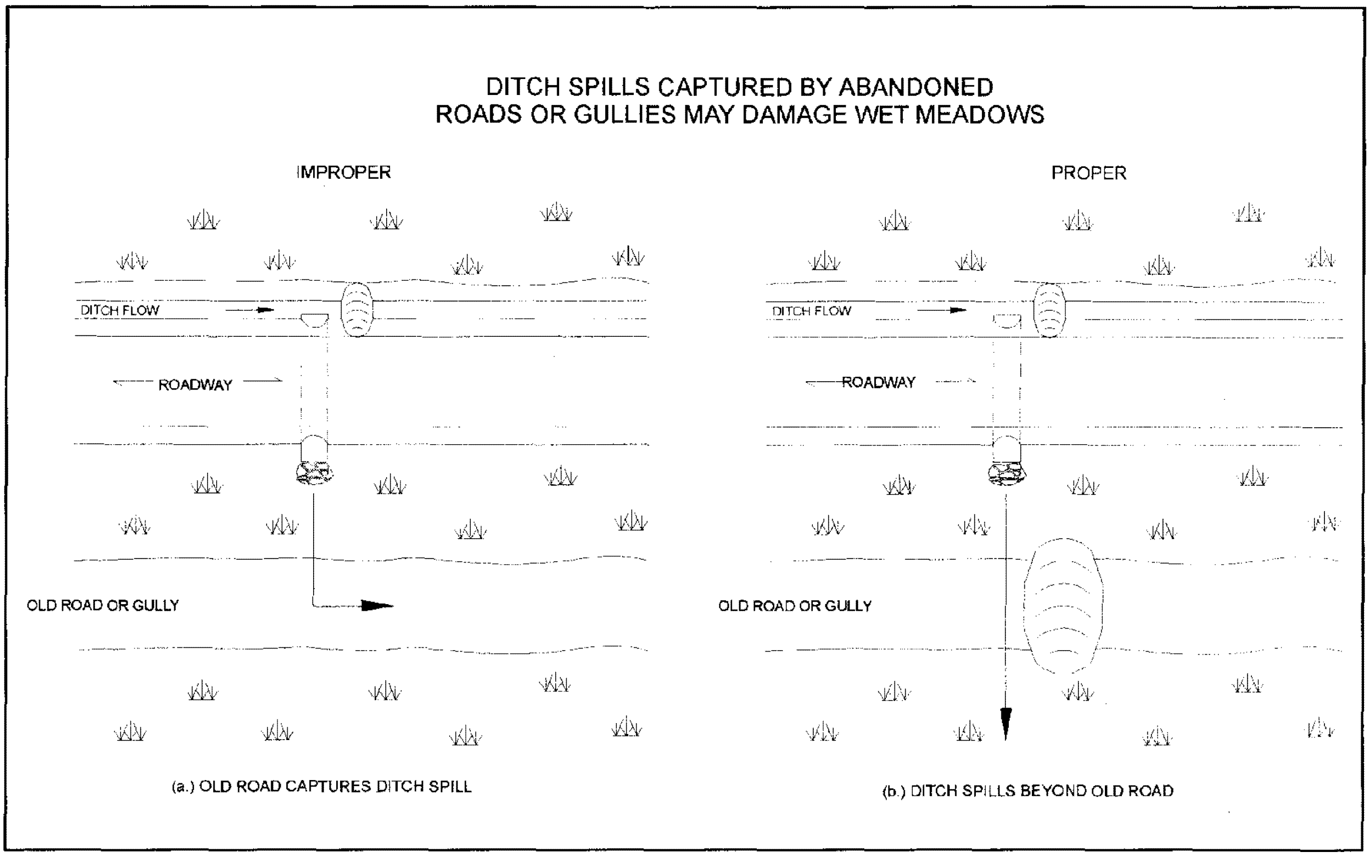

Figure 57. Ditch spills captured by abandoned roads or gullies may damage wet meadows.

sideslopes and road surfaces. Normally, the spacing of cross drains is directly related to road steepness. Where grades are gentle, cross drains are spaced at wide intervals. Where grades are steep, as on mountain slopes, cross drains are spaced more closely according to soil type, by formula. Seldom are cross drains properly spaced with regard to maintaining the hydrology of affected riparian areas or wetlands. On gentle slopes such as toe slopes, terraces and valley bottoms, cross drains are usually widely spaced. Consequently, meadows are denied the benefit of historic overland flows and concentrated ditch waters may erode gullies through meadow soils or downcut natural channels that previously interacted with surface and subsurface soils. In any case, affected meadows become dryer and are invaded by upland species as wetland vegetation disappears and the water table drops.

Possible Remedies

- Where roads on adjacent terraces or hill slopes closely parallel wet meadow landforms, spill ditch waters frequently through cross drains spaced at close intervals. To maintain meadow hydrology, locate cross drains according to natural variations in the land surface, not according to formulas that are based on protecting the ditch. Install additional culverts, dips and lead-off ditches as needed to distribute runoff as naturally as possible.
- Do not route ditch water directly into natural channels but divert low velocity flows across the meadow for increased infiltration and sediment retention and to avoid accelerated downcutting of natural channels.
- Protect outfalls with riprap, velocity checks, sediment pits or vegetated filter zones.
- Avoid any unnecessary or routine cleaning or pulling of ditches during road grading and maintenance operations. Remove blockages that impede ditch water flows; otherwise leave well rooted vegetation in place to control erosion and abate sediment yields.

In-Meadow Road Ditches

In-meadow road ditches are usually constructed on both sides of roads crossing through wet meadows. Their purpose is to drain surface and subsurface moisture and keep road embankments dry. Such treatments drain saturated soils and lower the water table. Normally, the bottoms of in-meadow ditches are excavated to depths well below the natural meadow surface in order to maintain positive hydraulic head or drainage. Channels receiving effluents from in-meadow ditches are often widened or deepened to accept the effluent from rain swollen ditches, usually with serious impacts on wetland hydrology. For the above reasons, it is difficult to mitigate the adverse effects of in-meadow ditch systems.

Possible Remedies

- For in-meadow roads crossing perpendicular to the channel or valley slope, install cross drains at frequent intervals, especially near the meadow's edge, to disperse ditch flows as widely as possible across the meadow surface.
- Raise the elevation of the road surface to create additional freeboard and reduce or eliminate the need for in-meadow ditching.
- Spill ditch waters onto the downchannel meadow surface through closely spaced lead-out ditches rather than transporting flows for long distances to the main channel crossing.
- Divert flow entering the meadow from upslope sources before it is captured by the in-meadow system.
- If possible, relocate the road outside of the wetland.

Lead-off ditches

Lead-off ditches are in-meadow extensions of roadside ditches used to lead ditch waters away from the road embankment and onto the meadow surface. Lead-off ditches are comprised of both a ditch and a berm. The berm diverts surface waters, while the ditch captures and diverts subsurface flows. With time and erosion the ditch is deepened and the berm is extended to accommodate sediments washing down from the roadside ditch. The net effect of the ditch and berm together is to divert runoff toward the center of the meadow in an area extending downstream from the tip of the ditch. Consequently, a portion of the meadow leeward of the ditch dries and is eventually converted to upland vegetation.

Possible Remedies

- Divert water from upslope barrow ditches through cross drains so that it spills on the meadow surface, eliminating the need for a wing ditch (see Figure 42).
- Extend the road ditch, on the contour, along the toe of the sideslope and spill ditch water at the meadow's edge well downstream from the road, thus eliminating the need for an in-meadow, lead-off ditch.

Cut-off Ditches and Berms

Cut-off ditches and berms are installed to intercept in-meadow surface and subsurface flows. The effect of a cut-off ditch is to accelerate velocity, induce head cutting and drain the meadow further upstream of the road than would otherwise have been the case without it (see Figure 25). Normally, cut-off ditches lead diagonally like chevrons to the main channel, emptying at the culvert inlet, increasing flow volumes, flow velocities and erosive forces in the main channel.

Possible Remedies

- Raise the road surface to create more freeboard; install multiple raised culverts or a permeable fill to disperse flows across the meadow (Figures 42 and 47).
- Reverse the orientation of cut-off ditches, i.e. invert the chevrons, so as to lead intercepted waters outward from the center of the meadow and through newly installed culverts at the meadow's edge. The result is to reduce runoff velocities and disperse flows across the meadow surface rather than to concentrate flows in the main channel.

Captured Groundwater

Roads and ditch works divert groundwater away from natural cienegas and generate gullies that reduce their value as wetland habitat. Because cienegas often exist as fine grained soils deposited on steep slopes, gully erosion is a very serious threat. Protection and restoration of cienegas should have high priority for remedial treatment because of their vulnerability to erosion and their importance to a wide diversity of plant and animal species.

Possible Remedies

- Avoid capturing and concentrating flows originating from seeps and springs.
- Attempt to disperse groundwater flow across the full breadth of affected cienegas by routing captured ditch waters through closely spaced cross drains or preferably through a permeable fill.
- Disperse overland flow originating from upslope sources, outside the boundaries of cienegas.
- Avoid concentrating overland flows through a central channel which could accelerate erosion and drain soils now wetted by groundwater flows; eliminate such channels if already present.

Buffer Zones and Filtration Zones

Buffer zones that screen wetland wildlife from road related disturbances and filtration zones that filter sediments from road runoff are important mitigation measures for sustaining properly functioning wet meadow ecosystems. Often these functions can be combined in a single strip of vegetation. Unfortunately, road corridors often impinge, without the benefit of separating vegetation, upon wet meadows and riparian areas, degrading natural functions and reducing their value for wildlife, fisheries, water quality protection, groundwater recharge and other benefits. Re-establishing buffer zones can improve habitat for many species of waterfowl, bald eagles, other raptors, elk, wild turkeys, and other disturbance sensitive wildlife. Improving filtration zones can reduce stream turbidity, improve infiltration and modulate stream flows.

Possible Remedies

- Relocate or realign road segments away from affected wetlands.
- Install traffic barriers or fences to prevent travel within the buffer/filtration zone.
- Plant trees, shrubs or grasses for screening and sediment capture.
- Exclude livestock from the buffer zone to facilitate natural revegetation, reduce soil compaction and improve infiltration rates.

VII. Maintenance

A few modifications in customary road maintenance procedures could lead to widespread improvement in the ecological function and stability of wet meadow ecosystems throughout the Southwest. Suggested modifications include both administrative procedures and technical practices regarding maintenance operations.

Three administrative procedures are suggested for review: 1) the issuance and enforcement of rules regulating road use during periods of inclement weather when road surfaces and ditch systems are most vulnerable to damage by vehicular traffic; 2) the development and enforcement of special performance standards governing maintenance work affecting wet meadows conducted under contract or cooperative agreement between land management agencies and state and local governments, and 3) the provision of wetlands specific training for equipment operators, maintenance foremen, engineers, and specialists whose road management responsibilities might affect wetland areas. A more detailed discussion of technical practices follows with emphasis placed on techniques regarding drainage systems, selection and treatment of surfacing materials, blading and grading practices, care and maintenance of structures, re-engineering of sensitive road segments, and obliteration of abandoned roads where wetlands are affected.

Maintaining Ditches and Drainage Works

Practices used in the maintenance of roadside ditches and drainage works have a direct bearing on the condition and trend of wet meadow ecosystems. Because there is great variability in the application of maintenance practices, there is great variability in results. Some wetlands are recovering while others continue to decline even though practical techniques are available to reverse declining conditions.

Ditch maintenance directly relates to two key factors that affect wet meadow productivity: runoff concentration and sedimentation. Some practices concentrate runoff, others disperse it. Some practices increase sediment generation, others abate it. Any practice that concentrates runoff will tend to accelerate erosion and increase sediment production. Conversely, any practice that disperses runoff will tend to reduce erosion and abate sediment generation. Unfortunately, many routinely practiced maintenance procedures often contribute to wet meadow deterioration through flow concentrations and sediment generation.

Proper ditch maintenance is critical to sediment control. Wide, shallow, "U"-shaped and well vegetated ditches produce little sediment. But steep, narrow, "V"-shaped ditches produce large amounts of sediment, depending on slope gradients, particle sizes and other factors. If ditches are customarily cleaned or "pulled" in a manner that deepens the ditch or removes stabilizing vegetation, sediment yields will exceed that of ditches where only blockages are removed. Thus, spot treatment is recommended. Also, sediment yields are greatly increased where the base of the cut slope is scraped or undercut during maintenance because undercutting destabilizes the entire slope above the ditch. Sediment yields can be reduced by converting V-shaped ditches into U-shaped or flat-bottomed configurations. Not only can reshaping and revegetation reduce sediment yields, it can also reduce maintenance costs by reducing treatment intensities and frequencies.

Two additional ditch treatments that reduce sediment generation include rocking or riprapping between cross drains and the approaches to cross drains or culverts, and installing berms to prevent storm flows from bypassing culvert inlets. If ditches are actively eroding, the need for additional cross drains or lead-off ditches may be indicated. Sediment generation can also be curtailed by riprapping or otherwise protecting culvert outfalls which have not previously been treated. Unfortunately, with a decrease in road maintenance funds, the above listed practices seem to command less attention rather than more. In deference to current funding realities, if greater emphasis were placed on just those sites that affect wet meadows and riparian areas, marked reductions in sediment yields, stream turbidity and damaging runoff concentrations might be realized.

From the standpoint of management priorities, ditch systems contributing turbid runoff and sediment to playa basins should have top priority for treatment to protect basin capacity and water quality from the effects of turbidity and sedimentation.

Dispersing ditch flows to avoid runoff concentrations is extremely important in preventing or controlling gully formation and in restoring wetland hydrology. Ditch maintenance practices which concentrate runoff damage wetlands. Three ditch maintenance practices that concentrate runoff are: 1) carelessly damaging or obstructing culvert inlets thereby blocking effective cross drainage; 2) unnecessarily extending or deepening lead-off ditches; and 3) unnecessarily cleaning stable lead-in and lead-out ditches.

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Road Surfaces

Road surfaces concentrate runoff. If not properly graded, road surfaces yield large quantities of sediment to wetlands while generating rill and gully erosion. Proper maintenance of road surfaces is important to avoid wetland impacts.

Ruts or wheel tracks inevitably develop on both graveled and ungraveled roadways from compaction and displacement of surfacing materials by vehicle traffic. When rainfall accumulates in even very shallow wheel tracks, it can be channeled for long distances before being diverted from the roadway. Wheel track channeling tends to develop on long, straight, gently sloping road segments without crowning or undulating surfaces. As trapped runoff gathers volume and velocity, its power to erode and transport sediment rapidly increases. If concentrated runoff is diverted directly onto a meadow, productive meadow soils may be buried under coarse-textured sediments or eroded by high velocity flows.

Recommended measures for maintaining gravel surfaced roadways include outsloping, crowning, removing unneeded berms, installing "rolling" dips, and constructing built-in grade checks or grade reversals. Grade reversals and undulating road surfaces have proven most reliable in maintaining effective drainage over the long term. Other techniques, unfortunately, are subject to diminishing effectiveness due to traffic use, elapsed time between treatments, and variability in the skill and diligence of grader operators who perform routine maintenance operations. For roads adjacent to wetland and riparian areas, it is important that surfaces be maintained for optimum drainage effects, and not necessarily maximum traffic speeds.

The correct choice of replacement surfacing aggregates is also important. Surfacing aggregates that are fine-textured, that crumble easily under sustained use or produce high quantities of dust may pose sedimentation and turbidity problems for wetlands. Long-term maintenance goals of road segments affecting wet meadow ecosystems might include replacement of unsatisfactory aggregates with coarse-textured or harder materials. Dust stabilizing agents can be used to bind surface particles and reduce sediment generation.

Structures

All culverts and cross drains, including any specialized structures installed for meadow restoration purposes, require special care and attention during maintenance operations. Routine cleaning helps.

Elbow extensions and raised culverts need to be inspected for signs of piping, debris clogging, and roadway overtopping. Roadway overtopping could indicate that modification of a culvert by use of an elbow extension or a drop inlet structure had compromised the hydraulic capacity of the pipe to handle storm events.

Drop inlet structures, such as tie and timber inlets and rock berms, if improperly constructed, are subject to endcutting and undercutting. Again, early maintenance is recommended with periodic follow up. Any washouts or voids created by undercutting or endcutting should be promptly plugged, and any dislodged or missing riprap replaced.

Fords and low water crossings are vulnerable to undercutting due to the scour pool effect. If undercutting is occurring, a more substantial apron or energy dissipator may be needed. An alternative might be to place a lip at the downstream edge of the scour pool.

Finally, permeable fills can be damaged by careless blading or snow removal operations, and by heavy equipment and off-highway vehicles. Another source of damage to permeable fills could be the loss of permeability due to unusually large volumes of sediment being routed through and plugging the rock voids within the structure.

Re-engineering/Reconstruction

With declining maintenance budgets and increasing reliance on contracted or cooperative maintenance activities, re-engineering and reconstructing road segments that impact wet meadow sites could be cost effective in the long run. For example, a one-time investment in additional cross drains, grade reversals, or replacement surfacing aggregates could restore and protect important wetland sites while reducing future maintenance costs. The extra cost of installing additional culverts to achieve improved flow dispersal may be insignificant in comparison with potential wetland benefits. Even where potential benefits are modest, the environmental cost of permitting a damaging situation to continue may be unacceptable.

Obliterating Roads Within Wet Meadows

Obliterating abandoned roads within wet meadows requires taking steps to restore normal hydrologic functions. Effective obliteration depends upon securing dispersed surface and subsurface flows. Simple revegetation of abandoned road segments is seldom sufficient to assure meadow restoration: structural work is usually required. Allowing abandoned roads through wet meadows to heal themselves is seldom a responsible decision with regard to restoring wetland integrity.

Many old roads have become incised below the meadow surface. To restore hydrologic function, the road surface must be reshaped to allow overland runoff to cross over rather than be captured by the abandoned segment. Abandoned ditches should be blocked or drained at closely spaced intervals and all culverts must be blocked or removed. It may be necessary to end haul materials from an upland source to obliterate an incised road segment and restore natural patterns of flow. Water bars are seldom effective here. In some situations, it may even be desirable to design and construct a new channel having the appropriate characteristics of gradient, capacity, shape and sinuosity to assure bedload transport and proper dispersal of overbank flows. Constructing a channel may be more desirable than allowing an abandoned road to capture a stream course, thereby inducing erosion and damaging a meadow, with its associated values, beyond repair.

Obliterating Upslope Roads

The objective in obliterating roads on upslope locations affecting wetlands should be to restore overland drainage to the meadow's edge. It is not sufficient merely to block off and revegetate the abandoned segment without returning overland flows to natural drainage ways. If not properly drained, abandoned roads will continue to capture and divert both surface and subsurface flows while further expanding active gully systems.

The recommended treatment for obliterating upslope roads is to remove any culverts which will not receive scheduled maintenance, block all ditches with berms, install closely spaced, well-built water bars, outslope roadways wherever possible and revegetate with native plant materials. A complete treatment will help to disperse runoff and restore the hydrologic regime of the affected meadow by bringing about improved patterns of infiltration and percolation.

VIII. Monitoring

Purpose

The purpose of monitoring is to gather information managers need for assessing progress and planning future actions. Monitoring provides answers to these and other managerial type questions: What can be learned for future reference? Have project goals been satisfied? Has the desired condition been reached? What follow-up actions are needed?

Information gained from monitoring is useful to management if it is relevant, reliable, objective, timely, documented and easily replicated with similar results. An important related aspect of monitoring is its training value. Scheduled monitoring provides opportunities for gaining first-hand knowledge and experience. Disciplined monitoring hones technical skills. It can provide insight into the complex physical and ecological relationships affecting ecosystems.

Although some changes in wet meadow conditions become apparent soon after treatment, others take years to develop and progress can go unnoticed or be misinterpreted. Monitoring offers a structured framework for detecting, tracking, documenting and interpreting changing conditions, for better or worse.

Selecting Parameters for Monitoring

Monitoring wet meadow recovery following treatment is more a question of what parameters to monitor, and of when and why than of how. Methodologies and equipment available for data collecting are beyond the scope of this handbook, but suggestions regarding what parameters to select are addressed, on the following pages in Table 3, "Wet Meadow Monitoring Guidelines." Nine topic areas, corresponding with indicators of desired future condition identified in Chapter 3 are addressed. A careful consideration of which parameters to monitor in terms of detecting significant change in wet meadow conditions or in providing information for changing road management practices should be emphasized in the development of monitoring plans. Unfortunately, the selection of monitoring techniques and equipment is too often emphasized over the detection, documentation, and interpretation of information important to management.

Table 3. Wet Meadow Monitoring Guidelines

Indicators of Desired Condition	Parameter (What)	Relevance (Why)	Timing (When)	Method (How)
Vegetation	Species occurrence and frequency Aereal distribution (cover patterns) Production Vigor	Determine composition and trend of wetland and upland species. Determine change in plant productivity, health and vigor.	Variable depending on plant phenology and taxonomic considerations concerning plant identification. Late summer for production and utilization studies. Annually to track changing conditions.	Visual inspection Vegetational transects Clipping studies Remote sensing Color infra-red photography Aerial videography

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Table 3. Wet Meadow Monitoring Guidelines (continued)

Indicators of Desired Condition	Parameter (What)	Relevance (Why)	Timing (When)	Method (How)
Up Stream Channel Characteristics	Width:depth ratio Channel slope:valley slope ratio Sinuosity Point bar development and revegetation Condition of headcuts Longitudinal continuity Bank cover and stability	As indicators of recovery, determine if channel is aggrading and revegetating, if headward erosion has moderated, if channel slope is decreasing, if sinuosity is increasing.	Following spring runoff and flooding events. At end of growing season.	Small format aerial or terrestrial photography Visual inspection Longitudinal transects Remote sensing
Downstream Channel Characteristics	Presence/absence of flow Width: depth of active channel Sinuosity Vegetation Bank cover and stability. Sediments	Determine stability and trend of downstream channel Has road treatment stabilized or destabilized downstream channel? Has the volume and periodicity of base flow increased or decreased?	Variable	Visual inspection Temporary transects Permanent transect or reference points

Table 3. Wet Meadow Monitoring Guidelines (continued)

Indicators of Desired Condition	Parameter (What)	Relevance (Why)	Timing (When)	Method (How)
Soils	Soil temperature Soil chemistry Saturation Compaction Depth to water table Depth to capillary fringe Litter accumulation Expanse of vadose zone Depth of penetration and density of wetland plant roots Porosity	Track annual and seasonal fluctuations in water table and soil moisture conditions. Expansion of water table and vadose zone. Expansion and development of hydric soils. Change in infiltration/permeability. Change in organic accumulations.	Variable	Visual inspection Piezometer Wells Ground penetrating radar Color infra-red remote sensing Nutron probes Sonic reflectance equipment Tensiometers
Surface Runoff	Season, duration and aereal extent of inundation by overland or overbank flooding events. Surface ponding Channel storage, bank storage, water quality.	Determine what proportion of potentially flooded area is periodically inundated as indicator of recovery. Locate and remove unnatural impediments to flow dispersal. Determine changes in runoff characteristics as related to treatment. Change in water quality parameters such as turbidity, plant nutrients and pollutants.	During or soon after snowmelt or storm runoff events.	Visual inspection Stream gages Reference marks (stakes or pins) Mapping Remote sensing Photo points Stereo photography Standard water quality testing methodology.

Table 3. Wet Meadow Monitoring Guidelines (continued)

Indicators of Desired Condition	Parameter (What)	Relevance (Why)	Timing (When)	Method (How)
Terrestrial Wildlife	Species occurrence and abundance. Daily and seasonal uses and activities. Presence of keystone species (pocket gophers, voles, beaver).	Determine species diversity and species richness. Species sensitivity to road related disturbance. Suggest mitigation for improved habitat effectiveness. Unique habitat values.	As relevant to seasonal or daily occurrence and use and activities such as feeding, courtship, nesting, rearing of young, and migration.	Visual inspection Breeding bird counts or transects Nest surveys Pellet count Trap count Species specific surveys
Aquatic Wildlife	Same as above. Water quality parameters (temperature, toxins, sediments).	Determine species diversity. Identify barriers to seasonal or annual migrations. Presence/absence of important aquatic invertebrates as indicators of habitat condition.	During spring/ summer breeding season Spawning runs (fish)	Variable Species specific sampling techniques
Macroinvertebrates (terrestrial and aquatic)	Occurrence/abundance of important prey species, indicator species. Occurrence and abundance of keystone species such as crayfish, ants, annelids, crickets (burrowing species).	Water quality. Indicators of habitat suitability for vertebrate species. Indicator presence/ absence of perennial surface water. Soil porosity.	Variable depending on life cycles of indicator species.	Species specific sampling techniques Benthic surveys Traps
Facilities and Improvements	Structural integrity and function relative to intended purpose for meadow recovery.	Maintenance needs. Suitability for future applications. Need for structural modifications or supplementary treatments.	Variable following runoff events. Routine scheduled inspections.	Visual examination

Glossary

A

Active channel: the channel cross section corresponding to bankfull discharge.

Aerobic: a situation in which molecular (free) oxygen is present in the environment.

Anaerobic: a situation in which molecular (free) oxygen is absent from the environment. Microorganisms living in anaerobic environments get their oxygen by decomposing compounds that contain it.

B

Bedload: soil, rock particles, or other debris rolled along the bottom of a stream by the moving water, as contrasted with the silt load carried in suspension.

Bankfull discharge: the flow which just fills the channel to the top of the banks. The reoccurrence interval of bankfull discharge is in the range of 1 to 2 years, with 1.5 years being the average.

Baseflow: The stream discharge composed of groundwater drainage and delayed surface drainage.

Buffer strip (zone): a strip of vegetation managed to reduce the impact of a treatment or action of one area on another.

C

Capillary fringe: a zone just above the water table that remains almost saturated. The extent and degree of definition of the capillary fringe depends upon the size distribution of micropores between soil particles.

Capillarial percolation: percolating subsurface flows above the water table drawn vertically or horizontally through micropores between fine-textured soil particles by surface tension; the force of capillarial percolation is indirectly related to particle size.

Channel gradient (channel slope): the longitudinal slope of the active channel bed, expressed as a percent.

Channel degradation: a lowering of the mean channel elevation; downcutting.

Chlorotic: a yellowing discoloration of foliage indicative of declining plant health due to disease or environmental stress.

Cienega: a riparian grassland characterized by low velocity surface and subsurface flows, fine-textured hydric soils with high organic content and sustained by groundwater discharge from deep, not alluvial, aquifers; infrequently flooded; an elevated or hillside marsh containing springs (local in Southwest).

Cross drain (relief drain): a culvert or pipe used to drain an upslope road ditch.

Cutbank: the concave (eroding) wall of a meandering stream that is maintained as a steep bank by impinging water at its base.

D

Ditch, cut-off: a ditch used to intercept and divert surface water away from the road ditch.

Ditch, flat-bottom: a "u-shaped" roadside ditch usually broader than deep; preferred for reduced sediment yield.

Ditch, lead-in: a ditch used to collect and lead surface flows into the culvert at the main channel crossing (an in-meadow or in-channel ditch).

Ditch, lead-off: a ditch used to lead surface water away from a roadside ditch.

Ditch, lead-out: a ditch used to lead water away from the outfall of a cross drain or channel crossing.

Ditch, road, roadside: the ditch paralleling the road surface used to drain the road surface, road embankment and cut slopes; usually "v" shaped.

Ditch system (ditch works): the combination of all ditches, cross drains and channel crossings used to drain a road or road segment.

Diversity: the distribution and abundance of different plant and animal communities and species within an area.

E

Embankment: an artificially deposited bank of earth, rock or rubble used to hold up or support a road or hold back water.

F

Flooded: a condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks or runoff from adjacent or surrounding slopes.

Frequently flooded: a class of flooding in which flooding is likely to occur often (more than 50 percent chance in any year or 50 times in 100 years).

Floodplain: that portion of a stream valley, adjacent to the channel which is covered with water when the stream overflows its banks at flood stage.

Freeboard: with regard to road drainage, the vertical distance from the top edge of a drainage structure to the road surface at its lowest point.

G

Geomorphic: geological processes which shape surface features of the earth or landform.

Geomorphology: the study of the landforms of the earth and the processes that shape them.

Glaying: discoloring associated with deposits of reduced minerals; indicative of hydric soils.

Gravitational percolation, gravitational water: percolating subsurface flows drawn through the soil profile by the force of gravity; flows propelled by gravity move rapidly through coarse-textured particles and fragments, more slowly through fine-textured particles.

Groundwater: water in a saturated zone of a geologic stratum.

H

Headcut: an escarpment associated with the extension of a stream channel into a previously unchanneled area, or an area within an established channel where there is an abrupt and actively eroding drop in streambed elevation.

Headcutting (headward erosion): the process in which the location of a headcut moves progressively upstream due to the erosive force of water

Historic (former) hydric soil: a soil that was once hydric as evidenced by high organic content and a reduced, mineralized or glayed horizon, but which has been drained directly or indirectly by human activities.

Hydric: characterized by, relating to, or requiring an abundance abundance of moisture.

Hydric soil: a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation.

Hydrogeomorphology: the study of landforms of the earth as shaped or affected by water, especially processes involving flowing water.

Hydrology: the science dealing with the properties, distribution and circulation of water, especially the study of water on the surface of the land.

Hydrophytic: a plant species that has an affinity for abundant water.

M

Mesic: between extremes. Between hydric and xeric.

N

Nickpoint: the point of interruption of a stream profile.

P

Permeability: a quality of soil that enables water to move downward through the soil profile.

Permeable fill: a road embankment constructed of porous rock fill for the purpose of efficiently conducting dispersed surface flows. Also called rockfill embankment, permeable fill embankment, stabilized natural drain and French Drain.

Playa: a shallow central basin of a plain where water gathers after a rain and is evaporated; a closed basin wetland characterized by deep, fine-textured hydric soils and wetland obligate vegetation.

Point bar: sediment deposited on the inside of a growing meander loop.

Ponded: characterized by standing surface water.

R

Riparian: a zone of transition between an aquatic ecosystem and an adjacent terrestrial ecosystem, usually identifiable by soil characteristics and by distinctive vegetation communities that require free or unbound water.

S

Saturated: a condition in which all voids between soil particles are filled with water.

Scour pool: a pool or depression in a streambed or channel created by the force of falling water.

Sediment: solid material, both mineral and organic, that is in transport, or has been transported from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface.

Sedimentation: the deposition of detached soil and rock material that has been transported by water.

Sinuosity: the ratio of active channel length between two points on a channel to the straight line distance between the same two points.

U

Upland (xeric) species: a plant able to survive and reproduce on relatively dry, well drained and well aerated upland soils, but unable to survive and reproduce in wetlands.

V

Valley gradient: the longitudinal slope of the valley expressed as a percent.

W

Water table: the zone of saturation at the highest average depth during the wettest season. It is at least 6 inches thick and persists in the soil for more than a few weeks.

Watershed: the area or basin that contributes water to a drainage or stream.

Water yield: that portion of annual precipitation which contributes to stream flow and groundwater recharge.

Wetland faculative species: a plant, while not dependent upon the water table or its capillary fringe for survival, able to survive and reproduce itself in a wetland environment.

Wetland obligate species: a plant dependent on the water table (saturated zone) or its capillary fringe to survive and reproduce itself.

Wetland hydrology: the sum total of wetness characteristics in areas that are inundated or have saturated soil for a sufficient duration to support hydrophytic vegetation.

Wetlands: those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal conditions, do support a prevalence of vegetation typically adapted for life in saturated soil conditions. The current legal definition requires a site to have hydrophytic vegetation, hydric soil, and wetland hydrology.

Wet meadow: a riparian (riverine) grassland characterized by low to high velocity surface flows, low velocity subsurface flows, with frequently flooded hydric soils, dominated by wetland obligate grasses and grass-like plants, especially grasses and sedges, and sustained primarily by incoming channel flows, shallow alluvial groundwater and overland flow.

X

Xeric: relatively dry (see hydric and mesic).

Appendix A

Wet Meadow Indicator Plants[1]
List of Species by Forest Type[2]

Upland Periphery (Xeric)	Mid Meadow (Mesic)	Aquatic periphery (Ponded or flowing water)
Ponderosa Pine Type		
Agropyron smithii	Achillea lanulosa	Agrostis alba
	Agrostis alba	Carex sp
	Chrysothamnus sp	Equisteum sp
	Iris missouriensis	Juncus sp
	Poa praetensis	Polygonum sp
	Taraxicum officinale	Sagittaria sp
		Scirpus acutus
		Sidalcea neomexicana
		Typha sp
Mixed Conifer Type		
Danthonia sp	Achillea lanulosa	Agrostis alba
Iris missouriensis	Agrostis alba	Bromus sp
Poa praetensis	Bromus sp	Calamagrostis sp
Taraxicum officinale	Carex sp	Caltha leptosepela
	Equisteum sp	Carex sp
	Geranium sp	Eleocharis sp
	Iris missouriensis	Glyceria sp
	Juncus sp	Hordeum sp
	Mentha arvensis	Juncus sp
	Oenothera sp	Polygonum sp
	Potentilla fruticosa	Ranuculus sp
	Sisyrinchium demissum	Rorippa sp
	Veratrum californicum	Rumex sp
		Sagittaria sp
		Salix sp
		Scirpus acutus
		Typha sp

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List of Species by Forest Type[2] (continued)

Upland Periphery (Xeric)	Mid Meadow (Mesic)	Aquatic periphery (Ponded or flowing water)
Spruce Fir Type		
Achillca lanulosa	Aster sp	Calamagrostis sp
Iris missouriensis	Agrostis alba	Caltha leptosepcla
Potentilla fruticosa	Allium sp	Carex sp
	Calamagrostis sp	Deschampsia sespitosa
	Carex sp	Eleocharis sp
	Cirsium sp	Juncus sp
	Deschampsia caespitosa	Pedicularis groenlandica
	Equesteum sp	Picea pungens
	Hordeum sp	Polygonum sp
	Juncus sp	Sagittaria sp
	Mentha arvensis	Salix sp
	Phleum sp	
	Trifolium sp	
	Veratrum californicum	

[1]Partial list compiled by B. Zeedyk and R. Fletcher, Regional Ecologist, USDA, Forest Service (R-3) from variously related reports submitted from the Carson, Santa Fe, Cibola, Gila, Apache-Sitgreaves and Coconino National Forests.

[2]Species and genera listed were selected based on relative ease of identification by laymen. Their occurrence indicates possible presence of hydric, or formerly hydric soils; check for other indicators. Seek professional botanical assistance in making positive identifications of specimens. Most, but not all, species shown appear on the Fish and Wildlife Service, *National List of Plants that Occur in Wetlands: Southwest (Region 7)* (Reed P.B. 1988).

Appendix B

Water Rights Considerations[1]

Managers frequently ask questions about what water rights considerations need to be addressed to implement wetland projects. Although most projects will not involve water rights issues, some could. This appendix is intended to help answer some of these questions from a National Forest System perspective.

Background

The Forest Service's objective in appropriating water is to assure water needed for National Forest System purposes is obtained in accord with legal authority and with due consideration for the needs of other water users.

Two water law authorities are available for National Forest System (NFS) water use. They are the Reservation Doctrine, a federal authority, and the state water codes adopted by the state legislature and subsequent court rulings. The Reservation Doctrine evolved as Federal law, through several federal court cases. The rationale was that Congress implied water would be included with the reservation of lands from the public domain for federal purposes. That is, the U.S. retained the rights to use water needed for achieving federal objectives on lands reserved from the public domain.

State water codes evolved in the developing western states to add some order to the utilization of water for economic development. They generally followed the doctrine of prior appropriation. This doctrine is based on the principle of first in time is first in right, and putting water to beneficial use is the measure of appropriation. A physical diversion or impoundment is often required as proof of applying water to beneficial use.

The Reservation Doctrine

Determining the applicability of the reservation doctrine requires some thought about the water use purpose, and the status of the land on which the water will be used. That is, will the water be used for a federal purpose defined in some federal enabling legislation, and will it be used on land reserved from the public domain? If not, then state law water rights are likely needed.

The Organic Administration Act of 1897 is the basic enabling law for the Forest Service. This Act provides the authority for the Forest Service to claim water for consumptive or nonconsumptive needs on reserved lands directly related to securing favorable conditions of water flow or to furnish a continuous supply of timber. Securing favorable conditions of water flow is interpreted to include activities carried out for watershed protection and restoration.

Watershed restoration may include wetlands restoration or other actions needed to rehabilitate site conditions to predisturbance conditions. Watershed enhancement might include the improvement, maintenance, and management of watershed conditions for a particular function or value. Enhancement could be argued to be watershed protection.

Wetland establishment or creation is the conversion of a non-wetland area into a wetland where a wetland never existed. It becomes more difficult to argue that wetland establishment is part of watershed protection or restoration. A plan to establish a wetland requires more thought as to hydrologic function in the watershed before a determination can be made as to the applicability of the Reservation Doctrine.

One should consider the likely historic presence of wetlands in the watershed and certainly potential impacts on downstream water users before planning a wetland establishment project. Also, what are the potential ecological effects of creating waters or wetlands in areas where historically there were none?

Two questions must be answered in deciding if the Reservation Doctrine applies to a project: (1) Is the proposed project on lands reserved from the public domain? (2) Will the project fit under one of the federal purposes stated in the enabling legislation for the agency's management? If you can conclude, after answering these questions on the purpose and land status of a proposed project, that the Reservation Doctrine provides the appropriate authority for using water, then the priority date is the reservation date for the land where the project is located. In the interest of state-federal relations, managers should keep the state engineer or water rights administration authority involved as partners in the project from the beginning.

There may be other authorities for applying the Reservation Doctrine, such as the Wild and Scenic Rivers Act and the Wilderness Acts. However, these laws are not as well tested in the courts as the Organic Act. Before assuming that either of these acts provides a basis for using water for wetlands, consult the Regional Water Rights Coordinator.

State Water Laws

Generally, waters needed for uses other than those covered by the Reservation Doctrine must be appropriated according to state laws and regulations. This means an application must be filed with the state authority that administers the allocation of water. Priority dates are usually based on the date the application is received. The application process is described in publications maintained by these authorities and may change with time and are different in each state. Begin working with state officials early for current advice in the appropriation process.

Small quantities of water might fit under two concepts generally recognized in the western states, and considered not subject to appropriation. One is the deminimus use concept. This idea applies when small amounts of water rise and are used on the land by a landowner before flowing into a defined channel. Unfortunately, the quantity considered deminimus is not defined, so work with the state agencies to determine how much is considered deminimus.

Another concept is that of diffuse surface flow. This applies to waters flowing over the surface of the land before becoming concentrated in a defined channel. This concept applies to road surface runoff, for example, if it is captured before it reaches a channel.

In conclusion, water rights, in most cases, must be appropriated according to state water codes if the proposed wetland is on lands acquired by means other than reservation. State water laws must be followed if the wetland purpose is other than watershed protection or restoration. It is important to involve the state water rights agency when considering plans to use water in a restored wetland.

[1]Prepared by Doulgas W. Shaw, Deputy Director, Watershed and Air Management, USDA Forest Service (R-3).

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)