Characterization and Restoration of Slope Wetlands in New Mexico

A Guide for Understanding Slope Wetlands, Causes of Degradation and Treatment Options

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Quivira Coalition
Mollie Walton, PhD and Tamara Gadzia
1413 Second Street, Suite 1
Santa Fe, NM 87505
(505) 820-2544
www.quiviracoalition.org
admin@quiviracoalition.org

~

William (Bill) D. Zeedyk
Zeedyk Ecological Consulting, LLC
Sapello, New Mexico
billzeedyk@centurylink.net

~

New Mexico Environment Department
Surface Water Quality Bureau (NMED-SWQB), Wetlands Program
P.O. BOX 5469
Santa Fe, NM, 87502
(505) 827-0187
www.nmenv.state.nm.us/swqb/wps/#Wetlands

Content
Bill Zeedyk, Mollie Walton, PhD, and Tamara Gadzia

Layout and Design
Tamara Gadzia

Graphics
Concepts: Bill Zeedyk and Mollie Walton, PhD
Design: Tamara Gadzia

Cover Photo
Slope Wetland Restoration at Grassy Creek Site, Comanche Creek Watershed, Carson National Forest, New Mexico by Karen Menetrey, 2014, (NMED-SWQB), Wetlands Program

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CHAPTER 1 **INTRODUCTION**

The purpose of this document is to describe a wetland resource in New Mexico that faces significant challenges, yet holds great potential for stabilization and restoration. Slope wetlands are found throughout mountainous regions of New Mexico. Slope wetlands have been described by Novitsky (1982) as surface water slope wetlands and ground water slope wetlands, depending on the dominant source of water that supports the wetland hydrology. Slope wetlands have also been defined by Brinson (1993 and 2008) as a class of wetlands based on hydrogeomorphic wetland classification (HGM) system. Brinson defines slope wetlands as those that occur "where there is a discharge of groundwater to the land surface. They normally occur on sloping land; elevation gradients may range from steep hillsides to slight slopes. Slope wetlands are usually incapable of depressional storage because they lack closed contours." Figure 1 depicts the difference between a slope wetland and a depressional wetland. Figure 2 is a photograph of a slope wetland complex in the Comanche Creek Watershed, located in the Valle Vidal Unit of the Carson National Forest, Taos County, New Mexico.

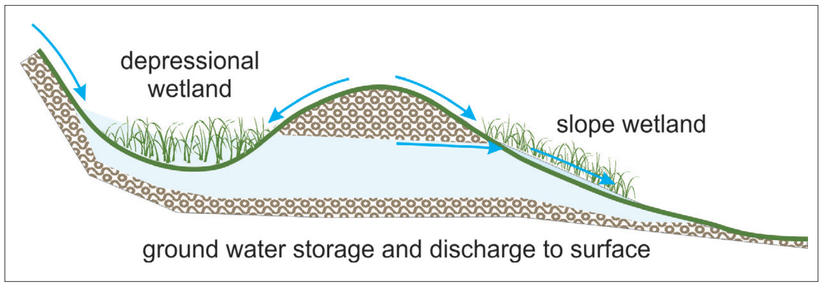

Figure 1. This schematic depicts a cross-section of a depressional wetland versus a slope wetland.

This document further characterizes subclasses of slope wetlands in New Mexico as those that have dispersed flow over the surface of the wetland but may have either precipitation-driven or groundwater-driven hydrologic characteristics or both. The main types of slope wetlands described in this document include Pleistocene Lakebed Slope Wetlands, Monsoon-Driven Slope Wetlands, Cienegas, Spring-Fed Slope Wetlands, and Headwater Slope Wetlands, with an emphasis on the headwater slope wetlands of the Comanche Creek Watershed.

In addition to headwater slope wetland characterization, this document discusses the site assessment method called "reading the landscape" to determine natural processes working on the landscape, which stressors (factors that influence degradation of wetland structure and function) are present, and which treatments will help stabilize these wetlands and/or help restore them. The information presented is based on observational data collected from mountain ranges in New Mexico, as well a targeted study of headwater slope wetlands in the Comanche Creek Watershed.

Figure 2. This photograph shows a slope wetland complex in the Comanche Creek Watershed, Questa Ranger District, Carson National Forest.

The New Mexico Environment Department (NMED), Surface Water Quality Bureau, Wetlands Program divides wetlands into classes and is currently defining regional wetland subclasses according to the HGM classification system. These classes are based upon the hydrogeomorphic factors identified by Brinson (1993 and 2008) and other factors of regional importance. Slope wetlands are a class of wetlands and regional subclasses are still being defined for the New Mexico Rapid Assessment Method (NMRAM). Regional differences in subclasses may be based on the five subclass types proposed in this document. Subclasses of slope wetlands in New Mexico are briefly discussed as examples of the different types of slope wetlands that result from the interaction of site conditions, including landform, geology, soil type, hydrology, precipitation regime, and ecological site conditions.

HEADWATER SLOPE WETLANDS

Slope wetlands may be further defined by subclass; however the slope wetlands which are described in detail in this paper fall within the classification of "headwater slope wetlands" and have been described specifically based on field characterization of headwater slope wetlands within the Comanche Creek Watershed of northern New Mexico (Figure 3) and a literature review. The excellent paper by Wood et al. 2006 is particularly pertinent.

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Figure 3. Photo of headwater slope wetlands in the Holman Creek Watershed, Questa Ranger District, Carson National Forest.

Comanche Creek is located in Northern New Mexico's Sangre de Cristo Mountains in the Upper Rio Grande River Basin. The headwaters of Comanche Creek lie at an average elevation of 10,400 feet. The entire watershed lies within the Valle Vidal Unit, Questa Ranger District, Carson National Forest. The health and function of headwater slope wetlands in places such as the Comanche Creek Watershed are important to the function of the larger, surrounding watersheds. In this case, the larger watershed that includes the Comanche Creek Watershed flows into the Rio Grande via the Rio Costilla. Restoration in the headwater slope wetlands has the effect of improving water availability over time to the largest river system in New Mexico.

IMPORTANCE AND FUNCTION OF HEADWATER WETLANDS

Water loss to a system begins at the highest place on the landscape where water is first captured in the terrestrial part of the hydrologic cycle. By securing these critical areas, the future stability of wetlands downslope and in floodplain valleys is enhanced. The level to which headwater slope wetlands are intact influences the water delivery rate (baseflow) to the downslope environments (Earman et al., 2004). Wetland vegetation also helps dissipate water energy before the water reaches tributaries and therefore has an effect on reducing downstream erosion and channel downcutting (deepening of the stream channel due to erosion).

It is important that water be captured and stored in wetland soils as high up on the landscape as possible. Wetland soils accumulate organic matter at a high rate, and soils high in organic matter hold more water than mineral soils.

Because of this attribute, wetland soils act as a sponge, holding water and slowly releasing it by gravimetric flow to downslope systems. This is important for sustaining wetland communities, including terrestrial and aquatic plants and animals, and occasionally rare plant communities. Riparian and wetland habitats in the arid Southwest are also a very important source of food and water for wildlife species that are not wetland obligates. However, headwater slope wetlands are particularly important to maintaining the cold temperatures necessary for cold water aquatic life downstream, such as New Mexico's State Fish, the Rio Grande cutthroat trout. Wetlands provide many ecosystem services in addition to being essential for plant and animal species. For more information on these services, see the World Resource Institute's 2005 publication, *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*, *www.unep.org/maweb/documents/document.358.aspx.pdf*

Wetlands are critical features in arid and drying landscapes. In the face of climate change and extended droughts, restoration activities in headwater systems increase the likelihood that the lower waterways can continue to support both human and wildlife populations in New Mexico. Current understanding of the local effects of global warming include a significant increase in the severity and duration of drought, the severity and intensity of precipitation events, increased stream water temperatures, and earlier snowpack runoff, all of which will increase stress on riparian and wetland systems and put them at risk (Intergovernmental Panel on Climate Change, 2014). If wetland degradation is not addressed, there is the sobering probability that the associated ecological functions and services that all humans depend upon will also suffer continued degradation.

LEGACY AND CURRENT STRESSORS

Legacy actions by humans have negatively impacted riverine and wetland ecosystem functions and services. The Valle Vidal Unit of the Carson National Forest, containing the Comanche Creek Watershed, has endured a long history of industrial use, including mining, logging, and livestock grazing (Figure 4).

Figure 4. This photo shows historic placer mining, LaBelle, New Mexico circa 1890-1910. La Belle, New Mexico was a small mining community not far from what is now the Valle Vidal. (Denver Public Library, Western History Collection, Aultman, Otis A., 1874-1943. CHS.A646).

Current conditions that affect the health of wetlands and streams within the watershed are in large part due to legacy land use practices. Since the Valle Vidal came under the ownership and management of the United States Forest Service in 1982, land conditions have been improving and many of the initial stressors (legacy stressors) that caused the degradation have been removed or remediated. The current stressors are the result of positive feedback loops set into motion by the original stressors. For example, as a result of a badly placed road or a deepening livestock trail, gullies have down-cut through the wetlands, causing the loss of dispersed surface flow and with it the inherent capacity of wetland soils to store water. As the gully deepens, slow moving dispersed flow spreading across the wetland surface is replaced by fast moving, highly erosive, concentrated flow in the evolving channel. The wetland shrinks in area and loses storage capacity as it dries.

Figure 5 shows a positive feedback loop in which a small disturbance becomes magnified and creates further degradation.

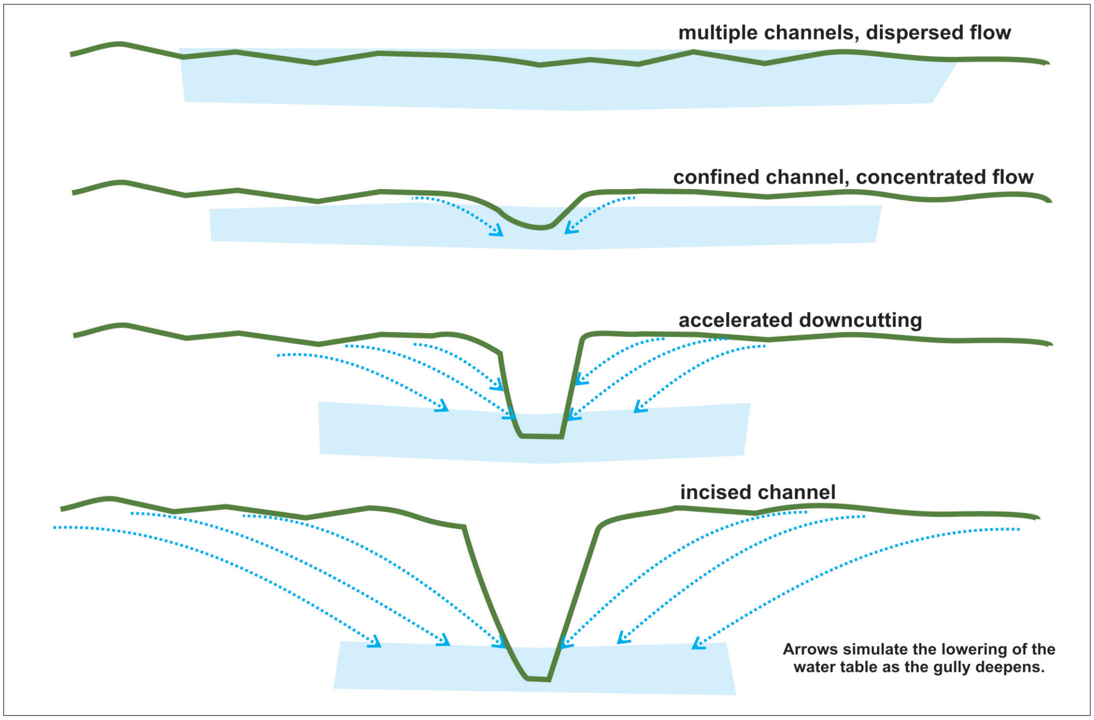

Figure 5. Cross-sectional profile of the change from dispersed flow across a slope wetland complex that accelerates the rate of channelized flow.

The original dispersed flow over the surface of a slope wetland is captured by a trail or road, resulting in a small channel that in turn captures even more water away from the wetland surface. The channel that is formed moves more water and at a higher velocity than before. The higher velocity in turn has more erosive force and causes the channel to incise more rapidly. The incised channel isolates the water from its former floodplain and storage in wetland soils. The headcut moves upslope and the effect of the positive feedback loop continues to grow in the form of larger and larger areas of degradation and loss of wetland function and ecosystem services.

If legacy stressors had not been present, intact slope wetlands might have been the dominant landform in the upper valleys of the Comanche Creek Watershed, rather than today's system of small tributary streams flowing to Comanche Creek. These valleys would have been expansive slope wetlands without active creek channels except for short reaches linking wetlands with steep elevational differences.

Understanding the interaction between the legacy stressors and current stressors is essential in order to understand how to interpret the positive feedback loops involved in headwater slope wetland degradation. The following section discusses how to read a landscape and understand its story.

CHAPTER 2 READING THE SLOPE WETLAND LANDSCAPE

"Reading the landscape" is necessary in order to identify the problem, determine the probable source of the problem, unravel its history, and identify potential solutions. For an extensive description of techniques for reading landscapes, see Zeedyk and Clothier's 2009 publication, *Let the Water Do the Work*. Questions to ask when reading a particular slope wetland landscape include:

- What processes shaped the watershed?
- What forces altered the condition in the watershed and caused the site to become degraded?
- What interactions between biotic and abiotic processes in the watershed affect resilience (or lack of resilience) in the ecosystem?
- What are some realistic actions that might be taken to slow or halt degradation of the slope wetland or reverse the drying trend?

The practiced reader sees geology, topography, hydrology, soils, aspects of plant and animal ecology, and the effects of disturbances. The goal is to understand both past and present processes at work on the landscape.

GEOLOGY

In reading the landscape, a basic knowledge of local geology is helpful. One reference is the appropriate volume from the Roadside Geology series by Mountain Press Publishing Company, *Roadside Geology of New Mexico* (Chronic,1987). It identifies New Mexico's dominant rock formations by geological period, prominent surface features, and how these landforms have been modified by events that occurred during the most recent period of geologic time (Quaternary Period). Each mountain range, plateau, basin, or desert valley is composed of a unique set of geologic formations. Figure 6 is a geologic map that contains the Comanche Creek Watershed (Fridrich et al., 2012). Each formation erodes to produce a unique sediment supply to be transported and deposited in characteristic patterns by erosional processes.

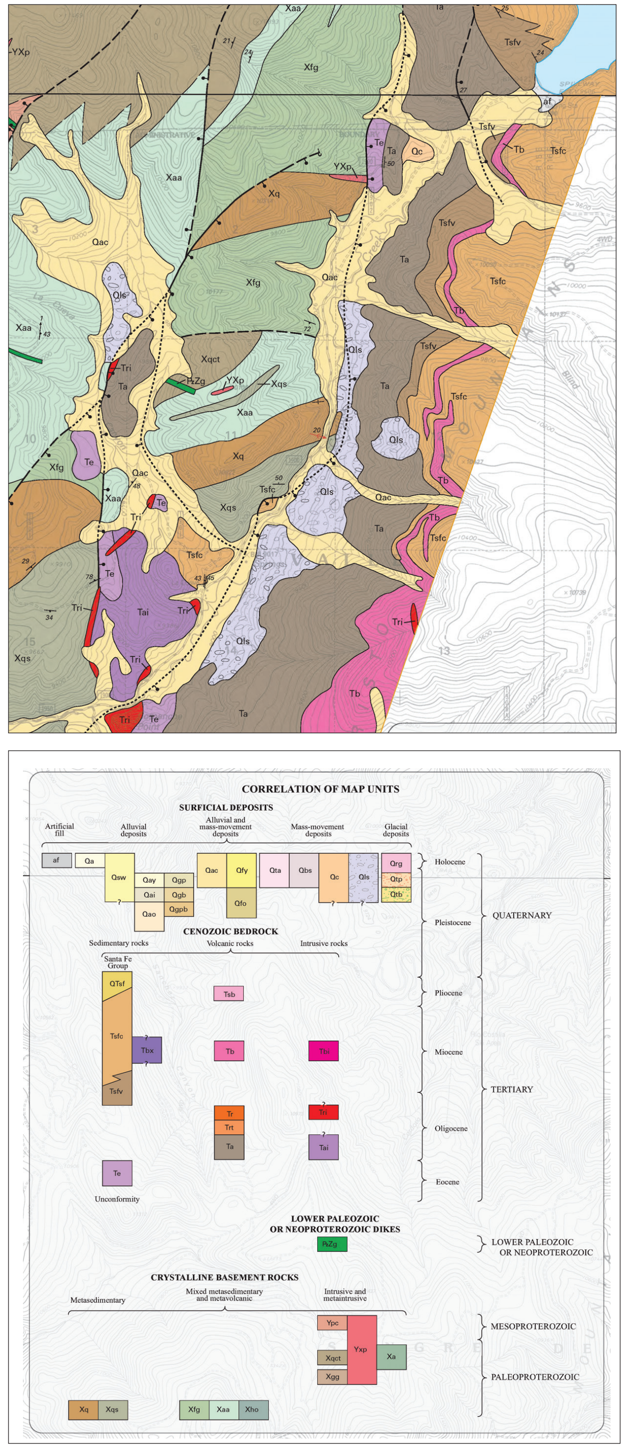

Figure 6. On the geologic map above, the light tan areas (Qac) represent younger formations that are the result of accumulation of unconsolidated sediment eroded from older rocks. Fault lines shown on geologic maps are possible locations where springs may emerge to saturate wetland surfaces. The lower legend is a correlation of map units by age and rock type (Fridrich et al., 2012).

TOPOGRAPHY

The topography of an area includes such factors as elevation, relief (changes in elevation between points), slope (steepness and extent), position on slope, aspect (directional orientation, e.g. a north facing slope), and drainage patterns. Of the many different topographic features affecting watershed function, hillslope processes, slope, aspect, and relief are central to reading the landscape (Figure 7).

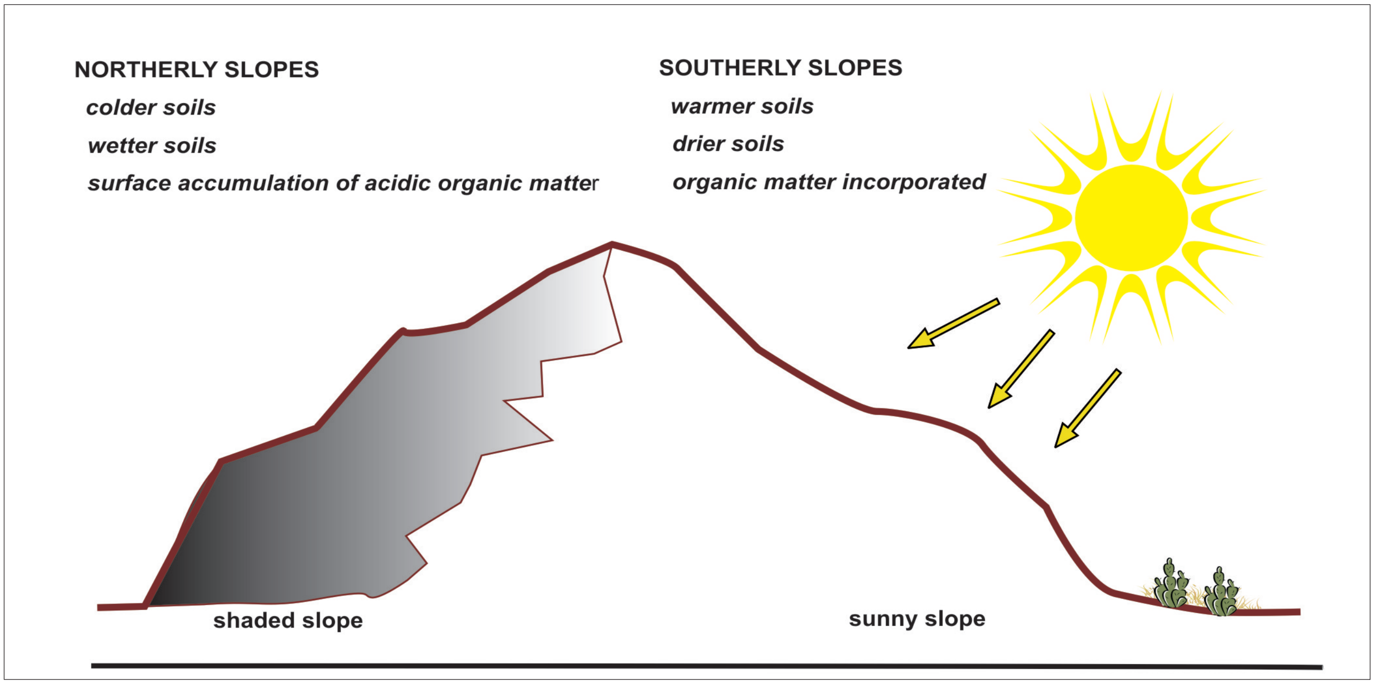

Figure. 7. Hillslope processes, slope, aspect, and relief all have a significant effect on the assemblage of vegetation communities and the potential for restoration success.

A basic understanding of geomorphology is helpful to understanding the surface processes at work on a landscape. Geomorphology shapes topography, including slope wetlands. Information in this document contains brief introductions to a topic that has considerable depth and complexity. For more information on the following topics see www.cec.uchile.cl/~fegallar/Fundamentals_of_Geomorphology.pdf.

Hillslope processes have much to do with the movement of sediment. Mass wasting, the movement of sediment by gravity or water down a slope, depends upon many factors. Hillslope processes are those that occur on the watershed slopes outside of a creek or river channel. Sediment particles carried by water in channels are governed by ***fluvial processes.***

Slope is a measure of the steepness of the land form. The steeper the slope, the faster water moves across it. Position on slope is important. The further downslope, the more accumulated flow will move past a given point. Where slopes steepen, water speeds up and soils erode, and where they flatten, water slows down and soils accumulate. Soil erosion rates are high on steep slopes and low on flatter slopes. Soil depths, moisture availability, and plant growth tend to vary accordingly.

Slopes may be uniform from top to bottom, but more often they vary in steepness. The point where there is a change in the steepness of a slope is known as a slope break. A long slope in mountainous terrain might have numerous slope breaks, interrupted by cliff lines or escarpments. Each slope break would have its own effect on steepness, the velocity of surface water runoff, the accumulation of soil particles, soil depths, and vegetation community.

Aspect refers to orientation or the direction a landform faces. In the Northern hemisphere, south slopes are warmer than north slopes. South slopes dry more quickly than north slopes. Snow accumulations are less because soils are warmer and snow melts more quickly. Site productivity is lower on south slopes and higher on north slopes. Plant species composition, tree heights, and canopy densities vary greatly between northerly and southerly slopes.

Soil erosion rates tend to be higher on south facing slopes, therefore soil depths tend to be greater on north facing slopes. Soils on northerly slopes also contain higher proportions of accumulated organic matter. More water permeates into and is held by soils on northerly sites. East and west slopes are intermediate between those facing north and south, depending on the degree of deviation, but east slopes tend to hold more moisture than west slopes because air temperatures are lower in the morning than in the afternoon and prevailing winds from the west tend to be more drying.

Relief is a measure of the difference in elevation between two points and, in total, a measure of the evenness or unevenness of the land surface. In relatively flat to rolling terrain, slight differences in relief, slope, and aspect can make relatively large differences in soil depth, moisture retention, and erosion rates. All of this will be reflected in the composition and distribution of species in the vegetation community.

HYDROLOGY

Hydrology is the study of the movement of water through the hydrologic cycle. Geology and topography both have a significant role in the path that water takes once it enters the terrestrial part of the hydrologic cycle. Water is transported as it runs off upland surfaces, infiltrates soil, percolates down into geologic layers, and is discharged at the surface in the form of springs. Some of the surface runoff will flow into streams and may eventually return to the ocean to complete the cycle (Figure 8).

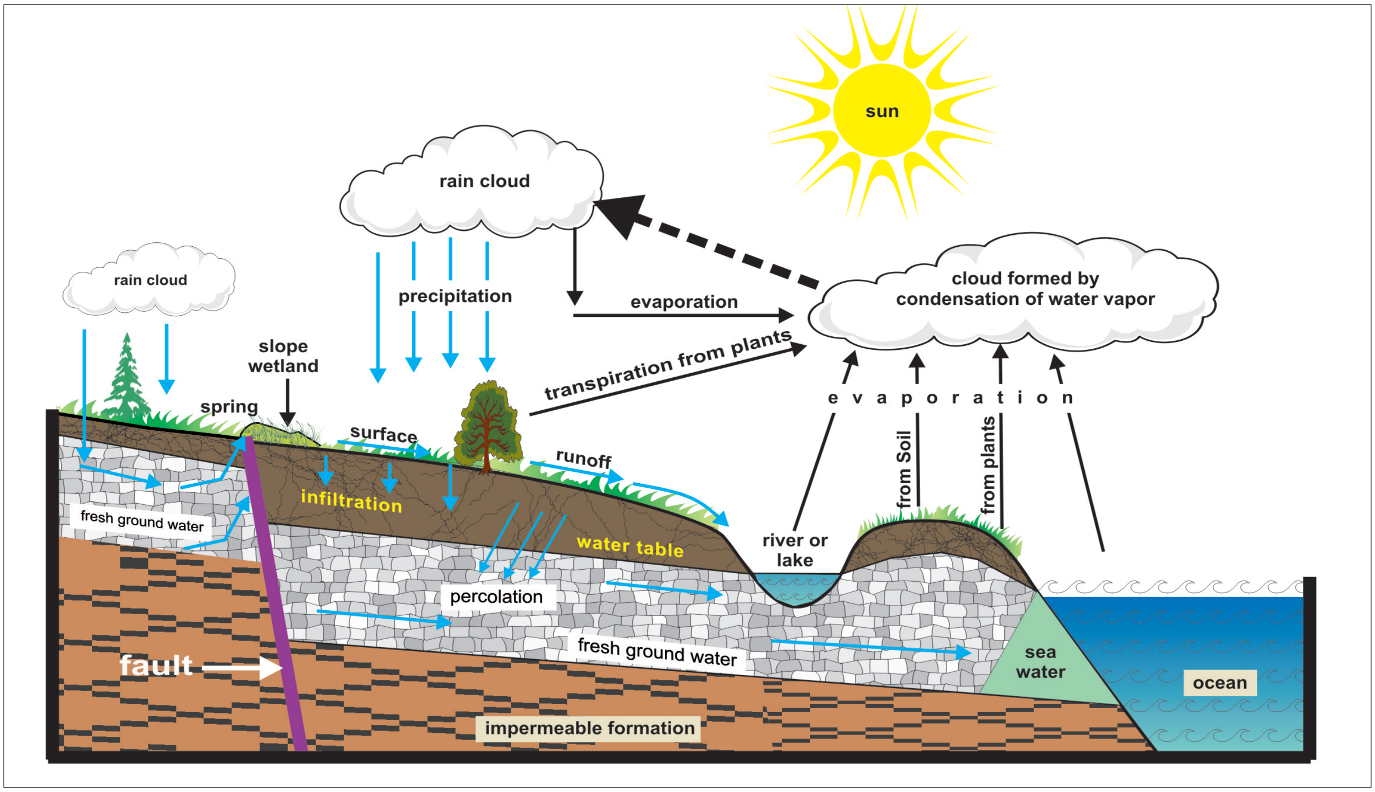

Figure 8. In this generalized model of the hydrological cycle, headwater slope wetlands occupy the highest place in the landscape where water is captured for storage in the soil (adapted from Zeedyk and Clothier, 2009).

The water will take many paths before it eventually reaches the ocean. Some water will be used by vegetation and be returned to the atmosphere by evapotranspiration. Some will infiltrate the ground surface and percolate downward through the soil to recharge both shallow and deep groundwater aquifers. Springs will emerge where aquifers intersect the surface, depending upon geologic conditions at the site (such as faulting), and some will run off the soil until it reaches the lowest place in the landscape. Topographically, slope wetlands are a crucial link between surface water runoff and groundwater storage, serving to intercept runoff and allowing water to infiltrate into the soil.

In reading the landscape, it is important to gain an understanding of the local hydrology in order to understand its influence on wetland formation and degradation. Questions to ask include:

- When does precipitation normally arrive and how is it distributed seasonally throughout the year?
- What is the normal amount of precipitation per event, season, or year?
- What is the normal storm duration and intensity and how great are the likely variations?
- How quickly will water run off?
- What is the duration of flow?
- How much discharge is likely to result from a precipitation event of a given magnitude per unit area of land?
- What is the location of springs, the volume of water discharge, the seasonality, and the reliability of flow?

These questions may be answered by observing the hydrologic regime of an area. Climatic data may be easily obtained by conducting internet research at websites such as the National Oceanic and Atmospheric Administration (NOAA), www.noaa.gov. The United States Geological Survey (USGS) water resources data site, http://waterdata.usgs.gov/nwis, will yield some information; however, hydrologic conditions will be site specific, based on all of the landscape-based factors discussed above. Knowing the interaction of factors will lead to a better understanding of the ecosystem drivers in the landscape that is being read.

PRECIPITATION AND GROUNDWATER FLOW

Water flow in slope wetlands includes four precipitation factors, which (in combination) determine the regime for a particular area (Figure 9). These factors are magnitude, timing, frequency, and duration of precipitation events (For a detailed description of hydrologic regimes in creek and rivers, see Poff et al.,1997). For slope wetlands, many of the same factors are important. The duration and magnitude of groundwater flow will also influence the hydrologic regime.

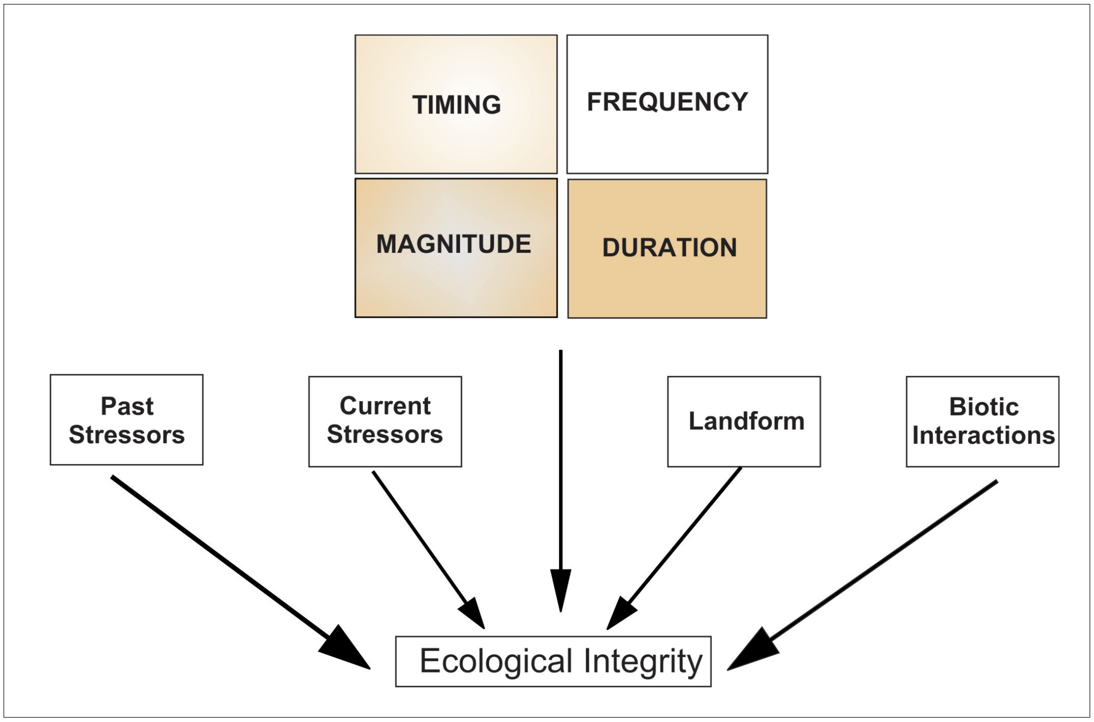

Figure 9. Understanding these factors as they relate to slope wetland function will help one make informed decisions on the restoration potential of a particular site (adapted from Poff et al.,1997).

The precipitation regime helps drive the hydrologic regime. Headwater slope wetlands are dependent on both snowmelt and summer monsoon-driven moisture events. Snowmelt events deliver moisture over a longer period of time. Although monsoon events tend to carry more coarse sediment, snowmelt and groundwater/baseflow may have a greater overall erosional effect. Even in groundwater dependent slope wetlands, snow and rain influence the overall hydrologic signature. However, constant flow from groundwater sources buffer the system against dramatic seasonal changes. The degree to which the surface structure is intact will affect how slope wetlands function, regardless of groundwater input.

The ***magnitude*** of a precipitation event can affect the scale of the surface area and depth wetted by a precipitation event. Restoration practitioners may be able to affect the surface area wetted by dispersing channelized flow and creating conditions which favor water infiltration into the soil rather than runoff. ***Frequency***—the interval of time between individual precipitation events, such as snowmelt, monsoon, drought—affects how water enters the system. There is no way to manipulate this factor by any restoration treatment.

The ***timing***, or seasonality, of precipitation in relation to the duration of snowmelt events affects how water infiltrates into the soil or flows through the system. Growing season precipitation in the form of monsoon events also has an effect on the amount of water that may be intercepted by actively growing vegetation. Restoration practitioners cannot control the timing of precipitation but are able to affect the ***duration*** of time that surface runoff remains available by careful placement of treatment structures and by maintaining a dense stand of wetland dependent vegetation (e.g., *Carex* Spp.).

Water storage in a slope wetland occurs in wetland soils. Successful restoration treatments that help to store water in the soil make this moisture available for a longer period of time for plants and soil-dwelling organisms and enhancing baseflow lower in the watershed. One may be able to influence how long the impact of a precipitation event lasts in the system by slowing the rate of flow through the wetland soils.

SOILS

Soils vary enormously in fertility, productivity, permeability, water holding capacity, and erodibility. Other properties include texture, depth, composition, organic matter content, and temperature. Soil profiles can be readily observed along road cuts, ditch banks, and erosion gullies. Soil maps and descriptions are generally available from local offices of the United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS, http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). Descriptions include information regarding soil capability and limitations for different uses. These descriptions aid in reading the landscape because plant species are listed based on what one could expect to encounter when site conditions are good, as well as when the site conditions are degraded.

Soils are said to be ***alluvial*** if formed by the action of moving water. Soil is made up of three different-sized particles — sand, silt and clay. Sand particles are the largest and clay particles the smallest. The amount of energy needed for flowing water to carry soil particles in suspension is based on particle size. Finer particles stay in suspension longer and are deposited last. Fine-grained alluvial soils are deposited by water flowing over floodplains or lake beds.

Permeability and water-holding capacity varies immensely among different soil types. Changes in soil type are almost always reflected in changes in vegetation. Vegetation increases surface roughness, which promotes deposition of fine grained particles. When reading the landscape, an apparent change in plant species composition, height, density, or distribution may indicate a difference in soil type and the soil's ability to capture and hold moisture. Wetland soils have higher organic matter than upland soils. This occurs because the rate of biomass production is high relative to the rate of biomass decomposition, due to the anaerobic processes at work in saturated soils (Reddy et al., 2000). Each one percent increase in organic matter gives the soil potential to store an additional 25,000 gallons of water per acre (Kansas State Extension Agronomy, 2012). Peat soils, such as those found in the fen component (see Vegetation Community section below for definition) of the slope wetland complexes, store the most water.

Headwater slope wetland soils are fed by surface runoff derived from snowmelt. As snow melts and runs over the vegetated surface of the land as dispersed flow, sediment particles are caught and the area is aggraded (gaining sediment). Many headwater slope wetlands have a slightly convex shape from the aggraded fine sediments. Snowmelt that does not runoff, but percolates into the soil, recharges the slope wetland. Finer grained soils may be deposited as strata perched above coarser particles (sand, gravel, and cobble) that serve as a shallow aquifer which conducts water more readily than the surface layers. Finer grained soils wick water by capillary action.

Infiltration

In reading the landscape, the most important observation to make about soil is its permeability and water-holding capacity, as well as its composition, structure, and depth. The next most important observation relates to the hydrologic condition of the soil surface. Infiltration rate is directly related to the amount of vegetative soil surface cover and surface roughness. Each blade of grass acts as a small dam to slow water flow over the surface. The water is funneled to the roots of the plant and infiltrates into the soil along the root channels (Figure 10). The more vegetative cover, the better the infiltration, and therefore, the less runoff.

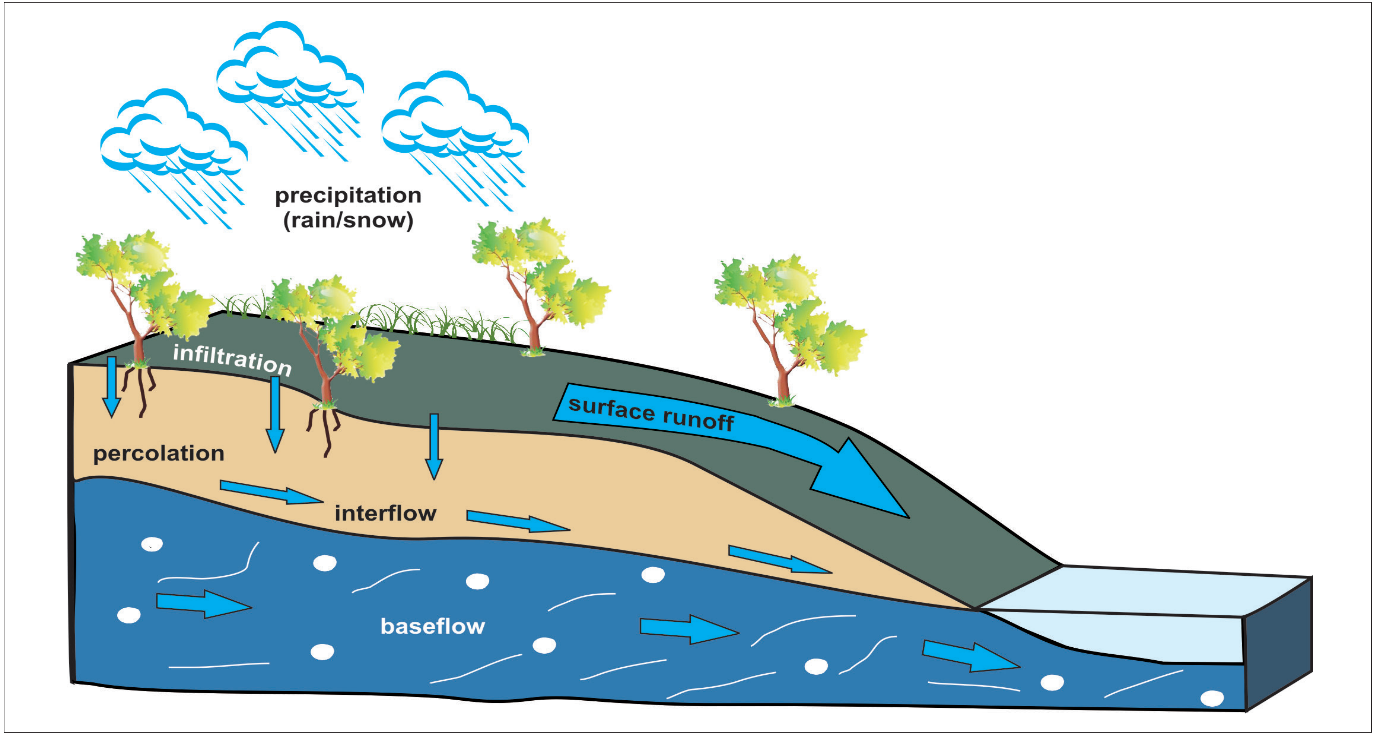

Figure 10. Surface runoff over the wetland surface as well as water infiltration is essential for the self-maintenance and continued functioning of slope wetlands. The existence of the slope wetland creates a positive feedback loop which enhances the water infiltration into wetland soils.

When the rate of precipitation exceeds the rate of infiltration, surface ponding will result. Water may be contained within small irregularities or indentations in the soil surface layer, but when these fill, water begins to flow as runoff, draining across the landscape and collecting in stream channels or erosion gullies. An observer would look for factors that promote rapid infiltration, or would identify natural conditions or land uses that might promote soil compaction and thus slow infiltration rates or cause precipitation to run off more quickly than expected.

For example, infiltration does not occur on frozen soils, so runoff occurs rapidly from rain that falls on frozen soil. Forest soils with deep organic layers and abundant macropores (pores that connect the soil surface to deeper soil layers) may produce little or no runoff during summer rains, but abundant runoff during snow melt if soils are frozen. It is important to make an assessment of apparent infiltration rates and the likely water-holding capacity of the soil.

Follow the Water (Source and Sink)

Before reading the landscape of a slope wetland, one needs to answer the questions in Table 1. Because of the ecological and geomorphic complexity of any slope wetland landscape, there are many possible answers for each question; and, those answers will dictate any number of possible stabilization and restoration solutions.

Table 1. This table contains essential questions and examples of answers for determining hydrologic drivers of wetland systems. Asking these questions and exploring for all possible answers will establish the basis for subsequent restoration decisions.

Question	Possibilities			
What is the source of the water?	Groundwater	Monsoon Precipitation	Snowmelt	Some combination of all sources
Where is the water going?	Soil Infiltration	Percolation to Groundwater	Concentrated Surface Flow	Dispersed flow
Where *should* the water be going?	Soil Infiltration	Percolation to Groundwater	Surface Flow	Dispersed flow
Why is the water not going to the correct sink(s)?	Legacy Stressors	Current Stressors		
Could the water be returned to the correct sink(s)?	Yes	No	Partially	

The condition of the vegetative community is a good indicator for determining where the water is in a system. If infiltration is good, the plant community will be more vigorous. Taking time to assess the plant community will give clues about the degree to which water is infiltrating into soil, and it will also give clues about the level of soil-water saturation as a result of the interaction between surface water infiltration and ground water. Where there is more soil moisture, vegetation will be more productive. Where soil is saturated, wetland plant species will make up the highest composition of the vegetation community.

VEGETATION COMMUNITY

An important ecological concept is that some species are adapted to a broad range of conditions under which they survive, produce, and reproduce, while others have very narrow ranges of adaptation. Plant species having narrow tolerances can be used as indicators of soil-site characteristics or other parameters. For example, wetland obligate species must have saturated soil conditions in order to survive. These obligate species cannot exist where the soil is not saturated by water for a significant portion of time during the growing season. Facultative species are those which tolerate a range of soil moisture conditions. Upland species will not survive long under saturated soil conditions. (For a detailed discussion of wetland species, see the 1987 *United States Army Corps of Engineers Wetland Delineation Manual* http://el.erdc.usace.army.mil/elpubs/pdf/wlman87.pdf.)

By knowing these relationships between plant species and other factors, one can interpret the history of a site and interpret ongoing processes. For example, a change in soil moisture conditions at a degraded wetland site might be reflected first in the decline and mortality of the wetland species as they are slowly replaced by upland species that can tolerate dryer soil conditions (Figure 11).

Figure 11. This slope wetland has only a narrow band of wetland obligate vegetation in an area that was formerly dominated by sedges (*Carex* Spp.). Shrubby cinquefoil (*Dasiphora fruticosa*) has encroached on the area, which indicates that the wetland system is drying and converting to an upland vegetation community. An ability to recognize changes in plant community composition due to changes in soil moisture conditions will help the observer to read the landscape, help date events that may have triggered the change and, to a certain extent, help determine the history of the site.

HUMAN INFLUENCES LEADING TO SLOPE WETLAND DEGRADATION

Slope wetland degradation is not always the result of a single impact. More often it is the result of multiple cumulative impacts that have synergistic effects. Stressors are the impacts that initiate degradation. Stressors can be current, such as a present day land management practices (poor grazing management or poor road placement). They can also be the result of a legacy land management action. An existing headcut (an abrupt drop in elevation) and downcutting channel that is the result of past management practices may create a current stressor (Figure 12). The degraded state sets into motion a positive feedback loop in which the degraded state itself becomes a stressor. For example, an advancing gully will propagate a network of tributary gullying.

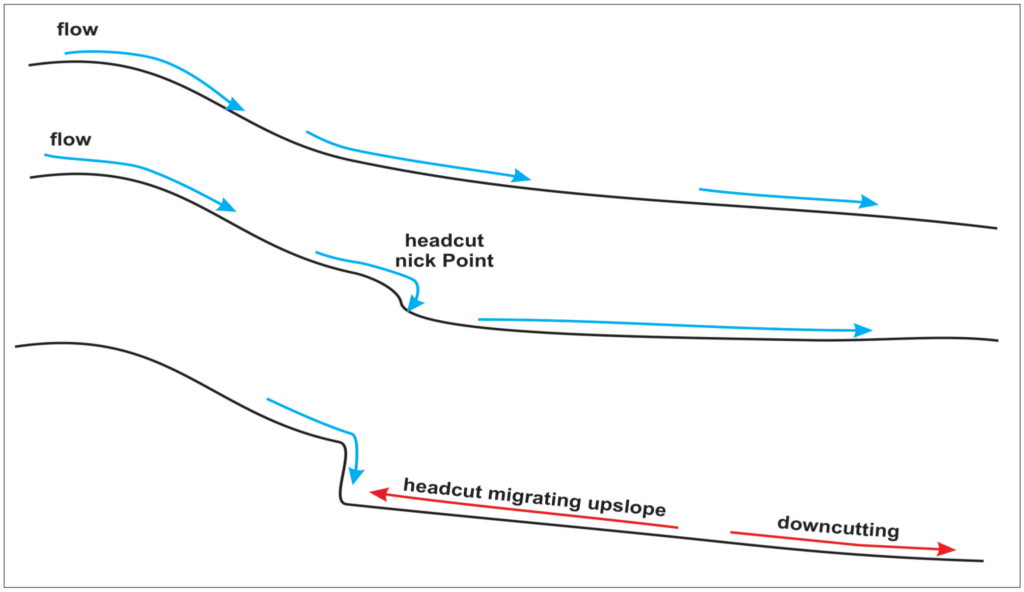

Figure 12. A headcut is a nick point in the soil surface which accelerates erosion. Headcuts migrate upstream as soil is lost, leaving a degraded and incised landscape below.

Climate stressors are another component of the stabilization or restoration success for headwater slope wetlands. An increase in the intensity of precipitation events, an earlier seasonal snowmelt runoff, or a prolonged drought will impact the stability of slope wetland systems. A constant source of groundwater discharge would buffer these effects, but without sustained, dispersed flow over the intact wetland surface, the wetland will eventually cease to function as a slope wetland. The erosive force of more intense storm events will both increase the rate of degradation of already unstable systems and decrease the likelihood of restoration success. Earlier snowmelt is also an issue where plant species have not yet broken dormancy and are less effective at intercepting runoff and allowing it to infiltrate the soil.

Wide-scale removal or alteration of vegetative cover can cause watershed degradation by exposing soils to compaction and accelerated rates of soil erosion and surface runoff. Increasing flood velocities cause channels to form and therefore increases erosion of water-holding soils in areas normally maintained by dispersed (sheet) flow. Some of the causes of channelization in slope wetlands include:

- Loss of riparian or wetland vegetation attributed to trampling by livestock or wildlife, trampling by human foot traffic, off road vehicle traffic, logging and clearing, and the flooding after-effects of extreme wildfire
- Loss of predators (such as wolves) which changes the behavior patterns and populations of prey species (such as deer, elk and cattle), resulting in increased and prolonged herbivory of vegetation in riparian and wetland systems (Beschta and Ripple 2010, Laundre et al., 2001)
- Direct incision and headcuts caused by wildfire, trailing, and off-road vehicle traffic
- Capture and concentration of watershed runoff by roads and ditches (including old or abandoned roads), trails, and irrigation ditches
- Diminished sediment supply and loss of overland, dispersed flow due to disruption by artificial dams, impoundments, or other barriers

Figure 13 is an example of the types of disruptions that can be observed by looking at an aerial photograph of a slope wetland. Look for landform disruptions and barriers that prevent the wetlands from reconnecting with their former water sources.

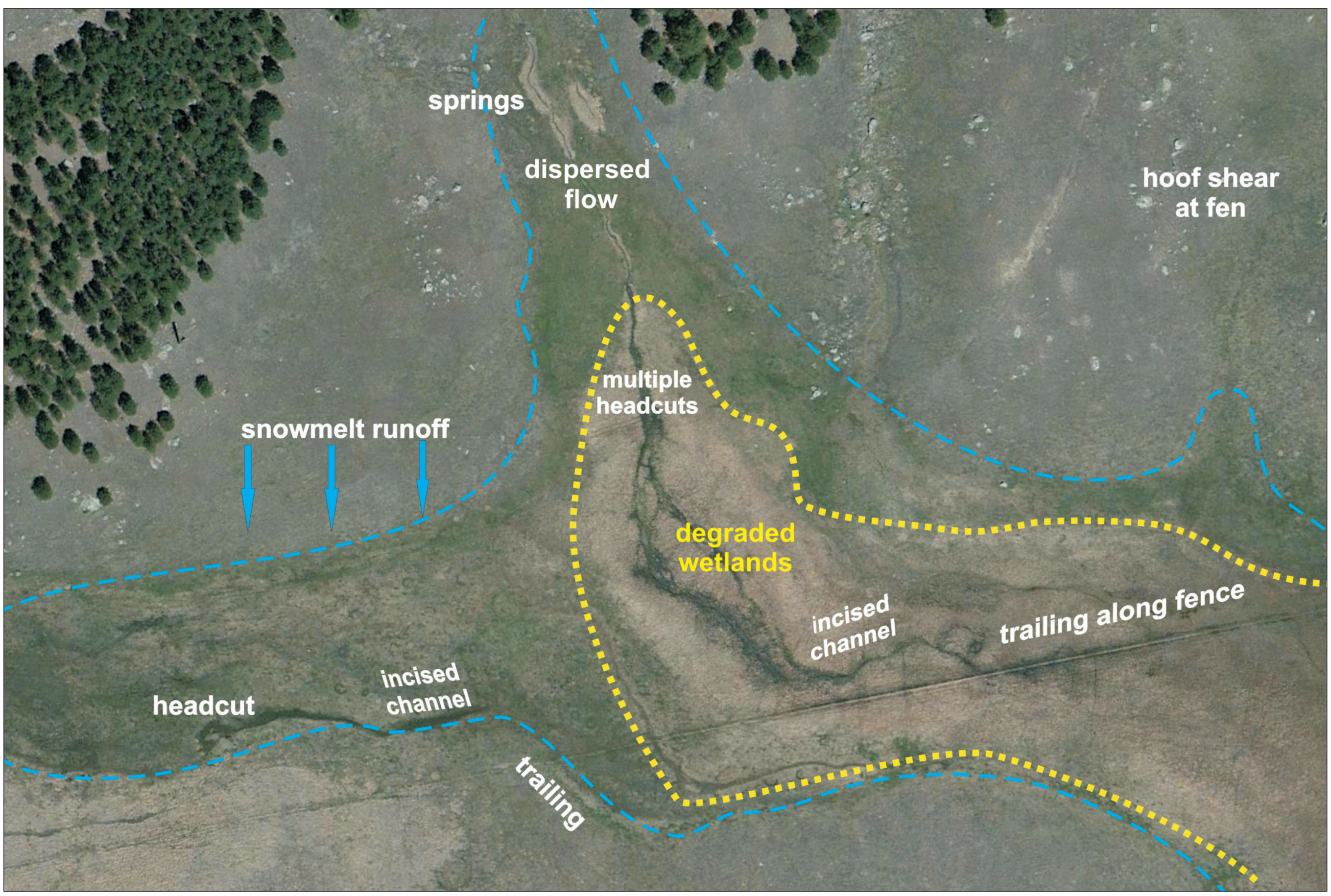

Figure 13. In this Google Earth image of the Valles Caldera, interruptions to dispersed flow across the slope wetland surface are labelled.

Could the water be redistributed and the hydrologic regime reestablished in the former slope wetland through restoration treatments? What is the hydrologic regime that drives the system? For example, is it snowmelt or monsoon, or groundwater flowing from an underground aquifer?

Factors to consider in designing a restoration project include:

- How is this precipitation regime likely to change under the influence of climate change?
- Are there materials close to the site which can be used for restoration treatments?
- Is the site accessible to large equipment or volunteer labor?
- What is the estimated cost to preserve or restore the site, and what are the economic and ecological consequences of leaving it in a degraded condition?
- What permits are required from state and federal agencies?

Walk the area multiple times and consider several alternative plans to stabilize or restore function to the site. All good ideas do not occur at the same time. There are an infinite number of possibilities to sort through. Some causes of degradation may be fairly obvious, such as a road built across a wetland. Other, less obvious factors, which might be equally as significant or might magnify the effects of obvious causes, may not be apparent on a first tour of the site. One of the most important concepts to consider is that often the "feel-good work," such as treating the ugliest and most eroded component of the system, may not affect the function of the wetland (Figure 14).

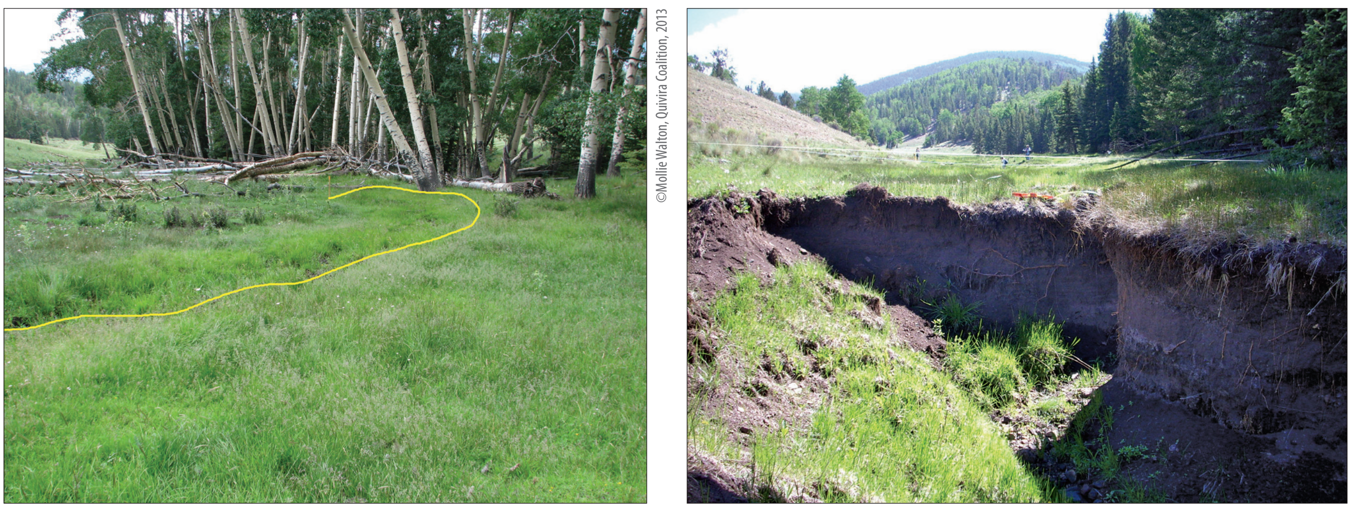

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Figure 14. The ugliest spot on the landscape is not always the best choice when prioritizing restoration activities, if it does not effect stability of the system. The photograph on the left is of a system in need of restoration activities. The dark green vegetation band (indicated by the yellow line) indicates where an incised channel cuts through and is draining a slope wetland. Returning the system to dispersed flow rather than concentrated flow that drains and dries the wetland will have a greater effect on the functionality of the system than repairing the large, dry gully (photograph on the right) far downstream in this same system.

However, if there is a headcut or gully draining the wetland lower downslope, it may require restoration before restoration upslope will be able to increase wetland function. This decision may only be reached by careful consideration of specific site conditions. Taking the time to read and understand the landscape in its past and current state will allow one to better prioritize the stabilization or restoration options. Having started with a landscape level assessment, the following section defines in further detail the specific conditions that form and maintain slope wetlands in New Mexico, focusing on headwater slope wetlands of the Comanche Creek Watershed as a general example.

CHAPTER 3 SUBCLASSES OF SLOPE WETLANDS IN NEW MEXICO

Slope wetlands can be divided into different regional types or subclasses. These are characterized within geographic areas in which factors such as geology, geomorphology, climate, watershed-size and other large-scale factors influence wetland development and function. For example, differences in precipitation and temperature may cause wetlands in the southern part of the state to develop and function differently from wetlands in the northern part (Munger and Eisenreich,1983, and, Groisman and Easterling,1994). There is considerable flexibility in defining wetland subclasses within a region (SWQB Wetlands Technical Guide #1, 2012). Five subclasses of wetlands that occur in New Mexico are described below. Each of these is described by its distinguishing characteristics, and examples are given of each type based upon observational knowledge of New Mexico systems. The characterization of headwater slope wetlands in the Comanche Creek Watershed is discussed in the greatest detail.

(1) PLEISTOCENE LAKEBED SLOPE WETLAND SUBCLASS

Some slope wetlands have formed in the basin of former Pleistocene lakebeds. The slope wetlands in Placer Creek in the Tres Piedras Ranger District of the Carson Nation Forest are an example of this type (Figure 15).

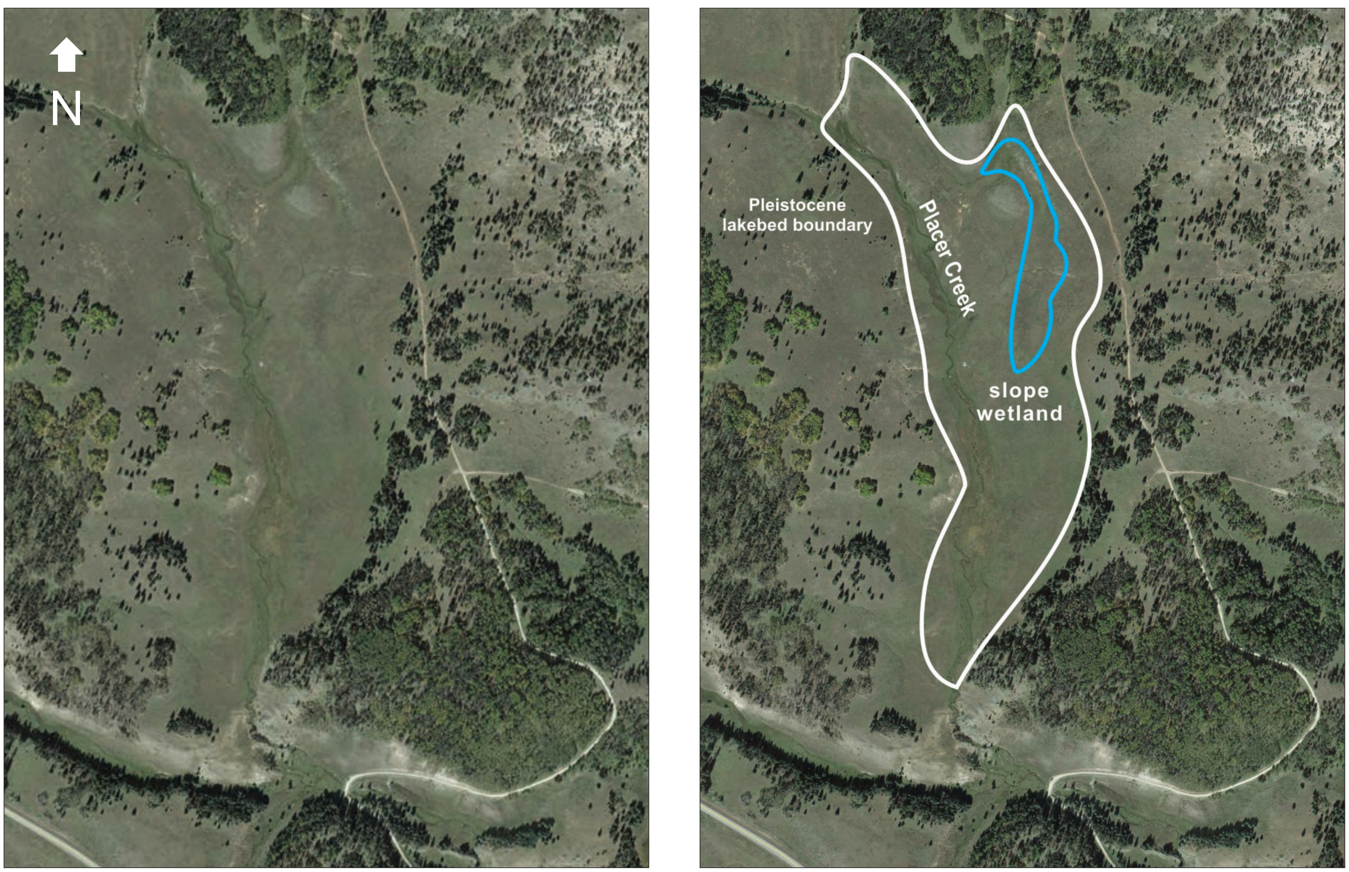


Figure 15. These slope wetlands along Placer Creek, Tres Piedras Ranger District, Carson National Forest, New Mexico formed in a Pleistocene lakebed. The white line shows the extent of the former lake bed, while the blue line shows the current slope wetland.

The lakebed has filled with alluvial sediment over time. The landscape feature created from the former lakebed has influenced subsequent water flow and therefore sedimentation patterns. The interaction of sediment accumulation and groundwater presence allow this subclass of slope wetlands to form.

(2) MONSOON-DRIVEN SLOPE WETLANDS SUBCLASS

Slope wetlands in monsoon-driven systems often form at the downstream end of tributaries as alluvial fans are formed from sedimentation. Monsoon events (seasonal rainfall pattern occurring during July and August in New Mexico) are more likely to move the larger soil particles. Wetlands are formed as sediments aggrade upstream from the confluence of a tributary with the main stream in the valley bottom, raising the bed and lowering the stream velocity, allowing for even more alluvial deposits to accumulate.

These systems may remain saturated during the summer monsoon season. The picture of a wetland in Cebolla Creek is an example of a slope wetland created by a monsoon-driven system (Figure 16). As in all slope wetland systems, there is a groundwater component, Cebolla Spring, that maintains baseflow through the wetlands during the dry season.

Cebolla Creek flows from south to north. The valley containing the Cebolla Creek slope wetlands was drained and converted to vegetable cropping in the 1930's. On the north side of Savage Canyon, a road created a gully which captured the ephemeral flow from the canyon. To the west, sediments from the outflow of Savage Canyon created an alluvial fan that blocked Cebolla Creek and created a slope wetland upstream of the blockage. The pattern is repeated downstream at the mouth of the next canyon that flows into Cebolla Creek. Restoration activities have been ongoing in Cebolla Canyon since 2001 to return dispersed flow to the system.

Figure 16. The Cebolla Creek slope wetlands are an example of a monsoon-driven slope wetland system on Bureau of Land Management lands southwest of Grants, New Mexico. The yellow outlines show the extent of the alluvial fans, the blue outlines show the extent of the slope wetland complexes, and the red lines show incised channels and gullies.

(3) CIENEGAS SUBCLASS

Cienega (or *cienaga*) is the Spanish word for "marsh" and is commonly used for any marshy area in the desert southwest. *Marsh* is a term used to describe a wetland that is dominated by herbaceous plants (non-woody plants like grasses and broadleaf flowering plants), rather than by woody plants, such as willows and cottonwoods. The definition of cienegas in the scientific literature (Henerson and Minckley, 1985, Minckley and Brunelle, 2007, Minckley et al., 2013) "refers to a set of freshwater environments in the North American deserts and semi-arid grasslands that are typically permanently wetted, either by springs or by water forced to the surface by channel constrictions or sub-surface features such as bedrock or sills." The following characterizes a type of cienega (slope wetland) that occurs in New Mexico.

Cienegas are formed during events resulting from geologic uplift, such as faulting and large-scale erosion. Faulting can produce a rise within a valley which causes the blocking of a stream in a monsoon-driven system. Cienegas can also form as a result of blockage by an alluvial fan at the mouth of a steep, ephemeral tributary that raises the valley floor at the confluence with the receiving stream. The valley of the main channel is not as steep and the streambed will be raised by the tributary channel depositing coarse bedload on the alluvial fan. Over time, fine sediments carried by the main stream accumulate upvalley from the blockage, which impounds groundwater and forms a perched water table above an impermeable layer such as bedrock.

An example of this type of cienega is "Burro Cienaga" in southwestern, New Mexico (Figure 17). Burro Cienaga flows from northeast to southwest where it intersects the ephemeral channel of Horse Canyon. At the confluence, sediment from Horse Canyon created an alluvial fan which blocked the channel and created the cienega.

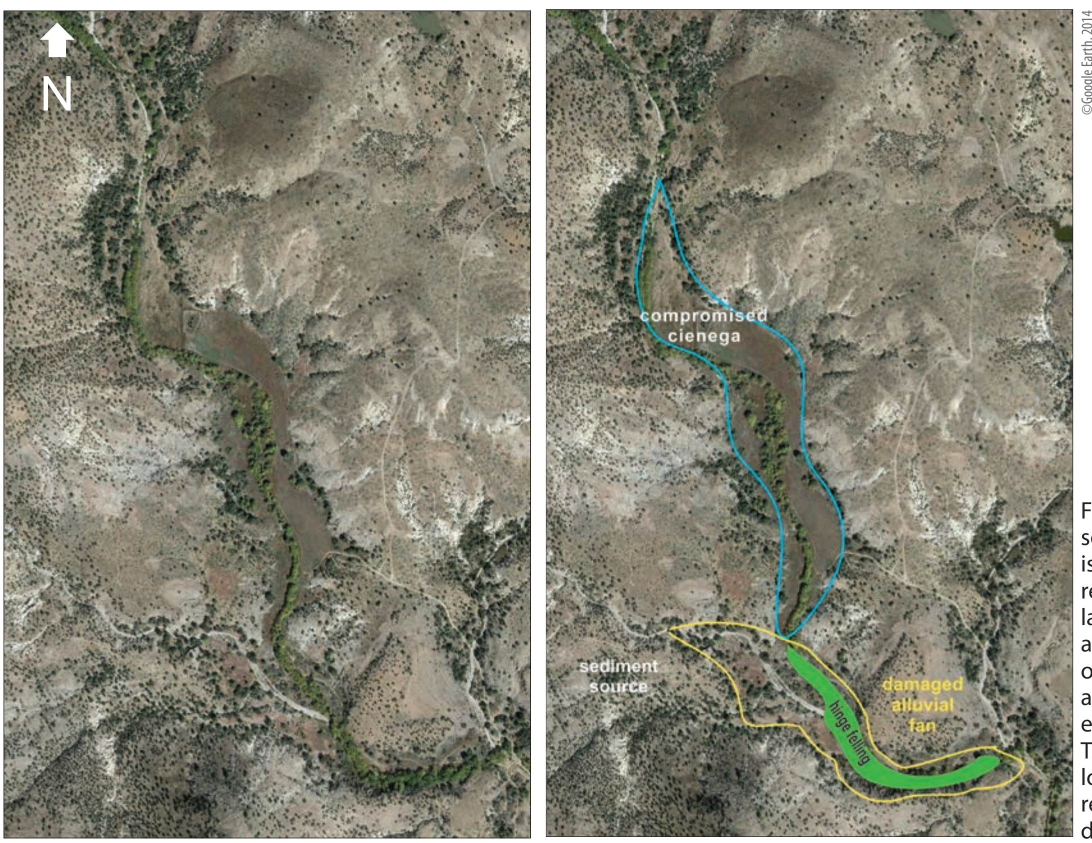


Figure 17. Burro Cienaga in southwestern New Mexico is a site of slope wetland restoration work on private lands. Yellow marks the alluvial fan created from the outwash of Horse Canyon and blue outlines the original extent of the slope wetland. The green area shows the location of the hinge-felling restoration treatment described on page 18.

The current area where the stream channel meanders through fields was the extent of the original slope wetland/ cienega. Degradation of the cienega occurred when a stage road cut through the alluvial fan and caused a channel to form. The nick point eventually cut its way upvalley and created a channel in the slope wetland where none originally existed. Current restoration of the Burro Cienega includes the application of a technique called "hinge-felling" below the alluvial fan created from the outwash of Horse Canyon. Over time, this technique will cause sediment to fill the channel through the alluvial fan and eventually reflood the former cienega wetland surrounding Burro Creek.

HINGE-FELLING

Hinge-felling, partially severing the stems of standing stream-side trees, has been successfully used to promote formation of an alluvial fan just below the mouth of an ephemeral, sediment-laden tributary of Burro Creek in southwestern New Mexico. The stems of selected trees were cut partially through with a chainsaw which caused the trees to fall into the channel (perpendicular to the direction of stream flow) and partially block the channel. Blockage has caused a reduction in flow velocities and initiated deposition of a new delta fan at the same location as the historical fan that initially formed Burro Cienega by aggradation of the Burro Creek channel.

Partially severing stems satisfies two objectives: 1) preventing trees from dislodging during flood events, and 2) enabling regrowth of branches as new trees to increase vegetation density in mid-channel over time.

The willows will take root and resprout from where the tops touch the creek channel. Regrowth increases channel roughness thereby increasing the rate of sediment deposition. To further increase the likelihood of this occurring, willow trees were hinge-felled along opposite banks of the channel in order to interlock the branches and increase their stability in times of flood.

The process is to make a shallow cut, 1 to 2 inches deep on the side of the tree facing the channel, and a deeper cut on the opposite side. This causes the tree to lean into the channel without snapping off as it falls (a "green-stick" fracture).

The key factors making this treatment feasible are an abundant sediment supply, an incised channel with a wide former floodplain that can be reconnected as sediment aggrades the channel, and a dense stand of willow trees lining the stream bank where needed.

Felling of trees has the added effect of increasing light into an otherwise densely shaded stream reach, which in turn stimulates the growth of obligate wetland vegetation, such as sedges, rushes, bulrushes, and cattails. This vegetation helps to anchor deposited sediment in place and, by increasing channel roughness, promotes additional sediment aggradation, especially particles of finer size (silts, clay and organic particles). Hinge-felling is only suitable for larger diameter, pliable species such as Goodding willow or black willow. It is probably not effective with cottonwood, sycamore, or alders, although this has not been tested.

(4) SPRING-FED SLOPE WETLANDS SUBCLASS

Spring-fed slope wetlands are predominantly formed and maintained by ground water erupting at the land surface. These predominantly spring-fed slope wetlands exist anywhere on hillslopes where groundwater stored in deeper sedimentary aquifers, faults, and other structural conduits discharges at the surface. The location of this subclass of slope wetlands is dependent upon the locations of the geologic strata and may occur at any elevation. These often also have both monsoon and snowmelt sources, depending upon elevation of the slope wetland complex. The wetlands in Figure 18 occur in the Valles Caldera in the Jemez Mountains of northern New Mexico.

These spring-fed slope wetlands in the Jemez Mountains are somewhat unique because of the volcanic history of the area. The caldera is a feature resulting from faulting and collapse following a volcanic eruption. There are multiple faults and many geologic strata which are ideal for storing groundwater. The geology of the Valles Caldera is relatively well-studied. For more information, see *https://nmgs.nmt.edu/publications/guidebooks/downloads/12/12_p0139_p0143.pdf*.

These wetlands may occur anywhere on the hillslopes where the groundwater emerges at the surface in the form of a spring or seep. They are not as dependent upon the erosional events that drive the formation of the other subclasses of slope wetlands. The degree to which these slope wetlands are fed by groundwater makes them more resilient to degradation and more likely to respond to stabilization and restoration treatments.

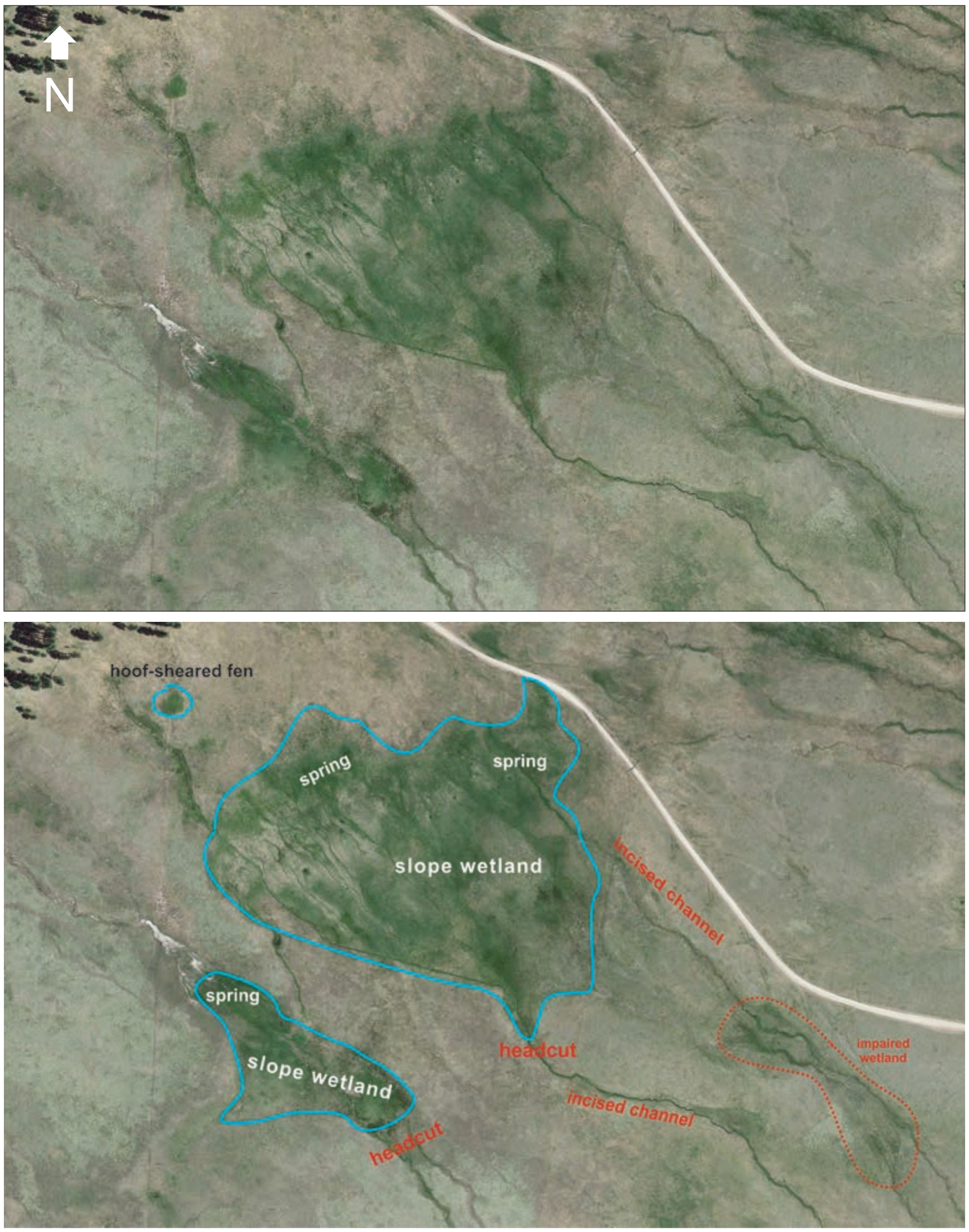


Figure 18. Spring-fed slope wetlands in the Jemez Mountains, New Mexico are the result of water being released at the surface from underlying geologic layers. Blue lines show the extent of the spring-fed slope wetlands.

(5) HEADWATER SLOPE WETLANDS SUBCLASS

Headwater slope wetlands are snowmelt-driven in their formation and continued function. The headwater slope wetlands in Figure 19 occur in the No Name drainage, a tributary to Comanche Creek.

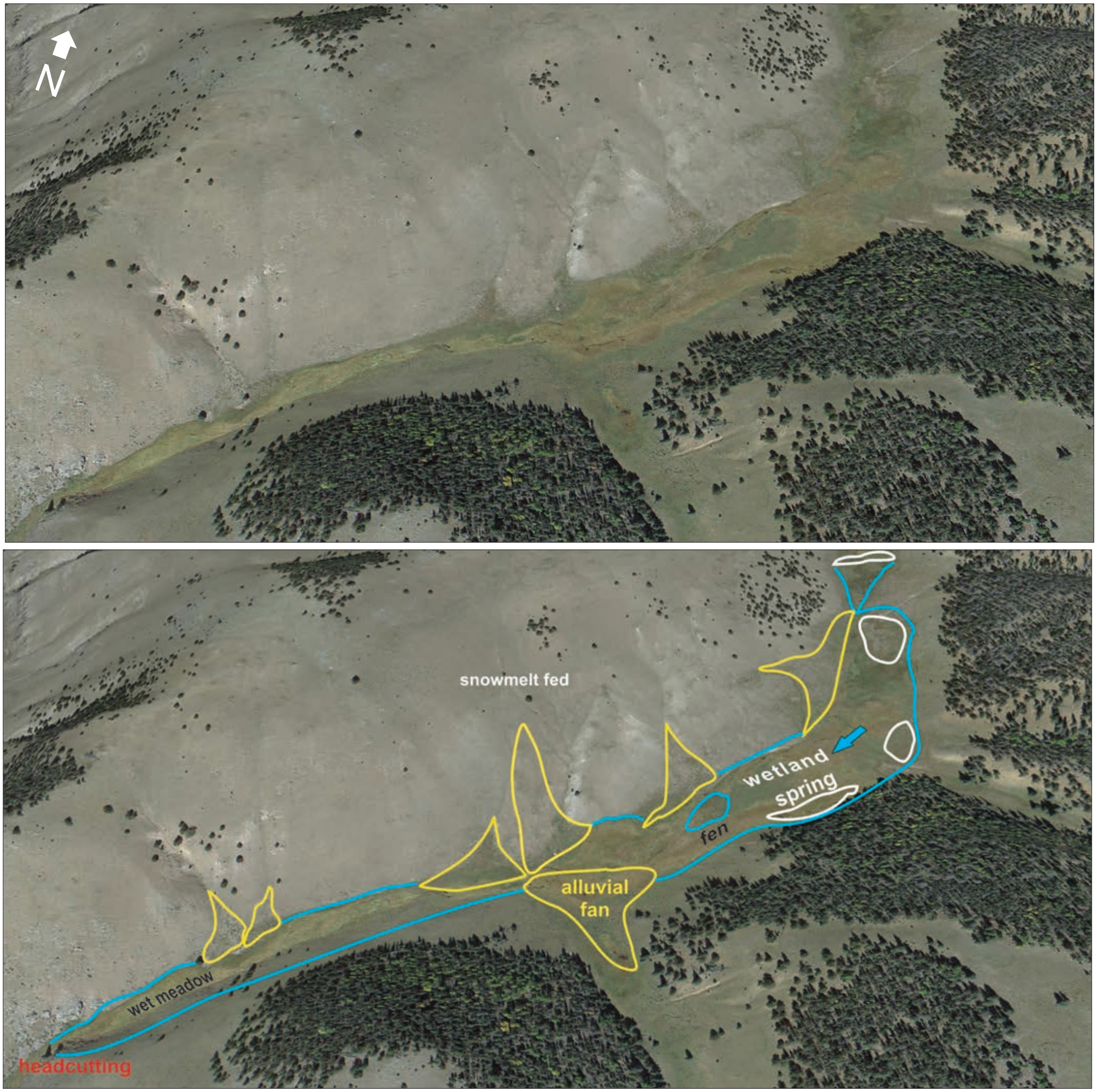


Figure 19. In these headwater slope wetlands in No Name Creek, Questa Ranger District, Carson National Forest, New Mexico, the yellow lines show the multiple alluvial fans that contribute to the formation of slope wetlands. The blue lines show the boundaries of the headwater slope wetlands, and the white lines show the locations of springs that contribute groundwater to the wetlands in the complex.

These wetlands fill the valley and are the result of alluvial deposition with snowmelt flowing over the surface and aggrading the wetlands over time. They are also augmented by groundwater sources. A detailed description and characterization of headwater slope wetlands in the Comanche Creek Watershed follows.

CHAPTER 4 HEADWATER SLOPE WETLANDS CHARACTERIZATION

GEOLOGY - FAULTING AND AQUIFERS

Faulting and porous rock layers (aquifers) that expel water in the form of springs in the valley walls or floor often dictate the location of slope wetlands (Figure 20). Not all slope wetlands have a spring component, but they do have a confining geologic layer that moves water downslope, underneath the wetland, rather than simply percolating into deeper groundwater reserves through fissures.

Figure 20. The emergence of springs high on the slope wets the slope wetland complex below.

GLACIATION

Some headwater slope wetlands in New Mexico have developed as relics from a time of glaciation. These include valley wetlands and wetlands formed in the bottom of glacial cirques. Glacial valleys tend to have a pronounced U-shaped cross-sectional profile. This is in contrast to valleys that are caused by stream erosion, which are V-shaped. No Name Creek in the Valle Vidal is an example of a glacially formed U-shaped valley (Figure 21).

Cirques are bowl-shaped depressions that occur at the top of glacial valleys. The slope wetlands in the headwaters of McCrystal Creek in the Valle Vidal are formed in cirques (Figure 22).

To read more about glaciated terrain formation, see "Landforms of Glaciation" at Physical Geology. net, *www.physicalgeography.net/ fundamentals/10af.html*. These glacial processes have carved out sites for deposition of alluvial materials. More recent erosional processes in mountainous regions have caused the formation of alluvial fans, a key component of headwater slope wetland formation.

Figure 21. There are extensive headwater slope wetland complexes in this U-shaped glacial valley of No Name Creek, Comanche Creek Watershed, Carson National Forest, New Mexico.

Figure 22. These slope wetlands formed in a glacial cirque in upper McCrystal Creek, Carson National Forest, New Mexico.

ALLUVIAL FANS

Alluvial fans are usually created as moving water erodes particles from upland sites, mountains, and canyon walls. When transported by a stream, these particles are called bedload. Bedload consists of the heavier particles which are still being transported by the flowing water at the base of the flow. Suspended load, or wash load, includes finer soil particles, which are transported farther by moving water because they require less hydraulic energy to move. The water that carries bedload and suspended load can be trickles of rainwater as dispersed flow, a fast-moving creek, or a powerful river. This moving water carries sediment to a less steep slope where it loses the velocity needed to transport the sediment farther and, deposits it. Once deposited, sediment is called alluvium. The landform containing slope wetlands in the Comanche Creek Watershed consists of fairly steep slopes with alluvial fans at their base that formed as the result of erosional events occurring in the upper watershed (Figure 23).

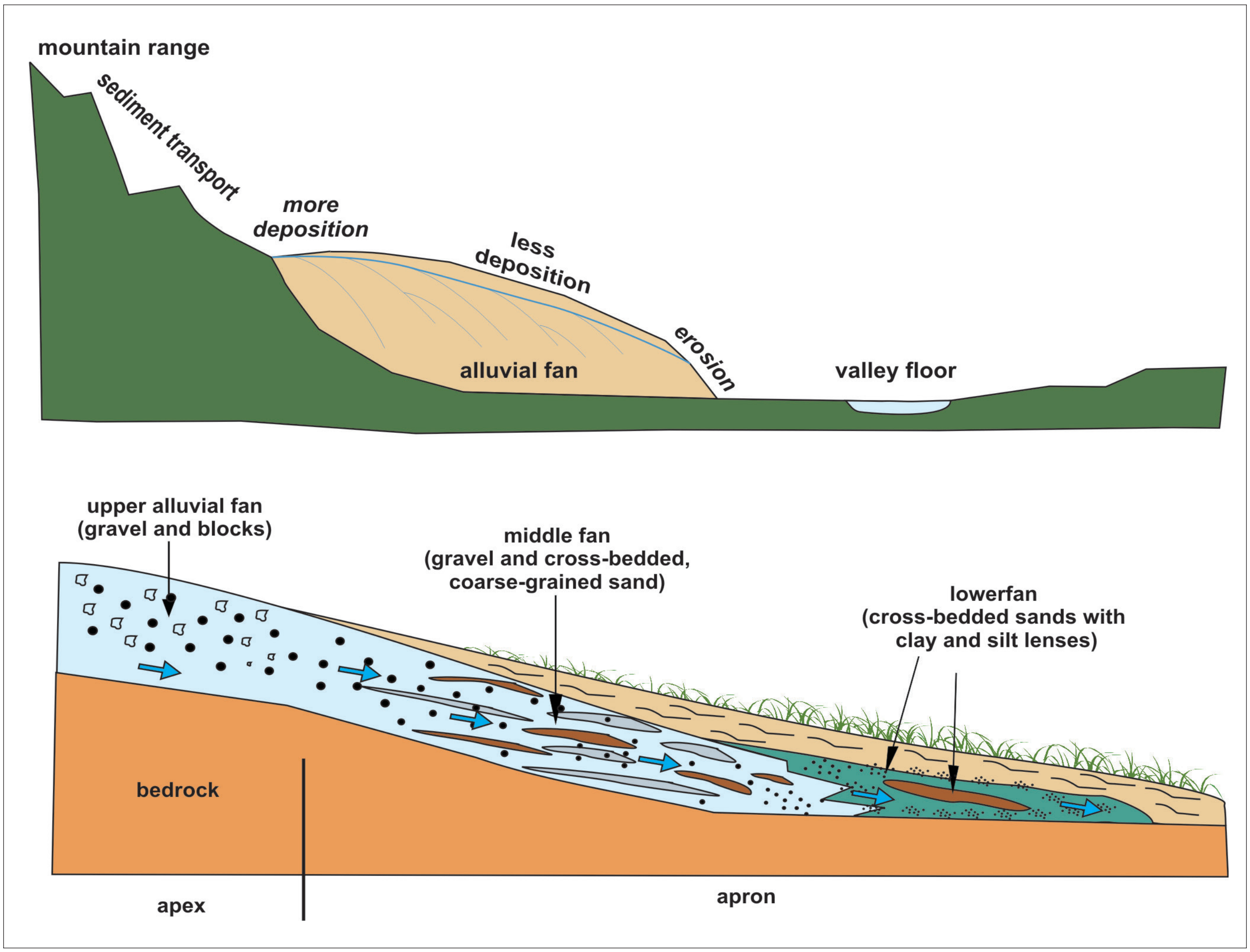


Figure 23. Alluvial fan morphology allows for water storage in interbedded soil layers.

Alluvium is deposited as the water slows and fans out, creating the familiar triangular-shaped feature of the alluvial fan land form. Water is stored in the interbedded soil layers of the landform. The structure of an alluvial fan, from its shape to the interbedded soil layers, results from different depositional events. These events are key components of slope wetland formation because groundwater stored between impermeable layers of the fan slowly drains from the fan, joining with groundwater in the slope wetland and eventually contributing to the baseflow that sustains creeks and rivers. Baseflow is the level of groundwater contribution to stream flow which occurs as seepage from saturated soil layers. It is not composed of surface runoff resulting from recent precipitation.

Discharge, Infiltration, and Percolation of Water into Soil

Much of the discharge of groundwater is driven by the geological structure of the area as well as the soil type. Groundwater can be local or regional, and water can be stored in and move through the aquifer (Figure 24). (For a basic primer on groundwater, see *www.ngwa.org/fundamentals/use/pages/groundwater-facts.aspx.)*

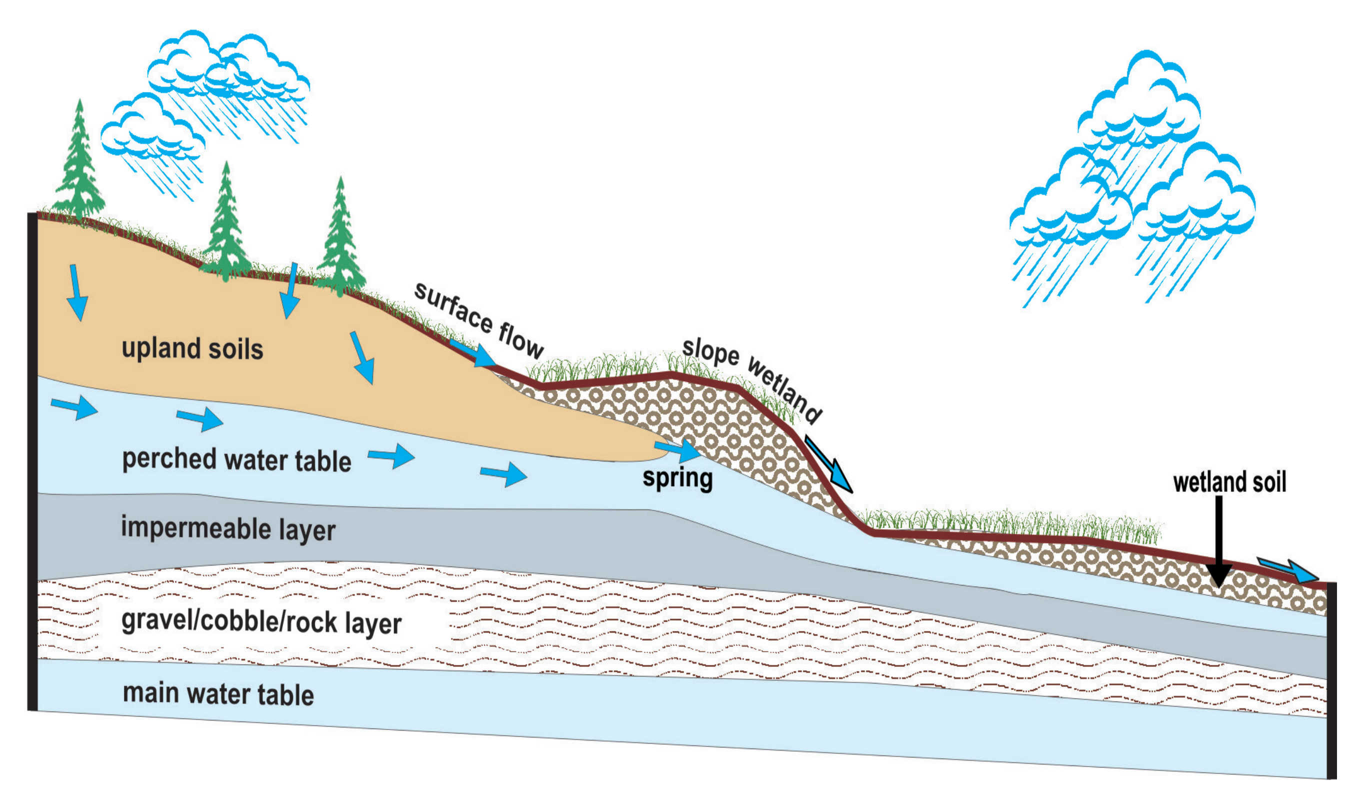


Figure 24. Precipitation infiltrates into the soil and also runs over the soil surface. In slope wetlands, surface runoff is augmented by groundwater emerging from springs and spring seeps at the surface.

The geologic parent material also determines soil physical characteristics (texture, mineral composition, etc.). As a result of erosional processes, different soil texture layers are deposited. For slope wetlands, finer textured soils build up, as aggrading occurs, when water flow loses enough velocity to deposit the finest (silt and clay) particles. The finer texture of soil allows for vegetation establishment. Once established, vegetation increases infiltration of water into soil.

Soils

The interaction of landform and soil in the form of alluvial fans is a key feature of headwater slope wetland location and development. The deposition of soil particles during erosional events depends much on the precipitation regime. Soil type is both a byproduct of slope wetland creation as well as a fundamental component of what causes a slope wetland to develop. Wetland soils have higher organic matter than upland soils. Each small increase in soil organic content adds the potential to store more water per acre. Peat soils, such as those found in the fen component (discussed in the following vegetation section) of the slope wetland complex store the most water.

Vegetation on the surface of the alluvial fan and slope wetland is critical to maintaining dispersed flow. Vegetation is what allows the precipitation to infiltrate the soil and be stored in the "sponge." The term slope wetland "complex" arises from the formation of multiple gradations of wetlands from the alluvial fan portion at the top to the eroding downslope edge. Erosion along the downslope edge of a slope wetland is normal. Slope wetlands are stepped wetlands due to their changing nature from top to bottom (Figure 25).

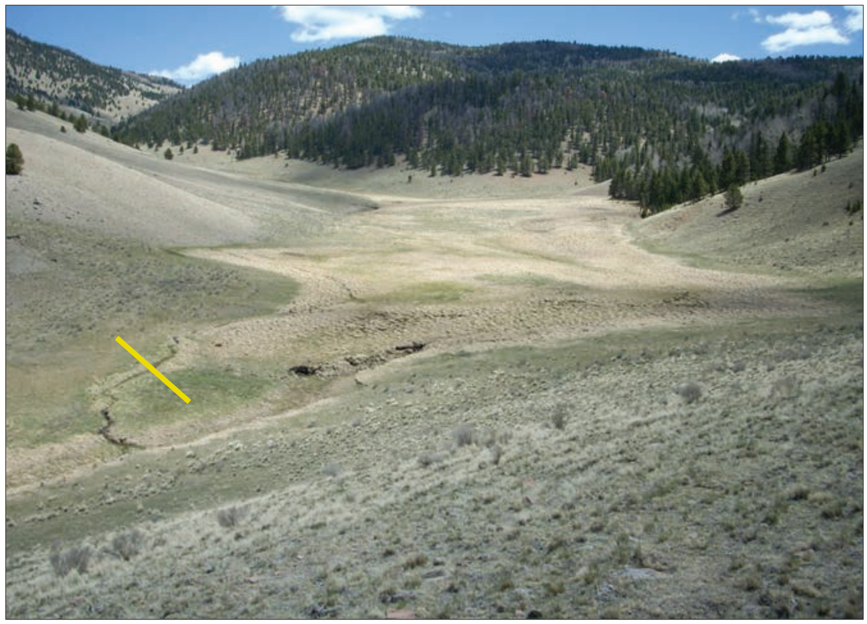


Figure 25. Headwater slope wetland complex in No Name Creek drainage, Carson National Forest, showing slope wetland progression and erosion. The yellow line shows a transect where soil samples were collected.

Three examples of soil from the headwater slope wetland complex show the different degrees of water storage and higher organic matter content (darker and with more soil aggregation) in a transect that began at the wettest part of a headwater slope wetland in the No Name Creek drainage and ended in upland vegetation as shown by the yellow line in Figure 25 (Figure 26 A, B, and C).

Figure 26 A, B and C. These soil samples were collected along a transect across a slope wetland in No Name Creek, Carson National Forest. Figure 26 A. The *Carex* Spp-dominated soils in the middle of the slope wetland transect are saturated, darkly pigmented, and aggregated. Figure 26 B. The *Juncus* Spp-dominated soils are transitional soils. These still show soil aggregates and are dark from high organic matter content. Figure 26 C. The upland soils are lighter (less organic matter), drier, and these show a textural transition to larger soil particle with fewer aggregates.

For slope wetland complexes, the soil acts as a sponge that holds water and slowly releases it downstream to perennial creeks such as Comanche Creek in the valley floor. Water stored in soil maintains a more steady temperature than water exposed to surface environmental conditions. Water that reaches the creek at the valley floor is cooler when it has been stored in wetland soils in transit down to the stream than when it has flowed on the surface in a creek channel. In winter, water is warmer when it reaches the main creek through soils. This can be important to the survival of fish species, such as the Rio Grande cutthroat trout.

DISPERSED FLOW (WETLANDS)

In slope wetlands, dispersed flow is not only favored over channelized flow, it is essential. Soil surface roughness (created in part by vegetation) favors sheetflow when the surface is of a relatively similar elevation. If the surface is very rough with large differences in surface elevation within a small area, the lowest places will intercept dispersed flow. Water will then flow to the lowest place on the landscape and begin to form a system in which surface roughness no longer facilitates dispersal, but instead favors channelized flow (Figure 27).

Figure 27. The vegetation in this headwater slope wetland complex in the Sawmill Creek drainage, Comanche Creek Watershed, shows a system that is beginning to move away from dispersed flow in favor of channelized flow around the *Carex* Spp. clumps. The system has a "hummocky" appearance because of the unevenness of the wetland surface caused by hoof-shear.

Conversely, dispersed flow spreads sediment out, which favors vegetation establishment, which increases sediment capture, which increases vegetation establishment…and the positive feedback loop is established creating an alluvial fan. An abrupt slope change from high energy (steeper) to low energy flow (flatter) signals aggradation of the system (Figure 28).

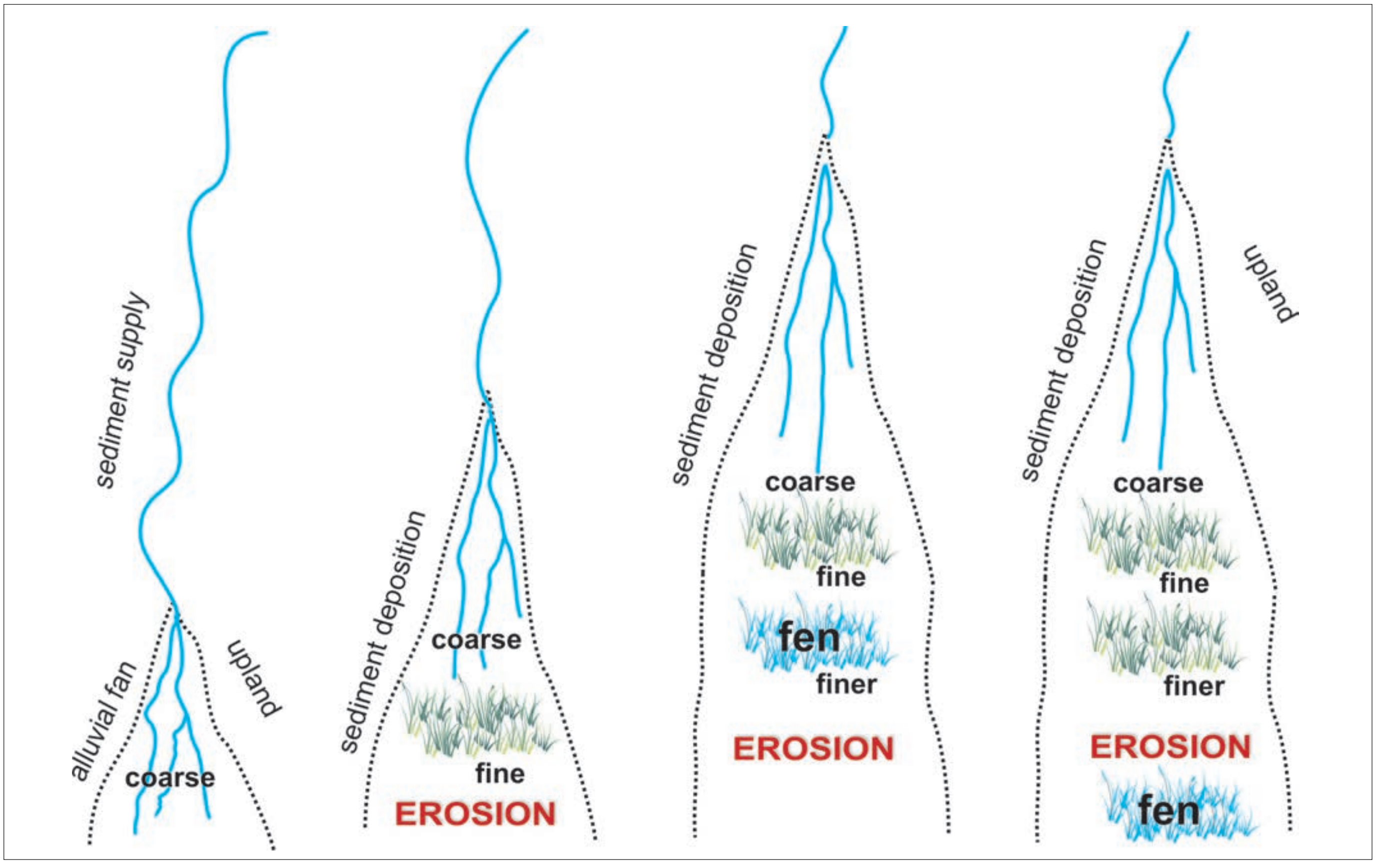


Figure 28. In this schematic of slope wetland progression, aggrading sediment causes formation of the headwater slope wetland complex. The downslope toe is continually eroding. The presence of a fen is dependent upon site hydrology and fens are not present in all headwater slope wetland complexes.

Vegetation filters and accumulates wash load (the finer part of a sediment load), collecting and accumulating sediment and plant debris on the surface. Water infiltrates and recharges shallow groundwater (alluvial storage) existing as baseflow. Steep tributaries transition from concentrated to dispersed flow, depositing sediments and creating distributary (braided) microchannels through sediments, thus forming a delta. When a creek cannot push bedload any further, the delta expands to become an alluvial fan on the landscape. Small distributary channels form but are repeatedly blocked so that the flow changes course often. This maintains dispersed rather than concentrated flow patterns.

Vegetation communities are dependent upon wetland status, slope, aspect, relief, and other site factors, but are often dictated by soil types linked to the geologic origin of parent materials such as the formation of an alluvial fan. This is one reason why understanding site landforms is critical to understanding the vegetation community.

VEGETATION COMMUNITY

The vegetation community is dependent both upon the soils and the combined amount of surface and groundwater available at a particular site. In turn, the vegetation community will affect the rate of sediment accumulation or loss and the relative proportion of dispersed versus channelized flow.

Wetlands

In slope wetlands that are not affected by degradation, vegetation is dominated by sedge species (*Carex* Spp.) (Figure 29).These are wetland obligate species, which means that they cannot exist where soils are not saturated by water for a significant portion of time during the growing season. For a detailed discussion of wetland species see the 1987 United States Army Corps of Engineers Wetland Delineation Manual at (*http:// el.erdc.usace.army.mil/ elpubs/pdf/wlman87.pdf*).

Figure 29. A *Carex* Spp. dominated slope wetland in the Comanche Creek Watershed, Questa Ranger District, Carson National Forest, New Mexico shows the convex shape of the headwater slope wetland.

Fens

Fens often occur within the slope wetland complex. "Fens are peat-forming wetlands that receive nutrients from sources other than precipitation: usually from upslope sources through drainage from surrounding mineral soils and from groundwater movement" (*http://water.epa.gov/type/wetlands/fen.cfm*).

Two types of fen occur in the Comanche Creek Watershed, mound fens and slope fens (Figure 30). Slope fens require seepage from a spring originating where the soil surface interfaces with a geologic layer that causes the water table to be perched. Mound fens depend on water erupting upward from an artesian source. Both exist because surface sheetflow has caused sediment to aggrade and become capable of sustaining dense vegetation.

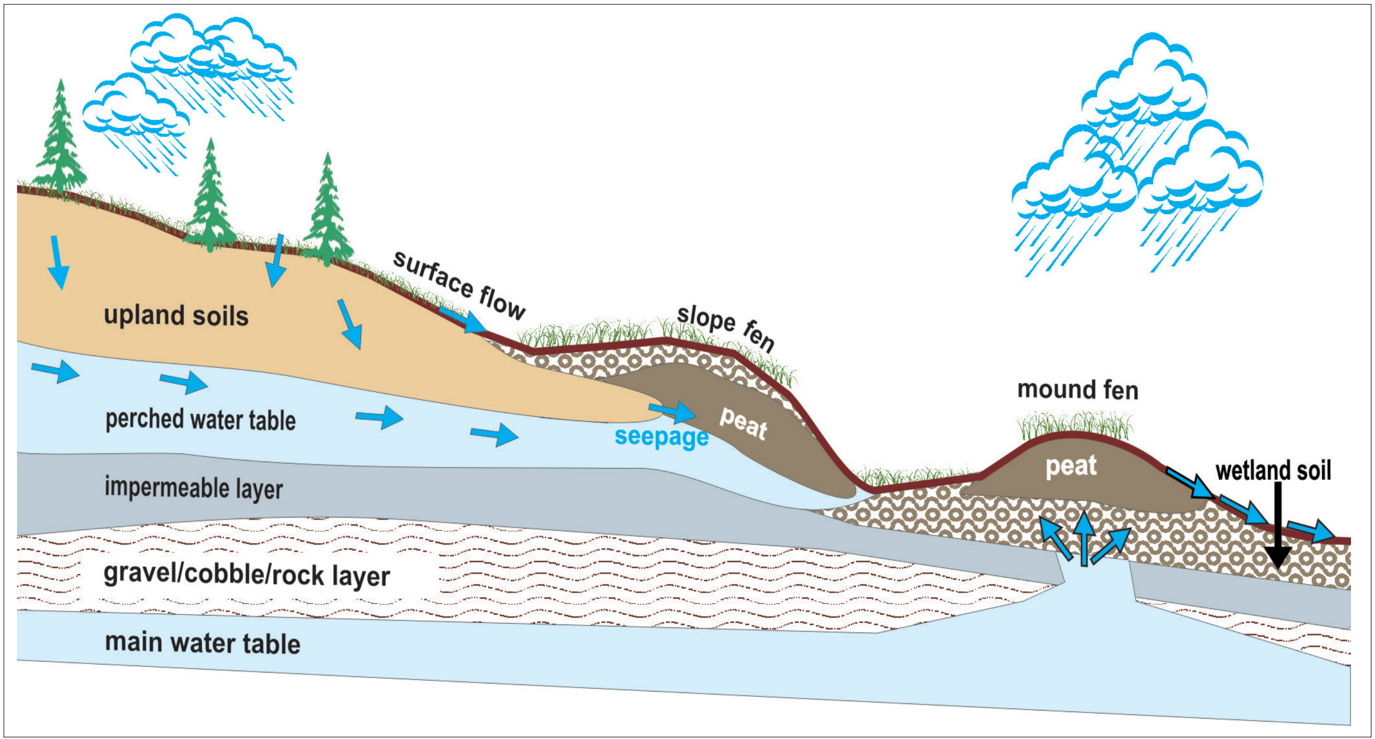


Figure 30. The Comanche Creek Watershed includes both slope and mound fens within headwater slope wetland complexes. Geology, topography, and the hydrology of a site determine the location of springs and artesian water sources that are key to the presence of fens.

In the Comanche Creek Watershed, fen vegetation often stands out from the surrounding wetland vegetation due to a different vibrancy in color (Figure 31). Fens also "quake" when walked upon because they have a liquid soil layer that magnifies vibrations within the soil surface.

In slope wetlands that have begun to degrade as the result of a change from dispersed flow to channelized flow, the vegetation will change to a mix of sedge with an increased component of species that can tolerate the dryer soil conditions (Figure 32).

The change in vegetation species composition begins with a change from dispersed flow to channelized flow. Facultative wetland species, those species that can occur in wetlands but which can also be found in dryer environments, start to dominate as the wetlands dry. Plant species in the Comanche Creek Watershed that are indicative of this drying condition include redtop (*Aragrostis gigantea*), timothy (*Phleum pretense)*, Kentucky bluegrass (*Poa pratensis*), and common yarrow (*Achillea millefolium*). At some stage in this process, the slope wetland is converted to a wet meadow.

Figure 31. Fens may often be identified within the larger slope wetland complex by their vibrant green color as they are at this location in the Comanche Creek Watershed, Questa Ranger District, Carson National Forest, New Mexico.

Figure 32. The *Carex* Spp. community in this photo, taken in the Holman Creek slope wetland complex, is giving way to facultative species. Kentucky bluegrass (*Poa pratensis)* is becoming the dominant species as the complex dries from wetland to wet meadow.

Once a slope wetland complex has dried and is no longer continually saturated, or even seasonally saturated, the vegetation will transition to a combination of facultative and upland species. In the Comanche Creek Watershed, these species include both cool and warm season upland grasses *(Muhlenbergia* Spp., *Elymus* Spp., and *Bouteloua* Spp.), a diversity of upland forbs, subshrubs such as fringed sagewort (*Artemisia frigida*), and upland shrubs like rabbit brush (*Ericameria* Spp.). Once these species are dominant, the wetland and its associated ecosystem services, are effectively gone. Depending on site conditions, it may or may not be possible to reverse this transition and reestablish a wetland or a wet meadow.

CONCENTRATED FLOW/CREEK OR STREAM CHANNELS

Channels are not a component of healthy slope wetland systems. Dispersed flow is integral to the formation and continuing function of slope wetland complexes. The presence of channels, and particularly incised channels, is a sign of degradation in these systems (Figure 33).

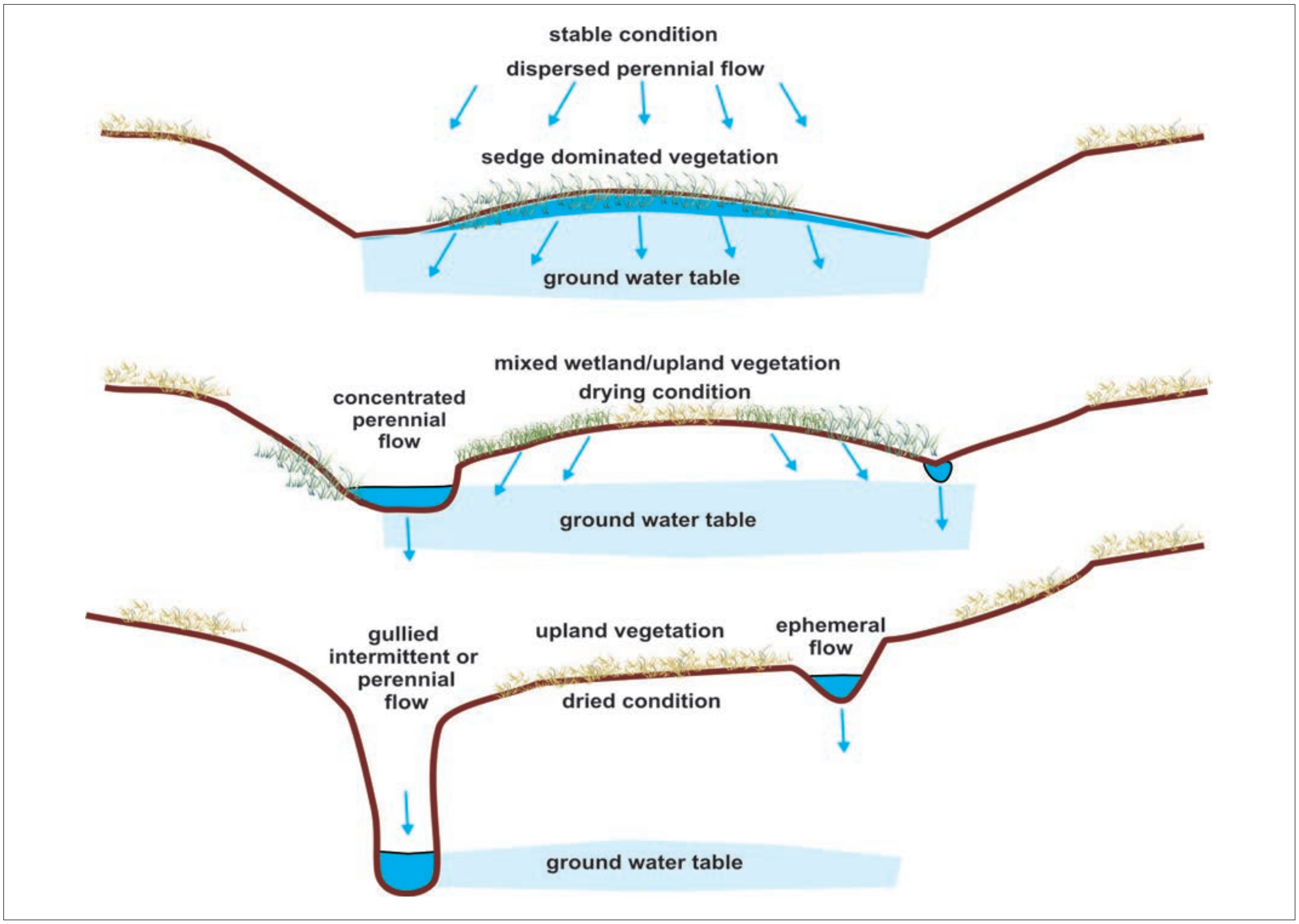
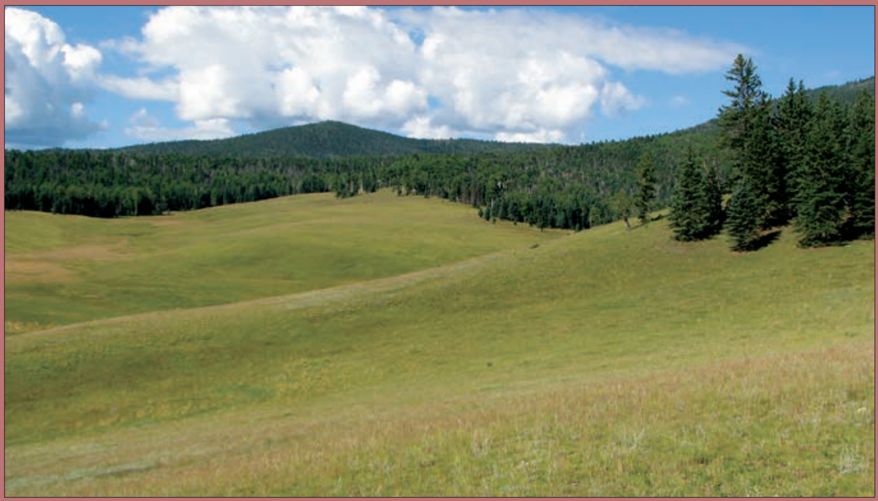


Figure 33. This cross section schematic shows the typical degradation sequence of slope wetland complex due to a change from dispersed flow to channelized flow.

Once dispersed flow is changed to concentrated flow as a result of stressors or changing site conditions, the resulting creek or gully is an unwelcome feature that becomes a component of a degraded slope wetland complex. The challenge becomes one of how to stabilize or restore a system that is now dominated by a drainage feature that interrupts the natural function of the headwater slope wetland.

THE GOOD, THE BAD, AND THE UGLY



GOOD CONDITION

These slope wetlands are in stable condition with sedge-dominated vegetation and dispersed perennial flow over the landform surface.

DEGRADING CONDITION

The slope wetland complex is beginning to show more mixed vegetation, as concentrated perennial flow replaces dispersed flow.

CONVERSION AT END OF DEGRADATION SEQUENCE

Gullies around both sides of this slope wetland complex have left the former slope wetland in a dried condition as evidenced by an increasing number of upland plant species in the vegetation community.

Photo Series ©Mollie Walton, Quivira Coalition, 2014

CHAPTER 5 STRESSORS AND DEGRADATION

REMOVAL OF STRESSORS

A stressor must be identified and addressed before any restoration work is undertaken. Identification of stressors is covered in Chapter 1 of this document. Most stressors discussed in Chapter 5 are ones that interrupt the hydrologic flow regimes in slope wetland complexes.

A current stressor may be the result of a legacy stressor. In this case, the original stressor (overgrazing, for example) has been removed, but the resulting conditions have created a degradation stressor (livestock trails). If the original stressor is still a factor on the landscape, it should be addressed in advance of any stabilization or restoration work. Table 2 lists some of the most common stressors in slope wetland systems.

Table 2. Both human-caused and climatic stressors negatively affect slope wetland health.

Human Caused Stressors
Inappropriate grazing by livestock and wildlife (timing, duration, and intensity)
Animal trailing within or across a wetland or in the immediate watershed above
Logging and associated roads in headwater watersheds
Mineral development and associated roads in wetlands and/or headwaters areas
Improper location and installation of livestock watering tanks and/or no upland water sources
Poorly sized and placed culverts, improper drainage
Placement of supplement block(s) near wetlands and creeks
Ditches, berms, and/or irrigation structures on wetland surfaces (floodplain clutter)
Engineered roads (location, alignment, and drainage features) encroaching upon or impacting wetlands
Unimproved roads: two tracks, hiking trails, ATV trails, and mountain bike paths (alignment, location, and lack of drainage features)
Utility lines and infrastructure
Complex interaction of stressors as a result of legacy land uses presenting continuing impacts

Climatic Stressors
Higher frequency of extreme precipitation events (floods)
Drought (more frequent and longer)
Higher temperatures
Reduced annual snowpack
Earlier and/or faster melting of snowpack due to dust and ash
Earlier timing of snowmelt (before vegetation has enters the active growing season)

There is no point in undertaking stabilization and restoration activities if the stressors at work on the landscape are not addressed. Unless the causes of degradation are resolved, even the best stabilization and restoration work may be quickly undone. For example, a logging road may no longer be in use but still acts as a current stressor because it channelizes otherwise dispersed flow. Before starting stabilization work on the incised channel, the road must be modified to no longer capture flow. On the other hand, legacy stressors that are no longer in play, such as overstocked pastures, will leave livestock trails that cause channel incision and active degradation. The remaining livestock trails are a current degradation stressor. In this case, work on the incised channel could be undertaken right away. However, if the land is still overstocked and overgrazed, then it is essential that overgrazing and trailing be addressed in order for any stabilization and restoration efforts to be worthwhile.

DEGRADED CONDITIONS

Degraded conditions have their own positive feedback loop. Degradation often causes further degradation. It is important to interrupt this cycle in order to start the system back on a trajectory to its best functionality. In the case of slope wetlands, the highest functionality relies on dispersed rather than concentrated flow and on maximum soil-water storage capacity.

Erosion is a normal component of a slope wetland complex (Figure 34 A). However, excessive erosion due to channelized flow will damage water storage capacity and change the system from one maintained by dispersed flow to one dominated by channelized flow (Figure 34 B).

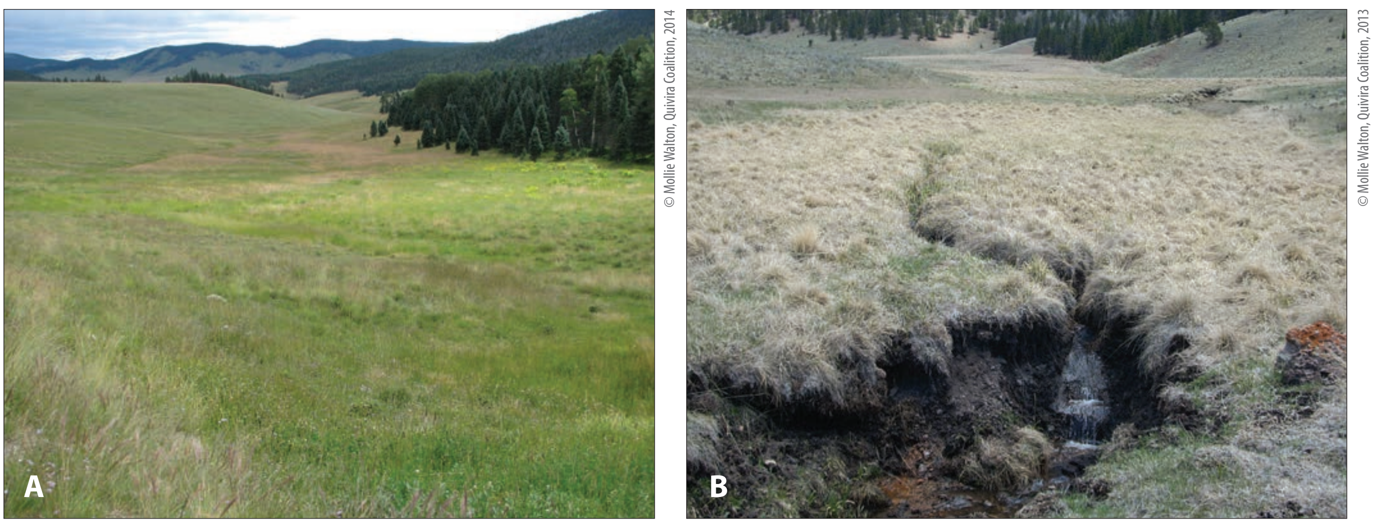


Figure 34 A shows a relatively intact slope wetland complex with stepped wetland features. Figure 34 B shows a slope wetland complex in which the erosion at the toe of the slope is severe, resulting in degradation and channelized flow.

The feedback loop in this case results from an initial nick point in the wetland, such as a road or other stressor that turns into a headcut. The headcut causes an incision on the wetland surface. This incision concentrates flow and accelerates flow velocity, which increases shear stress resulting in the downcutting of the channel bed. The presence of the channel changes the system to one in which channelized flow replaces dispersed flow across the wetland surface. Channelized flow reduces the supply of water available to the surface of the wetland. The water table drops as a result of the downcut channel.

The incised wetland begins to resemble a riparian floodplain wetland instead of a slope wetland. Water storage capacity is lost as interbedded, permeable strata are drained by the incision. In more extreme cases, the slope wetland becomes a wet meadow. In the most extreme case, the former slope wetland becomes a deep gully with little or no riparian vegetation present along its margins (Figure 35 A and B).

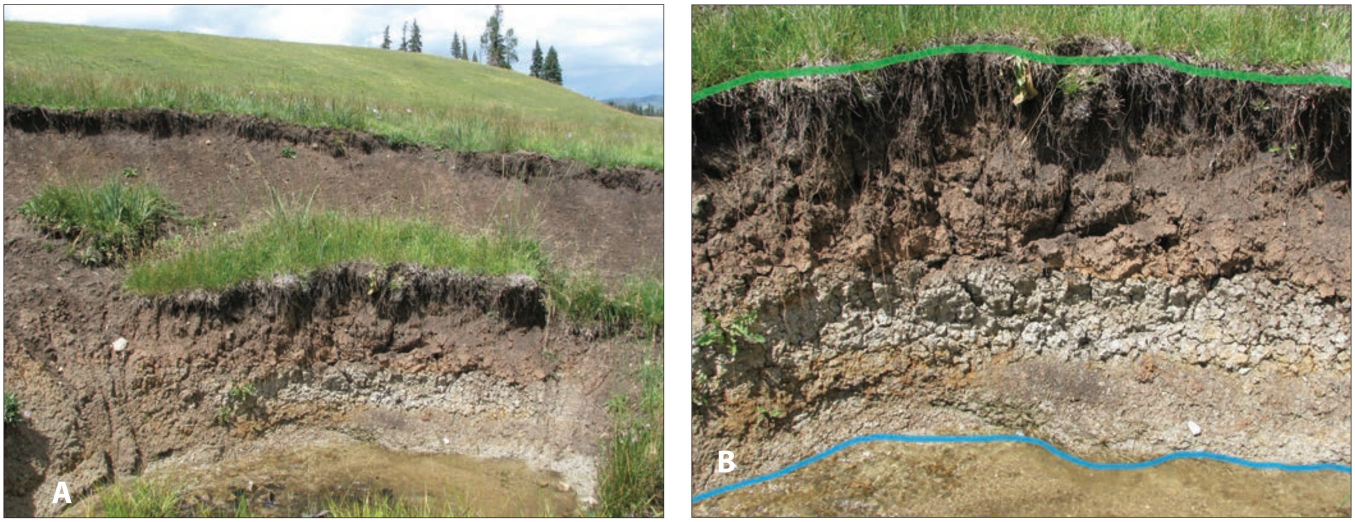


Figure 35 A. The photograph shows the original surface of the slope wetland. Due to a legacy stressor, the flow through the system changed from dispersed flow to concentrated flow causing a creek to cut through the headwater slope wetland. In Figure 35 B, the formerly hydric soil layers may be observed where the incised creek is no longer connected with the original wetland surface.

Once channelized flow has begun, the system changes from a slope wetland complex to a narrow riparian wetland bordering the incised creek channel. Eventually, riparian wetlands may downgrade to a gully with little or no soil water storage capacity (Figure 36).

Figure 36. A former slope wetland complex has degraded into a gully with narrow band of riparian wetland vegetation, surrounded by upland plant communities.

Table 3 lists the most common situations that result in degraded wetland conditions, along with treatment goals and treatment options. The goal for all treatments is to return dispersed flow and halt further degradation.

Table 3. Harmful conditions and possible treatments.

Harmful Condition or Situation	Degraded Condition	Treatment Options
Roads, foot paths, ATV trails, wagon trails and livestock trails currently in use	• Captured water • Channelized flow • Headcutting • Gully formation • Bisected shallow aquifers • Lowers water table both upslope and downslope • Compacted soils • Increased sediment transport	• Porous fill for road crossings • Hardened road crossings or waterways • Proper drainage • Barricades • Relocation/realignment of roads • Drift fence
Abandoned roads	• Drying of wetland area (depending upon placement)	• Reconnection of wetland to water source
Road ditches: lead-in, lead-out, barrow	• Channelized flow accelerating bed and bank erosion	• Reduction of spacing intervals • Drainage
Culverts/pipes	• Headcutting • Drying of wetland below due to blocked culvert	• Appropriately sized and placed elevated culverts (minimum of 18 inches diameter) • Porous fills and low water crossings
Berms	• Drying of wetland area (depending upon placement)	• Reconnection of wetland to water source
Stock tanks	• Loss of flow down meadow • Channelization	• Lowered berm • Redesigned/relocated spillway • Remove tank, develop upland water sources • Relocate tank out of wetland
Poorly managed livestock grazing and supplement block placement	• Hoof-sheer • Compaction • Loss of vegetation and root structure • Reduced water infiltration • Drying of fens • Bed and bank erosion • Reduced soil water storage/lower water table	• Managed timing, intensity and duration of grazing • Supplement blocks moved to uplands, away from wetland soils • Development of upland water sources
Poor upland range health	• Sediment loading • Channelized flow	• Managed timing, intensity and duration of grazing • Uplands rested for one entire growing season on a rotational basis (or longer in the event of drought conditions)

Headcut

A headcut forms as the result of a nick point on the landscape that channelizes flow. Once formed, a headcut will continue to move upstream, eventually causing the more rapid draining of the existing wetland (Figure 37 A and B). Both the headcut and the incised channel are degradation stressors that will continue to eat away at the system unless stabilized by human intervention (Figures 37 C and D).

Figure 37 A. This headcut at the toe end of a slope wetland is draining the wetland and decreasing its capacity for water storage.

Figure 37 B. The headcut will continue migrating upslope unless stabilized. The result is an incised channel that drains water from the slope wetland complex.

Figure 37 C. This photograph shows two separate headcuts migrating upvalley from the original nick point. The degradation has been occurring long enough that vegetation has stabilized the incised channel; however, the headcut will keep cutting through the slope wetland unless stabilized.

Figure 37 D. This headcut is slowly working upslope through a slope wetland in the Springwagon Creek drainage, Questa Ranger District, Carson National Forest, New Mexico.

Incised/Downcutting Channel

An incised or downcutting channel continues to move the water source farther and farther away from the dispersed flow conditions that created and sustained the slope wetland complex. Water in the channel does not touch the soil that contains the roots of vegetation and the system begins drying as water is shunted rapidly through the channel, without the opportunity to be stored by soil and vegetation. As vegetation dies, the roots no longer hold the soil and the whole process of erosion and downcutting is accelerated as the feedback loop of degradation continues (Figures 38 A, B and C).

Figure 38 A. In this incised channel, roots are beginning to die as the channel depth increases.

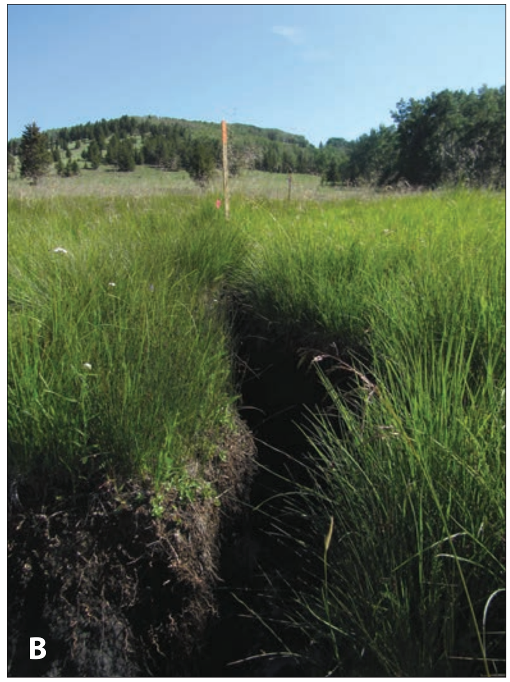


Figure 38 B. The incised channel captures formerly dispersed flow and continues to deepen.

Figure 38 C. Eventually the channel may become so incised that it is a conduit for channelized flow and any wetting effect it provides is limited.

Channel downcutting is often the result of trailing stressors. Trailing stressors can be both legacy and current impacts. These stressors create a headcut or channel that captures the water formerly dispersed across the wetland surface.

Trailing Stressor

Trails can be caused by wildlife, livestock, human traffic, mountain bikes, off road vehicles (ORVs), etc. It does not matter what causes the initial trail, the result is inevitably the replacement of dispersed flow with channelized flow. In the case of wetlands and riparian areas, wildlife and livestock trailing may have more negative impact due to the fact that the trails are used to get to a water source and may be frequently used for that purpose (Figure 39).

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Figure 39. This elk trail through this wetland will eventually degrade to a new channel where it crosses the slope wetland complex.

Roads

Old logging roads are legacy stressors in the Valle Vidal. Most of these roads were modified to help improve drainage in order to put water back on the soil surface instead of down the road to the next gully. Many roads were then closed by the Forest Service. Roads without proper drainage may create many problems in watershed function. This is true of upland roads as well as those that cross wet meadows, wetlands, and riparian areas. The basic impact that roads have is to channelize flow that was formerly dispersed across the landscape.

Results of these roads and other legacy stressors may be observed in the downcut channel and the loss of wetland area apparent in this valley (Figure 40 A and B). For a comprehensive document on how roads can affect the surrounding watershed and for treatment options see Zeedyk, 2006, Water Harvesting for Low-Standard Rural Roads.

Figure 40 A. Closed roads crisscross the Valle Vidal and are an example of legacy stressors that contributed to decades of wetland and stream degradation.

Photo Set ©Mollie Walton, Quivira Coalition, 2014

Figure 40 B. This photograph shows a road crossing a wetland complex in the Valle Vidal Unit of Carson National Forest, New Mexico (light green, lower left). Although the road has been closed and reclaimed, the damage it caused is still apparent as a large headcut where it crossed the valley floor. This is an example of a situation in which an initial stressor has been removed but the resulting degradation continues.

Culverts

Culverts by their nature, contain and channelize flow. Road culverts are often improperly sized and installed. The channelized flow from a culvert can be erosive on the downslope end, as can be observed in Figure 41. Conversely, a poorly sized culvert will fill with sediment and block the flow of water downslope (Figure 42).

Figure 41. The outflow of this culvert is causing erosion at the top of a slope wetland. Armoring the drain would help mitigate this condition. Culverts installed too deeply initiate headcutting on the upstream side of the road as well.

Figure 42. A blocked culvert will deprive downslope wetlands of water by diverting flow to another location.

Poorly Managed Grazing

Upland range condition may have a great effect on wetland conditions downslope. Uplands with poor vegetation cover are sediment sources, as precipitation events are likely to move the bare, unprotected soil. In extreme cases, rills and gullies may form upslope and eventually either bury a wetland in sediment or cut through it.

Grazing in riparian areas should be closely managed in order to maintain productivity for the grazers and the ecological integrity of the riparian or wetland system. Large ungulates, such as cattle and elk, will spend long periods in the high-quality forage that is close to water. In the absence of pressure from predators, wet areas will be overused (Figure 43). Reintroduction of wolves in Yellowstone National Park in 1995 changed the riparian systems dramatically (Mao et al., 2005). Without predator pressure, grazing management needs to include herding to keep large ungulates from camping out in wetlands and riparian zones.

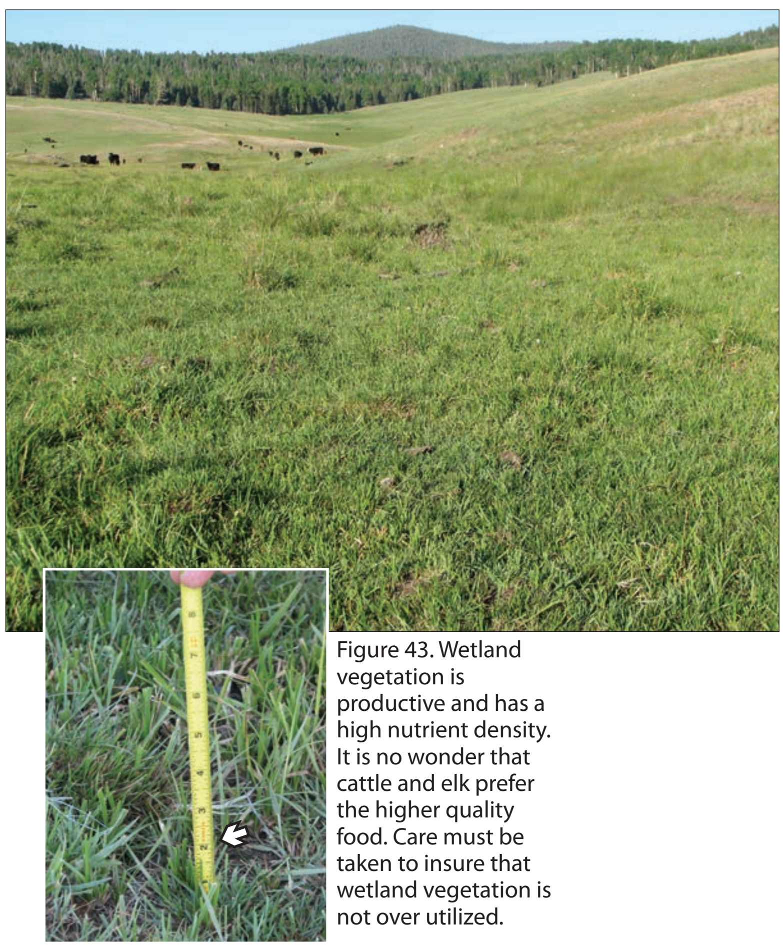

Figure 43. Wetland vegetation is productive and has a high nutrient density. It is no wonder that cattle and elk prefer the higher quality food. Care must be taken to insure that wetland vegetation is not over utilized.

Hoof-shear

A negative result when ungulates camp out on wetlands is damage from hoof-shear. Cattle and elk are heavy animals with sharp hooves. Their hooves cut wet soil, which results in the death of the roots in the soil where the highest impact occurs (Figure 44). This can lead to plant pedestals (Figure 45). The soil is no longer held by plant roots, there is less water infiltration and microchannels may form around the pedestals. All of these effects ultimately result in drying of the wetland.

Figure 44. Hoof-shear results from cattle or elk grazing on wetlands and fens. The wet soil is cut by the hooves and results in the death of plant roots and oxidation of organic soils. Plant pedestals are apparent in the areas with highest impact.

Figure 45. Plant pedestals from hoof-shear are apparent in this slope wetland.

Supplement Block Placement

Mineral and protein block placement can be used to encourage livestock and wildlife to graze in selected areas and away from others. Careful placement is recommended to draw livestock to upland watering sources. Placement of blocks near natural water sources results in trampling, soil compaction, and hoof-shear damage and is not recommended (Figure 46). The vegetation in wetlands is already an attractant to grazers, and therefore practices such as supplement blocks that encourage even more intensive use of the wetlands should be avoided.

Figure 46. Placement of supplement blocks resulted in a heavily trampled area. Placement in wetlands should be avoided.

Fen Damage

Fens may become damaged because ungulates are attracted to them as sources of water, minerals, productive forage, and potentially higher protein grazing (Figure 47). These attractants are all hypothesized and have not been tested in the Comanche Creek Watershed.

Figure 47. Cattle herds linger in fens even where good upland grazing conditions are present nearby.

The length of time and the amount of hoof-shear on wet soil have the following degradation effects. The large ungulates trail up to the fen and then spend time on the most productive part. What results are damage from vegetation removal, hoof-shear, and a trail leading to the fen that will capture and channelize sheet flow (Figure 48).

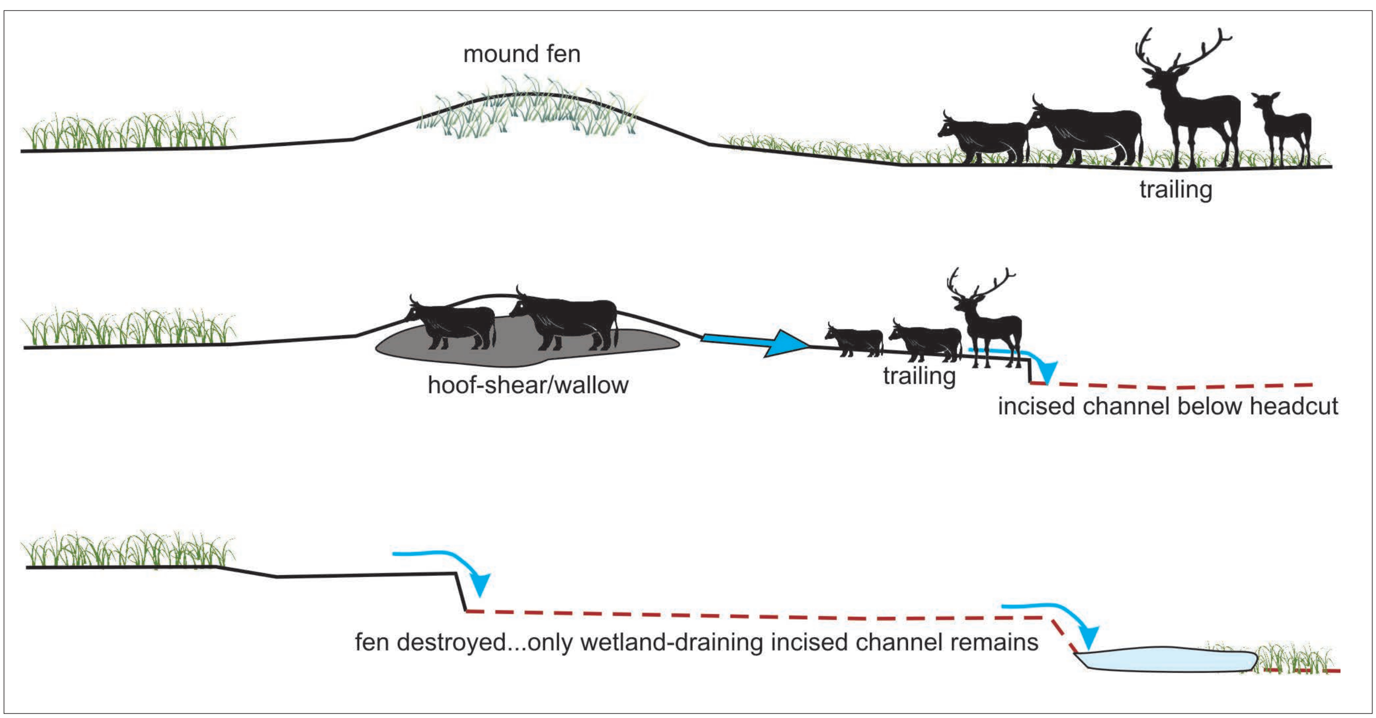

Figure 48. Cattle and elk walk to the top of the mound fen, creating a trail. The trailing causes a headcut, which turns into an incised channel. The channel begins to drain the fen. Wetland vegetation is lost and the fen dries.

Figure 49 A shows an intact fen with minor erosion on the edge. Figure 49 B shows the beginning effects of hoof-shear, and Figure 49 C shows the mud wallow that results. Figure 49 D shows the loss of wetland vegetation and drying of fen soil.

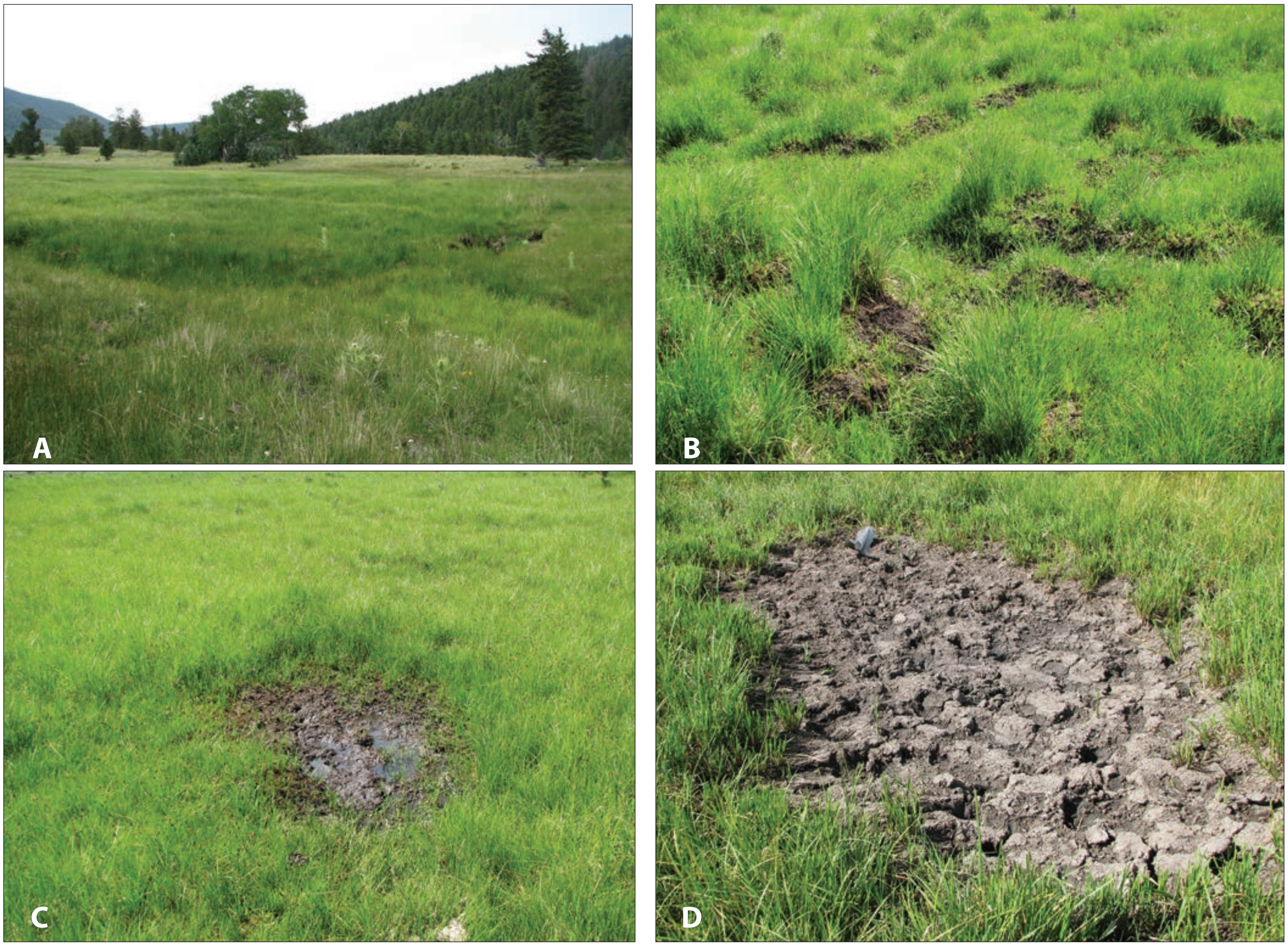

Figure 49 A, B, C and D show the progression of fen damage caused by large ungulates. Once dry, the oxidized peat soils no longer support vegetation.

The existence of the fen is dependent upon the artesian water source. More damaging than the drying caused by vegetation removal and hoof-shear is the interruption of the water storage capacity of the fen due to a channel or headcut that drains the fen (Figure 50). Once the path of water has changed and the artesian water source is drained and rerouted by channelized flow, it will be difficult to save the fen.

Figure 50. The downslope face of this fen is draining due to an incised channel that has cut through the slope wetland complex and bisected the fen (LaBelle Creek drainage in the Comanche Creek Watershed).

Stock Tanks

A stock tank may be a stressor if it is dug too deeply. This causes the water table to be artificially low and results in a headcut upslope of the excavated area. If the spillway is not properly formed and constructed, the water will cut channels around the sides of the stock tank berm (Figure 51).

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Figure 51. Placement of this small stock tank shows drying of wetland vegetation above and below the tank, an incised channel below the tank spill way, and a headcut that is migrating upstream.

Cattle tend to spend time around water sources, thus the same damage that occurs around fens due to over use also occurs around stock tanks (Figure 52). Placing a stock tank within a slope wetland complex will create a sacrifice area for the cattle and result in a nonfunctioning wetland. Choosing a location along the stream course, but outside the wetland complex is preferable, although associated impacts related to trailing would continue.

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Figure 52. This stock tank is an example of the negative effects from stock tanks placed in wetlands. Erosion and overuse of the area are apparent.

CHAPTER 6
STABILIZATION AND RESTORATION TREATMENTS

The treatments described in this section are not all-inclusive or exhaustive. An overview of different treatment types and their potential uses is presented. Construction details will differ by site conditions and desired outcomes. Many restoration contractors or practitioners will add their own touches, based on individual knowledge, experience, and talents.

SETTING PRIORITIES

In order to do the best work in stabilizing a slope wetland system, priorities must be set. In the "Reading the Landscape for Slope Wetlands" (Chapter 2) of this document, an description is given of healing the ugliest place on the landscape versus choosing the best place to try to increase wetland function. Both approaches may be required. If a headcut is drying a slope wetland complex or wet meadow, stabilization treatment is necessary before restoration treatments will be effective. In other places, if the eroded area is no longer draining the slope wetland complex, treating the eroded areas may provide little gain for the system. How does one know where to begin?

DEFINING GOALS AND ASKING QUESTIONS

Is stabilization or restoration the goal? If the goal is to "stop the hemorrhaging" of water in the system through existing headcuts, gullies, and incised channels, then stabilization treatments are necessary. If the system is stable, but water needs to be returned to dispersed flow, treatments should aim to restore function. There is much overlap between the two approaches.

Is stabilization necessary in order for restoration to be effective? Yes, most definitely. If the water flow pattern is restored to dispersed flow higher in the system yet there is a large headcut that drains the system at the bottom of the wetland, the goal of returning the system to its proper function as a sponge will be reduced or negated (Figure 53).

Figure 53. A large headcut is draining this slope wetland. Left alone, this headcut will continue to erode away at the wetland as the headcut moves upslope. In this situation, stabilization is necessary before any other restoration work could be effective. Construction of the log and rock step falls stabilizes the wetland complex and has positive effects in increasing slope wetland function both upslope and downslope of the stabilization site.

Photo Series ©Craig Sponholtz, Watershed Artisans, Inc., 2013

TREATMENTS FOR SPREADING WATER

Plug and Pond Design and Construction

The purpose of the plug and pond treatment is to return flows captured by an incised channel (gully) to the historic impaired slope wetland surface. Water captured behind the plug will spill across the former wetland surface as sheetflow. The term "plug and spread" might be more descriptive than "plug and pond." The plug is situated in the incised (downcut) channel at the place and in a manner that will achieve maximum rewetting of the wetland surface for the effort expended. Plug and pond treatments are most appropriate where perennial groundwater flow persists, although in some situations it may be appropriate in former slope wetlands totally dried by erosion.

Typically, the plug and pond treatment consists of four constructed features: the plug, the borrow area(s), the backfill, and a berm that creates freeboard above the plug. An earthen plug is used to fill an incised channel or gully. Soil for the plug is excavated from a one or both sides of the channel to form a shallow bay. The channel is not deepened and may be partially backfilled. The outlet or spillway from the bay is built on the contour and as wide as possible in order to spread water runoff across the wetland surface (Figure 54).

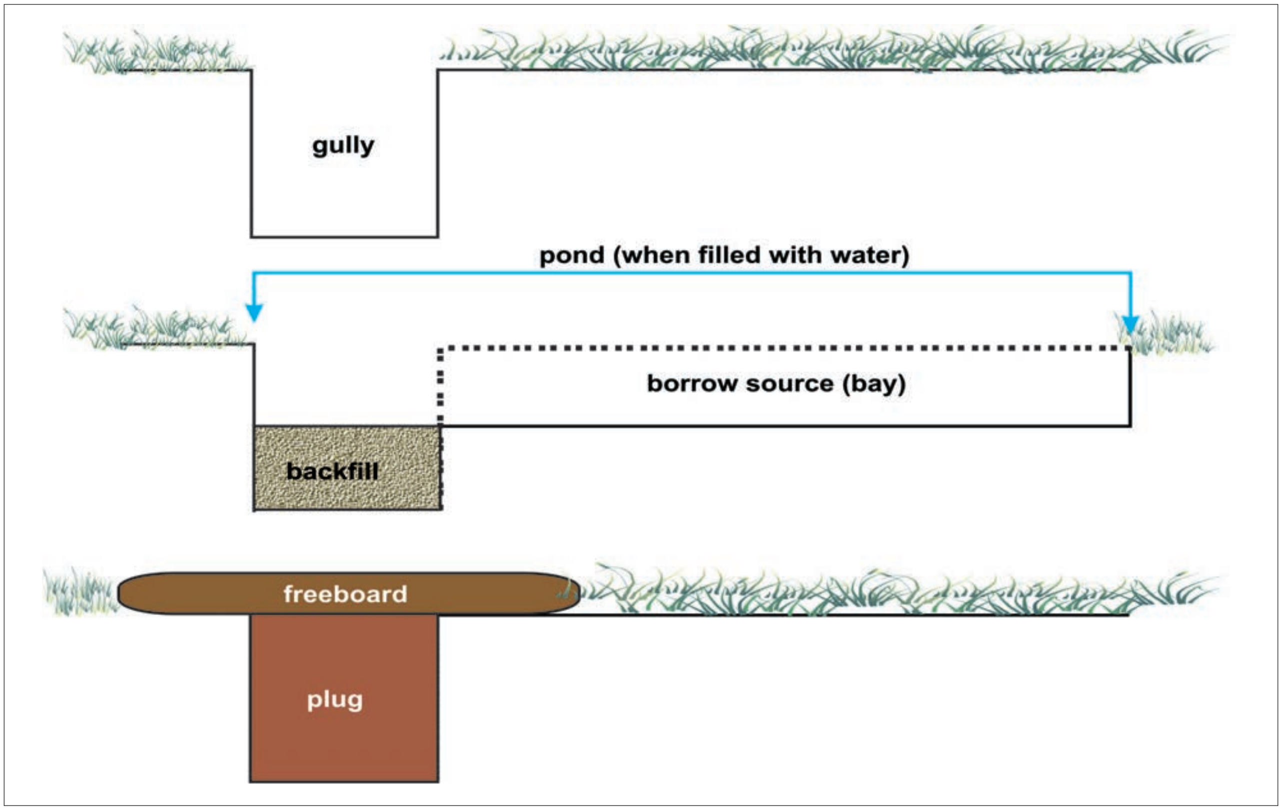


Figure 54. A channel in a slope wetland constitutes a degraded condition. The plug and pond treatment both stabilizes the system and returns water to dispersed flow across the wetland surface.

The earthen dam or plug (fill) should be built in layers of soil 3 to 6 inches thick and compacted after each layer is added. The plug should be the width of the incised channel and at least 4 feet in length per foot of channel depth. The purpose for the longer plug is to protect it from weakening by burrowing animals such as gophers, muskrats or crayfish. The plug is constructed to the height of the channel bank. Freeboard is the added height of the plug above the wetland surface or channel bank, which should be higher than the maximum expected flood depth across the wetland surface. Freeboard should extend out onto the wetland surface far enough to divert flood flows completely around the plug on both sides (Figure 55 A and B).

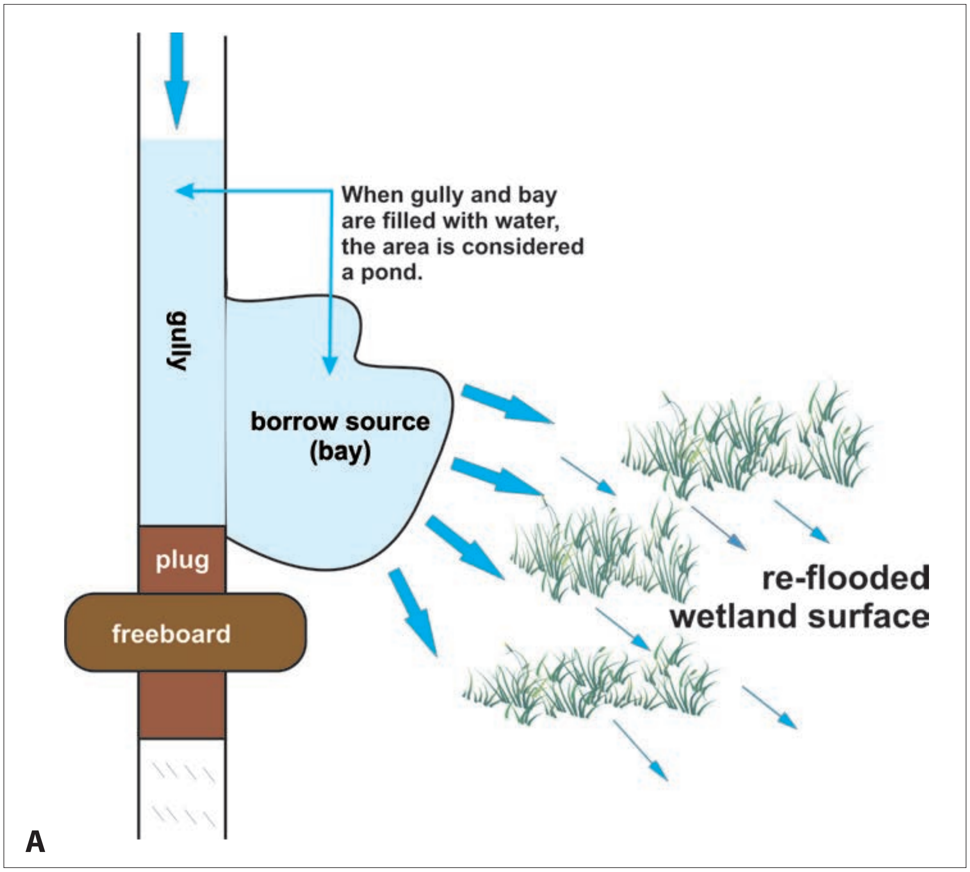


Figure 55 A. The schematic shows a plug and pond design with one bay flooded. Figure 55 B shows the implementation of the plug and pond treatment in a slope wetland complex near Gunnison, Colorado

©Betsy Neely, 2014

Where fill is borrowed from both sides of the gully, two bays are created. Each bay leads water to a pour-over edge (lip), where it is dispersed through native vegetation on the wetland surface. The impounded area is the total area made up of the original gully and the borrow area, or areas, and when filled with water is considered a pond.

Where suitable, sod of wetland plant species, such as *Carex* Spp., may be placed on top of the plug to protect it from erosion during flood events. In this case, the freeboard may not be necessary or could be of lower height above the plug.

The top of the dam can be stabilized in three ways:

1. Raise the height of the dam to an elevation at least 2 feet higher than the elevation of the spillway and reseed it.
2. Build the plug at least as long (channel length) as it is wide (channel width), and preferably longer.
3. Keep the pond (bay) to an average depth of 2 feet (maximum 3 feet) in order to favor introduction and growth of emergent wetland plant species across the bed of the pond.

The bay is the source of borrow material (dredge) to build the plug and is located to the left or right side of the channel, or on both sides as appropriate, to redirect flows onto and across the wetland surface. Because the purpose of the plug and pond treatment is to restore wetland habitat, the bay (or borrow area) should be kept wide and shallow rather than narrow and deep. Digging the bay to a shallow depth (2 feet or less) will favor colonization by emergent wetland obligate species, versus the creation of an open water pond within the wetland (Figure 56).

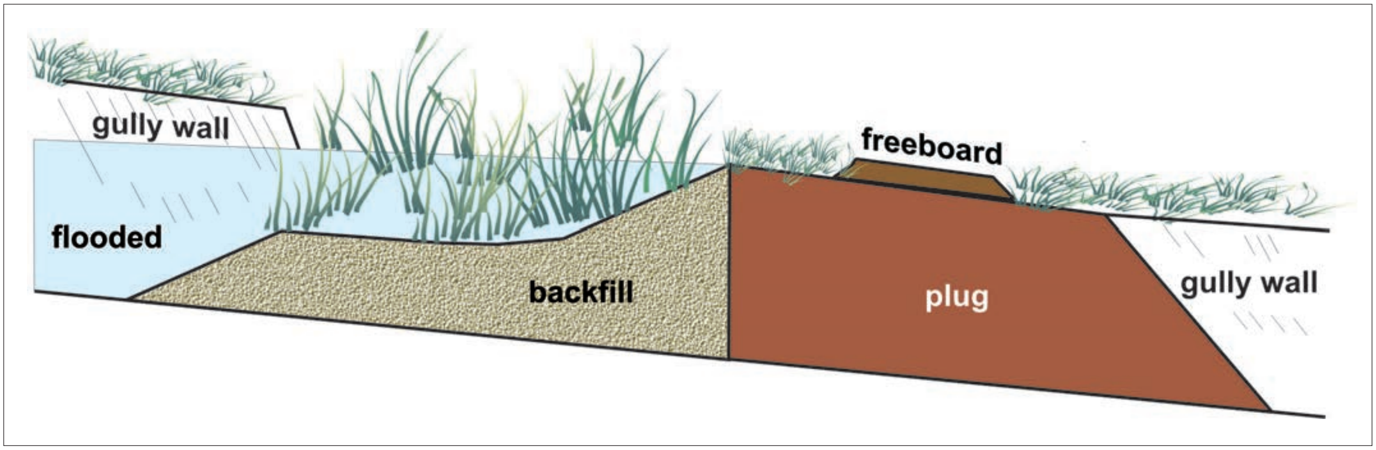


Figure 56. Plug and pond typical longitudinal profile schematic.

Digging the bay too deep will change the habitat type entirely. Deep water will be colonized by submergent rather than emergent wetland vegetation. Creating a pond is not the goal of the treatment. The goal is to spread water across the slope wetland surface as broadly as practical, based on the site conditions. Backfill should be used to raise the bed of the channel, if feasible, to the level of the bed of the borrow area. This will encourage colonization by wetland vegetation.

Ideally, the borrow area should be shaped and extended out from the edge of the channel in such a way as to maximize contact with the wetland surface on the down valley side of the pond. If the intention is to spread water to both the left and right sides of the incised channel, the borrow would be dug from both sides, and the resulting ponds would have two bays, one left and one right. Where this is the case, it is important that the downstream edge or shoreline of both bays be on exactly the same contour elevation, so as to achieve wetland flooding on both sides of the valley. Depending upon the variations in the topography of the restored wetland surface, it may be desirable to construct one or more ponds downstream from the first in order to spread flow more widely across the wetland.

An alternative approach to the plug and pond method of slope wetland restoration has been developed by restoration practitioners in the Valles Caldera National Preserve (see "Acknowledgements", page 66). These methods rely on smaller plugs which are immediately stabilized through the use of *Carex* Spp. mats. Primary application has been within the Jemez mountains. Such structures are built with the use of excavators operating within the incised channel, and a highly skilled excavator operator is required. These structures leave less impact on the landscape than using bulldozers for plug and pond construction. Plug and pond treatments can be both stabilizing and restorative in application.

Flow Splitters

Flow Splitters are used to split water flow away from an incised channel and return such flow to the wetland surface. They may also be used to more evenly distribute sheet flow across wetland surfaces. Flow splitters can be made of many different materials, depending upon material availability and site conditions.

Media Luna. A media luna is a curving, loose rock structure, shaped like a half moon and designed to spread or disperse water onto the wetland surface (Figure 57). Loose rock, usually 4 to 8 inches in diameter is spread on the wetland surface as a rock mulch in a band 4 to 6 feet wide and as long as needed (often 40 to 80 feet). The ends point up valley and are installed at equal elevations (on the contour). This application is for spreading water and may have applications for restoring dispersed flow to the surface of alluvial fans as well as slope wetlands.

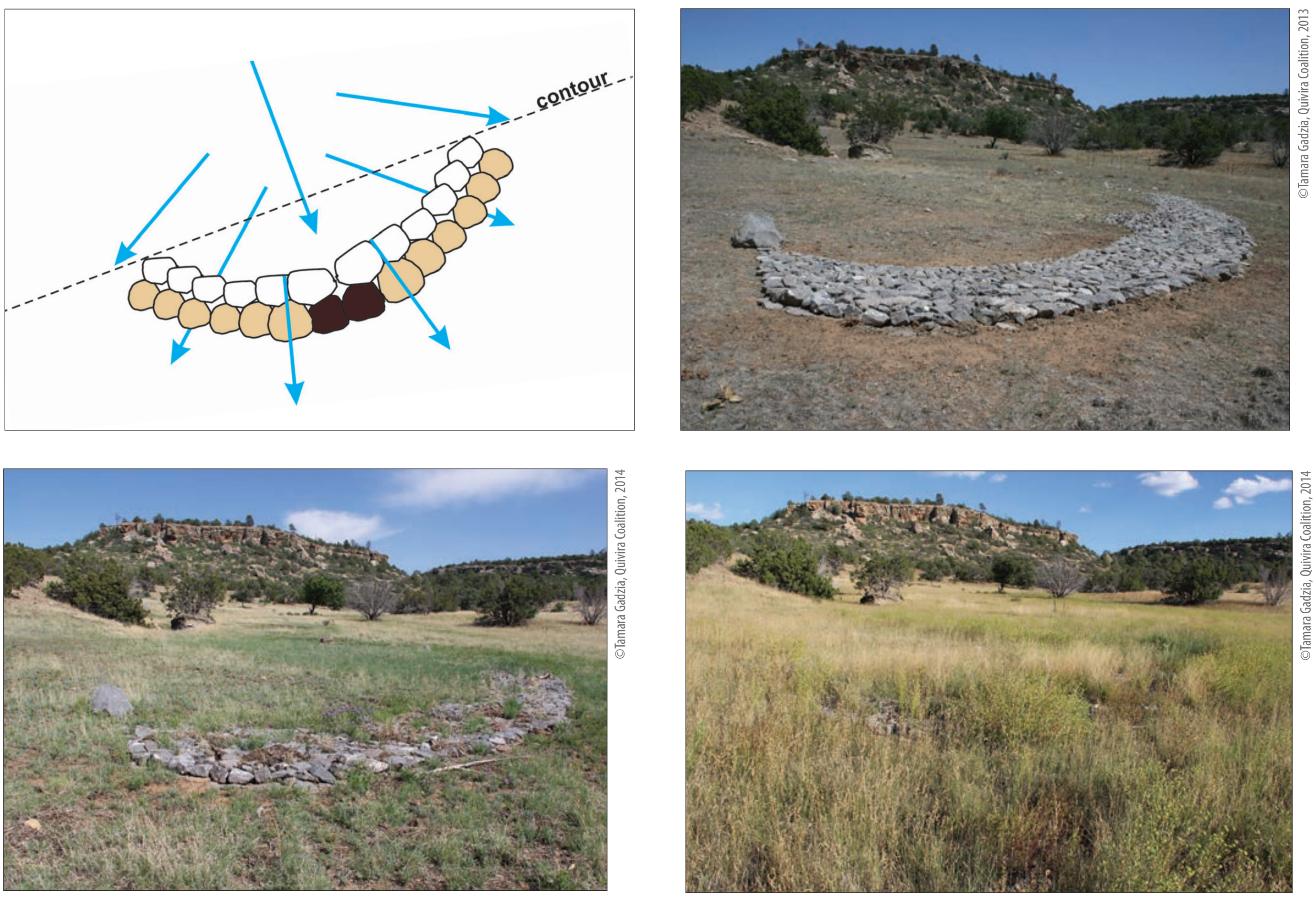


Figure 57. The schematic shows proper placement of the media luna structure and the subsequent photographs show a newly constructed media luna and the same media luna as recovery progressed at a restoration site near Wagon Mound, New Mexico.

Where flow volume is small the media luna can be built of brush. Each brush cutting should be placed flat on the ground with the trunk facing upslope and the brush cuttings 6 to12 inches apart.

Log Flow Splitter. These are good structures to use in conjunction with other treatments, such as a lateral or meandered worm ditch (Figure 58).

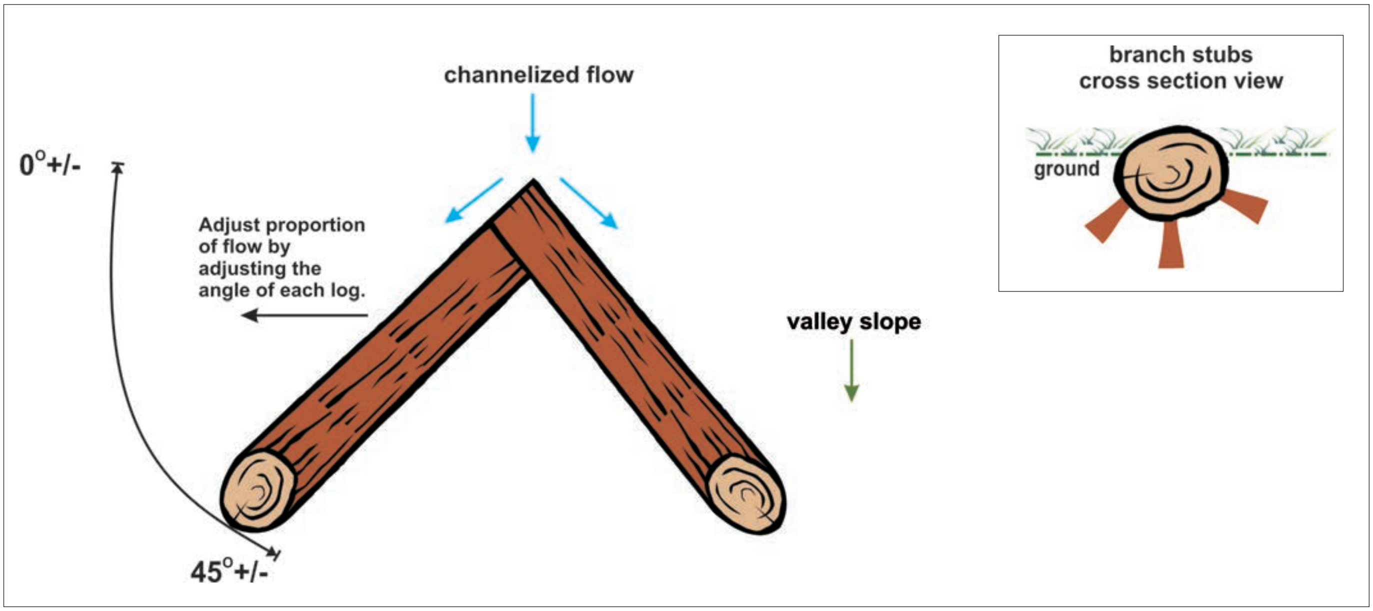


Figure 58. This schematic of a log flow splitter shows that the angle should be adjusted as site conditions dictate.

Splitting the flow can be used both to maintain the health and vigor of wetland vegetation occurring along an existing incised channel and to return water to drying slope wetlands. The key consideration is 1) how to apportion water flow between target areas and 2) how the flow should be apportioned during low flow periods versus seasonal flood events, such as spring snowmelt. Flow splitters can be both stabilizing and restorative in application (Figures 59 A and B).

Figure 59 A. This photograph shows a log flow splitter leading to worm ditch in the Springwagon Creek drainage, Questa Ranger District, Carson National Forest, New Mexico, and was paid for by a 2011 River Ecosystem Restoration Initiative grant to the Quivira Coalition. Figure 59 B. This photograph shows a flow splitter constructed from sod. These may be used to spread water flow when the channel is not deeply incised.

Worm Ditch. A worm ditch is used to spread water from the eroding or downcut channel back across the surface of the slope wetland. The alignment of the ditch is sinuous so that the grade is flattened more than that of the wetland. For example, if the length of the ditch is twice as long as the distance between the start and end of the ditch, its grade will be only half that of the wetland surface (Figure 60).

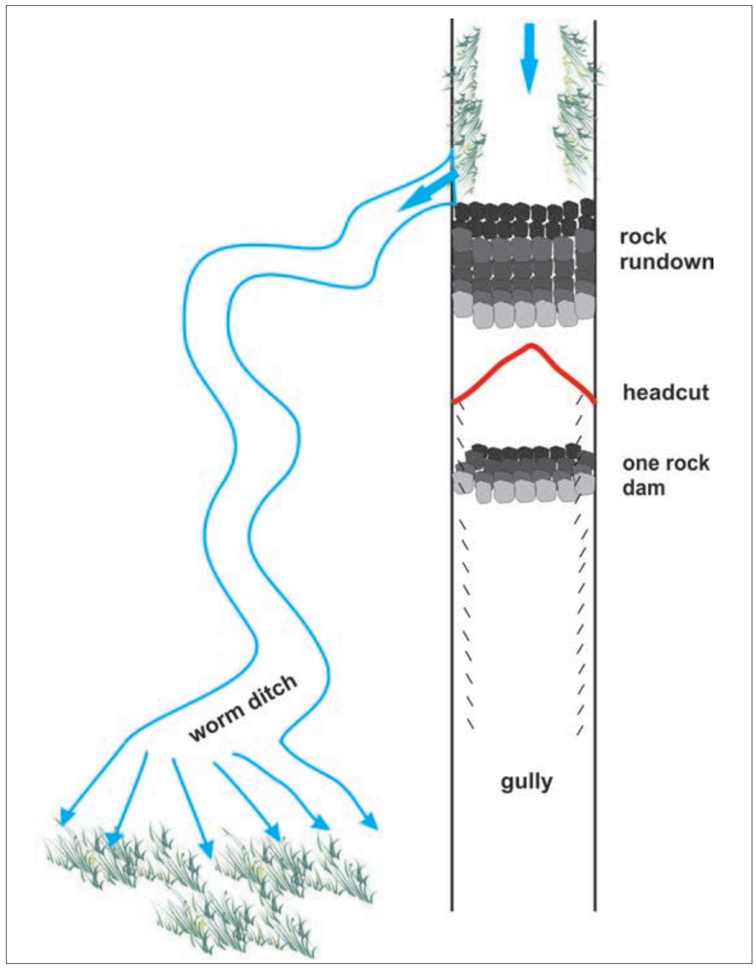


Figure 60. The photograph shows a worm ditch constructed by volunteers in the Springwagon Creek slope wetlands in the Comanche Creek Watershed. The schematic shows how to use a worm ditch in conjunction with other treatment structures to divert water out of an incised channel or gully.

A worm ditch can be used for any one of several purposes. For example, it can be used to divert flow around a headcut and to divert flow onto the former surface of the wetland drained by the gully. At the downstream end of the worm ditch, a spreader device such as a media luna can be used to disperse flow more widely across the wetland surface. The width of the ditch should be at least 2 feet with a depth of at least 1 foot. If the purpose of the ditch is to divert flow around a headcut, it should have a width and depth equal to that of the channel above the headcut.

A lateral worm ditch may also be used to move flow back across an expanse of former wetland. In this case, it does not have to be as sinuous or as wide as the worm ditch designed around dewatering a headcut or gully (Figure 61).

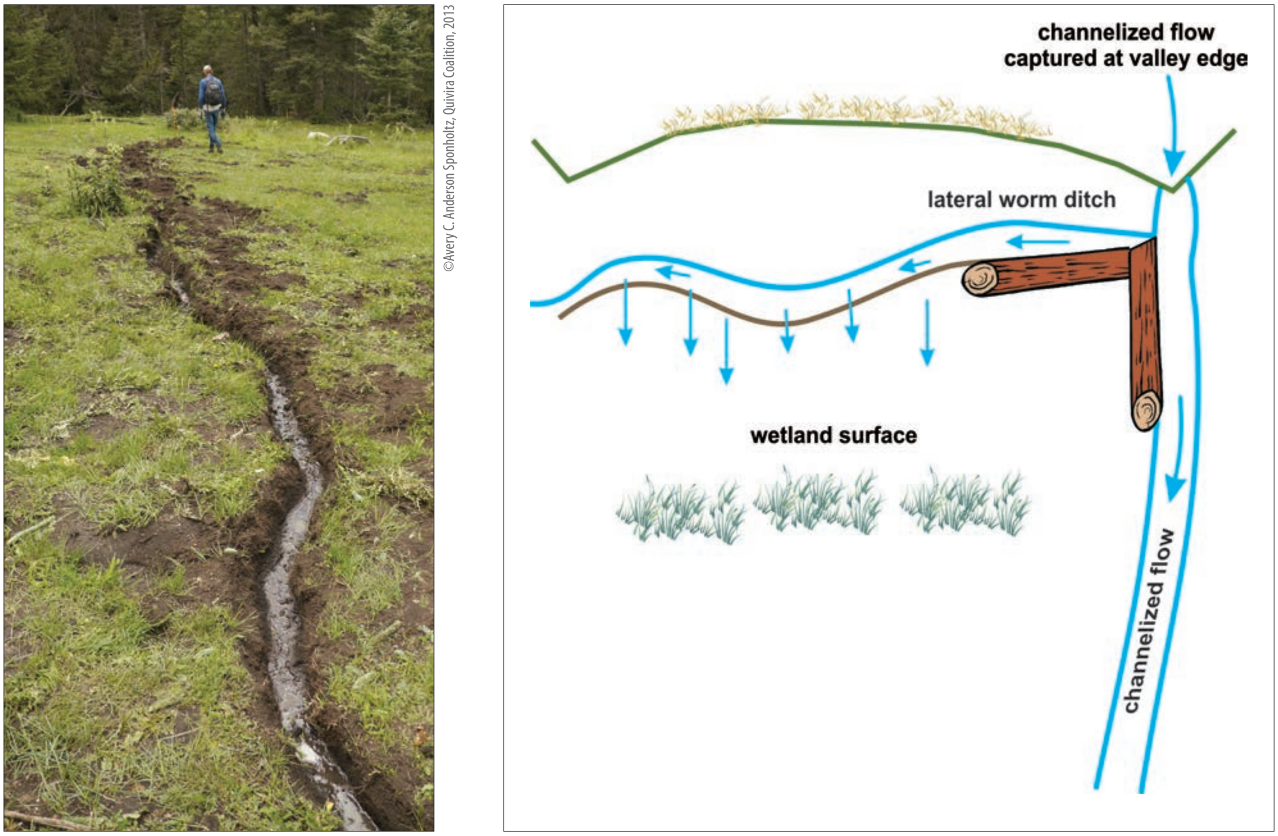


Figure 61. This lateral worm ditch was dug by volunteers in the Springwagon Creek slope wetlands in the Comanche Creek Watershed based upon design principles detailed in the schematic.

Burrito Dam. Burrito dams are used to divert shallow flows across flat surfaces in order to disperse water more evenly on the drier portions of a slope wetland. The advantage of the structure is that its components are light in weight and easily carried by volunteers to the wetland restoration site.

A burrito dam consists of filled sand bags enclosed or wrapped in a tube of geotextile fabric. The height of the structure is usually 8 to12 inches. The wrapped bags can be stacked 2 to 3 layers deep, if necessary for added height, and placed in straight or curving alignments as appropriate to the purpose of the structure.

The sand bags are first filled with soil gathered from an onsite source. The bags are placed end to end on a sheet of fabric wide enough to wrap one-and-a-half times around the bags, ending with the loose end tucked under the bags.

Sand bags deteriorate quickly when exposed to UV light. The purpose of the fabric is to shelter the bags from direct rays of sunlight. Fabric bags resemble a favorite New Mexican meal, the breakfast burrito, hence the treatment name (Figure 62).

Figure 62. This burrito dam was constructed by volunteers at Cebolla Canyon near Grants, New Mexico.

In Figure 62, brush has been placed on top of the burrito dam to dissuade elk from using the dam as a bridge across the wetland surface. The burrito dam provided a transportation conduit for elk which was not anticipated when it was designed. In subsequent years, when burrito dams were constructed for this wetland restoration project, brush was always used to top the structures and provided protection against elk crossings.

One Rock Dam

The one rock dam (ORD) is used to raise the bed of an incised channel or gully. Depending on the depth of the channel and height of the dam, a ORD or series of ORDs may be sufficient to reconnect flood flows with the wetland surface. Initially, rocks are placed in 5 or more parallel rows only 1 rock deep (Figure 63).

Use of an additional row of footer rocks on the downward side as a splash apron is recommended. Flat rocks can be stacked on their edges or ends for added height (book stacked).

One rock dams can capture and detain coarse bedload particles (sand-gravel and larger particles), but not silt and clay sized particles until grass and sedges become established between the rocks. When sediment has aggraded the channel to the height of the original rock layer, a second layer can be added to all structures in order to further elevate the bed of the incised channel, if necessary.

Figure 63. A one rock dam has been used in an incised channel to slow and raise the water level upvalley in order to reconnect the water with the wetland surface.

Sod Plugs

Sod plugs can be used to stabilize incised channels up to 2 feet deep cutting through slope wetlands. The purpose is to restore sheetflow across the soil surface. Sod plugs are most appropriate in wetlands dominated by sedges (*Carex* Spp.) and wetland grasses. Sod "bricks" used to build the plugs are cut with a sharp shovel from the adjacent wetland. Soil bricks should be cube shaped and approximately 10 by 10 by 10 inches in size. Use as many layers as needed to plug the incised channel and reconnect the wetland surface. Place sod bricks in tightly packed layers the width of the channel and 3 to 5 feet long in the direction of flow (Figure 64).

Two alternative modes of collection can be used. The first is to cut the bricks from isolated divots scattered across the wetland surface. The other is to cut the bricks from one or more shallow pits on the wetland surface. This method results in the formation of small, isolated pools that will fill with water. Where the incised channel is subject to flooding as during spring snowmelt, the sod plug can be augmented with a one rock dam for added stability and to control erosion of the downstream portion of the plug. This portion of the plug may function as a headcut, if it is not anchored with a one rock dam.

Figure 64. This sod plug, constructed by volunteers in the Grassy Creek slope wetlands, is slowing water flow in an incised channel cutting through the wetland. Water is spilling back over the wetland surface as seen in the photograph.

Channel Liner

A channel liner is a long, narrow one rock dam, much longer than it is wide, built in a recently incised channel or gully bottom. A channel liner is most useful where a new headcut has ripped through wetland sod. The channel liner armors the bed and reconnects water flow in the incised channel with the surface of the slope wetland (Figure 65).

Figure 65. This channel liner raises the water level in a short reach of incised channel.

Log Mat

The log mat is used to line the bed of an incised channel, trap sediment, and raise the bed elevation of the channel to reconnect the water with the surface of the slope wetland. Use is similar to that of the one rock dam. It is most successful when used at successive cross-over segments (the straight sections between the small meander bends) of an incised channel, which in total will raise the water level over the entire length of the treated incised channel reach.

Logs are placed side-by-side parallel with direction of flow (Figure 66). Logs can be 4 to 12 inches in diameter and should be as long as the channel is wide at the point of use. To guard against logs being washed away during high water, they should be wired together and tied to 3 foot T-posts driven into the ground adjacent to the structure. Wires can be stapled to the logs or wire can be looped in a figure eight fashion around adjacent logs for added security. Once logs have captured sufficient sediment to raise the bed elevation, a second layer can be added to each mat, but the second layer should be offset upslope—half the length of the mat.

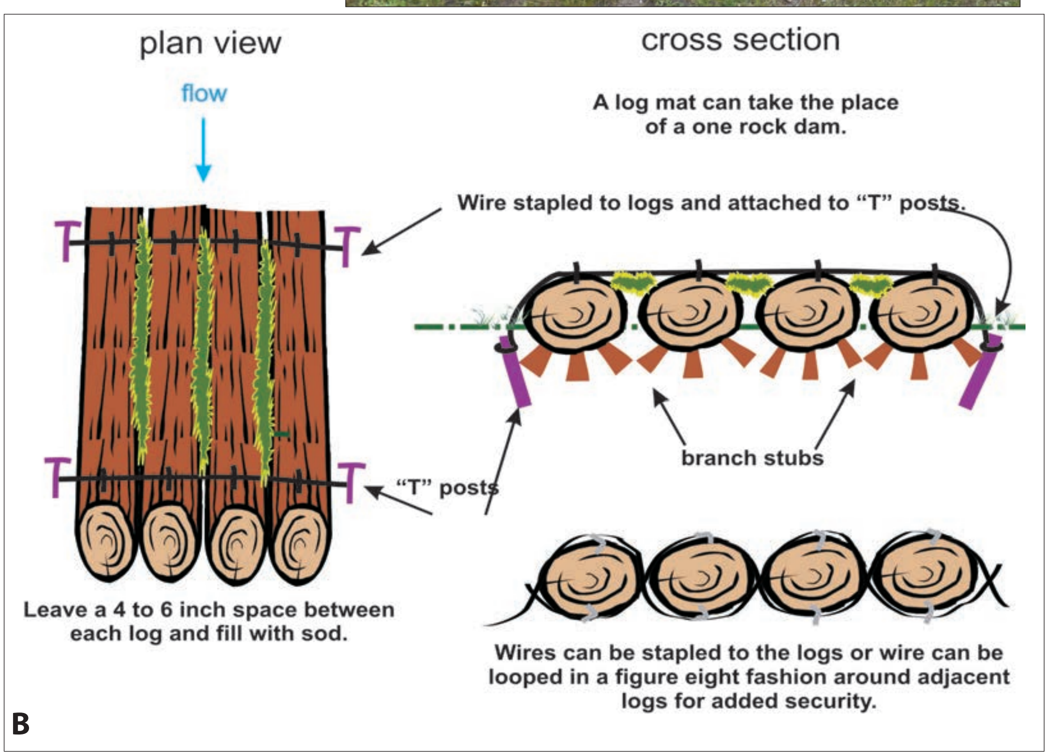


Figure 66 A. The log mat in the photograph was constructed in slope wetlands in the Springwagon Creek drainage. Figure 66 B. The schematic of the log mat shows the important features for stabilizing the mat on the wetland surface (see "Acknowledgements," page 66).

Tree Mat

The tree mat is more effective than a mat made of cut logs, but is more difficult to install. Tree limbs should be left in place on the top side of the log, but trimmed from what will be the bottom side when installed. Leaving uncut stubs on the underside increases stability of the log where it meets the soil surface. The trunk end, or cut end, should face upslope with the limbs facing downslope. Logs may be wired together, but this is more difficult when using tree–length logs. Tree length logs are more effective and more secure when wedged against the outside bank at a bend in the incised channel. Leaving limbs attached increases roughness and promotes sediment accumulation between the branches.

Obviously, the size of the tree is an important factor. Trees 6 to 8 inches in diameter and perhaps 30 feet in length can be installed by hand. Suitable equipment is needed to install larger stems particularly if the limbs are still attached. Using the weight of the equipment to press down the installed tree-length mat ensures greater stability in the face of flood flows. Once sediment accumulates in and around the stems and branches, the structure becomes increasingly secure (Figure 67).

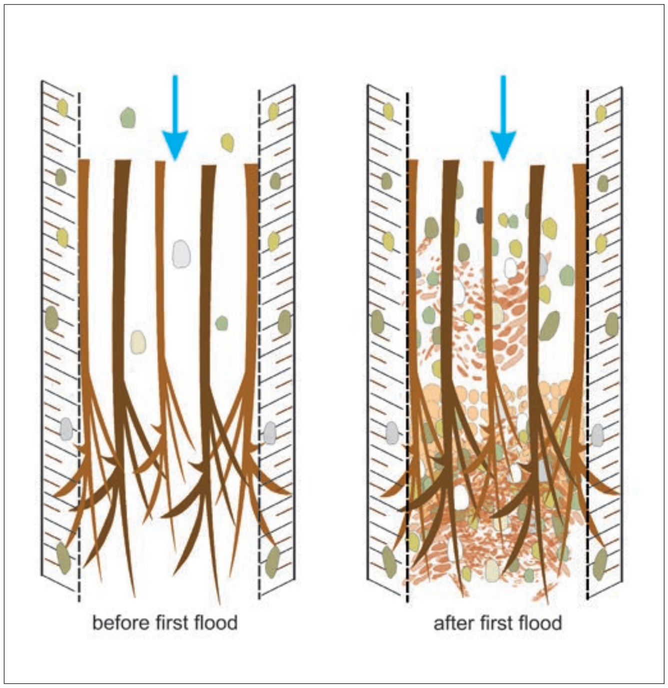


Figure 67. This schematic illustrates the effects of the tree mat on accumulating sediment (Zeedyk and Clothier, 2009).

BACKFILL (CHANNEL ARMOR)

Many gullies through slope wetlands are narrow and relatively shallow, ranging in depth from 1 to 3 feet, carrying small flows, and incised down to a gravel substrate that is not readily mobilized by the stream. Still, these channels prevent captured stream flow from dispersing across the wetland surface. Most are the result of animal trailing.

Depending on accessibility and the type of equipment used, it could be relatively easy to backfill many such channels with gravel-sized materials quarried from a nearby upland source. However, doing so would pose the risk of increased turbidity in downstream areas and would likely not be permissible under Clean Water Act regulations (404 and 401 permitting). For this reason, backfilling has not been tested as a potential tool in slope wetland restoration and cannot be recommended. Nevertheless, backfilling offers high promise as an effective treatment in slope wetland restoration and deserves to be tested under appropriate conditions and with appropriate supervision by a regulatory agency.

Backfilling could prove highly effective and very economical to implement as compared with other treatment methods currently in use. In order to not further damage the wetland surface, delivery of fill materials might require use of flotation mats, extended boom arms or cranes, delivery under frozen soil conditions, or other innovative measures.

Road Crossings

Other than animal trailing, no activity is more damaging to wetlands than roads. Roads crossing slope wetlands, and often roads traversing areas adjacent to such wetlands, can have devastating effects including the diversion or redistribution of surface and subsurface flows, channelization, incision, reduced water quality, and blanketing of organic soils under thick layers of sediment. All roads—whether simple "two-tracks," abandoned horse and wagon trails, or highly improved system roads and highways—can cause irreversible damage to wetland characteristics and function. Figure 68 shows several ways that a road crossing can be blocked or permanently closed.

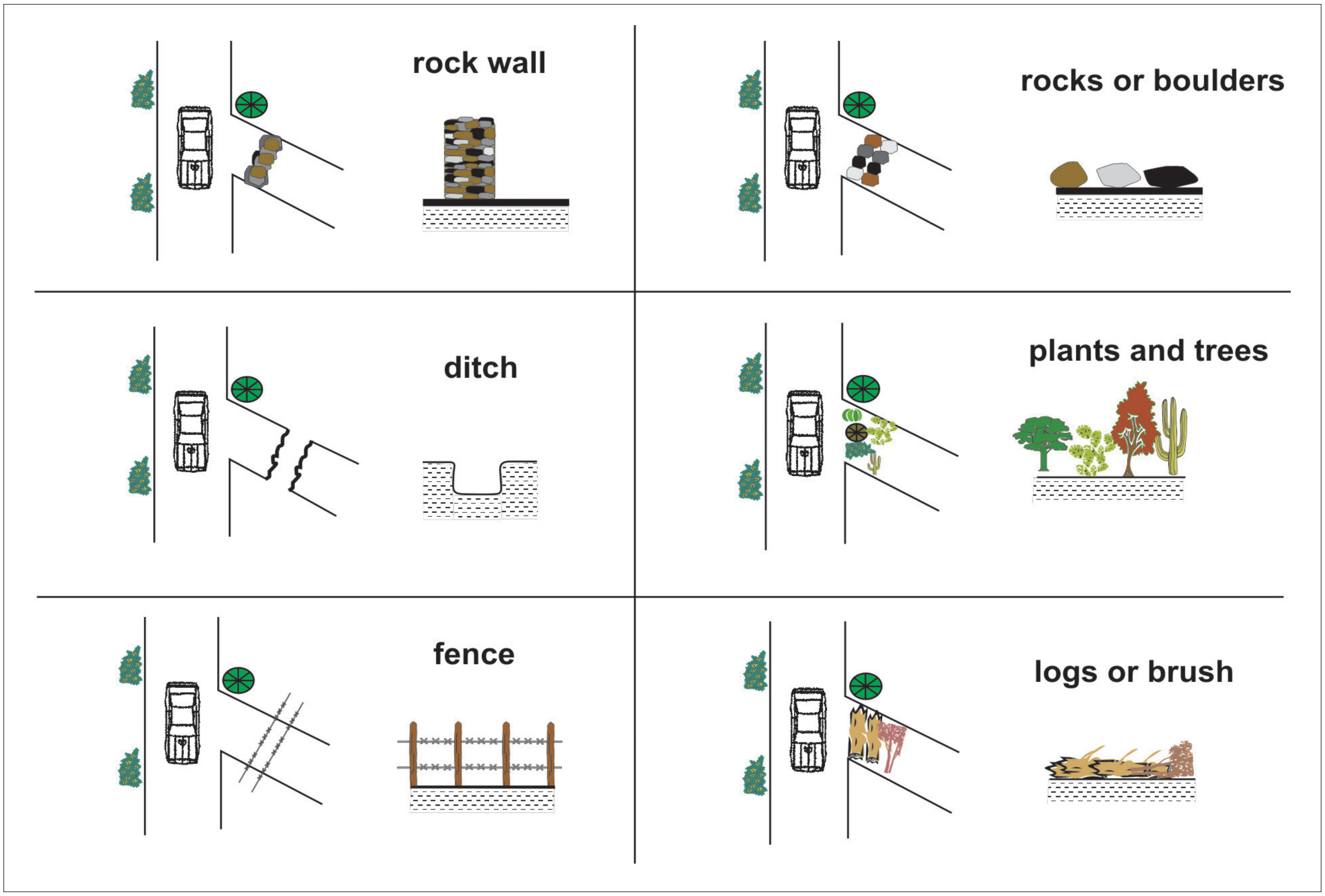


Figure 68. Methods for closing roads may be used to keep vehicle traffic off of slope wetland surfaces (adapted from Zeedyk, 2006).

Roads encroach upon and obliterate wetland surfaces. Drainage features including ditches, bridges, and culverts drain wetland surfaces and lower the water table both directly and indirectly by initiating headcut formation and migration. Roads adjacent to wetlands, even when not encroaching on the wetland surface itself, alter the course of hillslope runoff, and sediment mobilization (Figure 69).

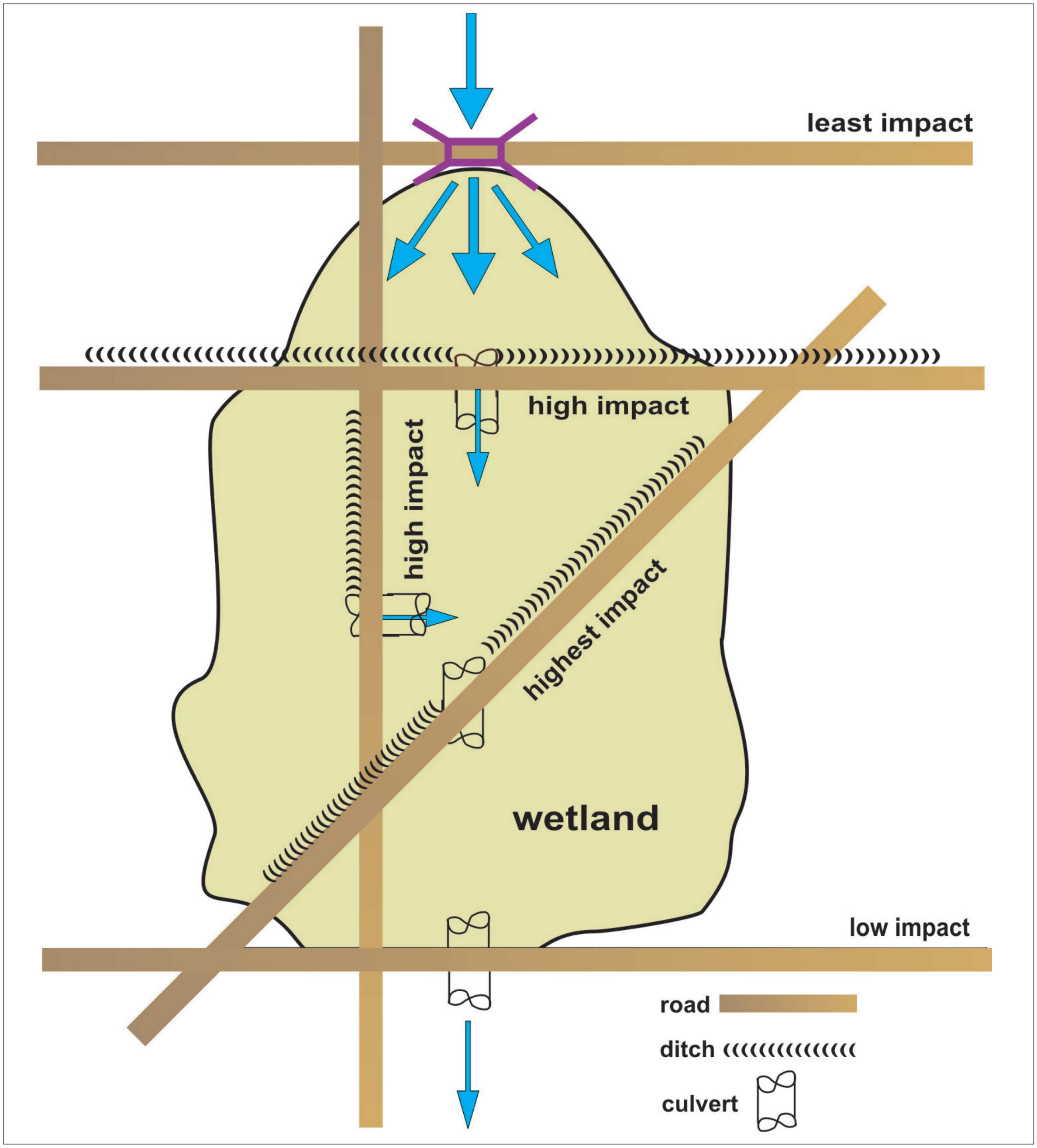


Figure 69. Relative impacts of alternative road alignments across a wetland are shown. How a road crosses a wetland changes the nature and severity of its impact.

Modifying the location and depth of roadside ditches and cross drains can be highly effective. Raising the invert elevation, placement, distribution, and outfall characteristics of culverts can be highly effective in restoring slope wetland function, and the nature and course of affected flows in order to resaturate soils and recreate lost wetland habitats.

Ditch outfalls can be treated with rock rundowns, media lunas, and contour swale applications that effectively redistribute flows across the wetland surface, rather than concentrating, accelerating, and channelizing them. Replacing culverted stream crossings with rock-lined, low water crossings can be highly effective in restoring the proper streambed elevation and reconnecting the channel with the wetland surface, both upslope and downslope of the crossing. Obliterating abandoned road-related ditches and berms from the wetland surface may be highly effective in wetland recovery.

When a road cannot be moved, elevated road surfaces crossing slope wetlands can be provided with porous sections that allow flows to move through the road fill and be evenly distributed across the downslope surface (Figure 70).

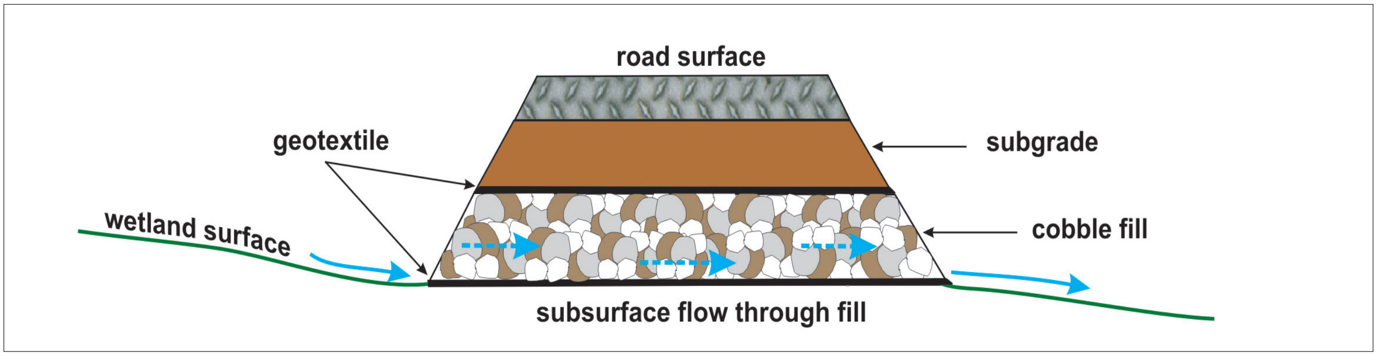


Figure 70. This schematic shows the components of a porous fill road crossing (adapted from Zeedyk, 2006).

Porous fills, such as the one shown in the Figure 70, are nicely suited for well-vegetated wetland surfaces because they transport clean water low in sediment content. They should not be used where high sediment transport is expected. Finally, ditch and cross-drain outfall locations should be carefully placed, modified, or supplemented so as to spill upslope runoff diverted by the road at optimum locations for distributing sheet flow across the wetland surface.

The treatment of offending roads and their associated drainage structures can be either stabilizing or restorative, depending on the type of impact and the nature of the treatment. The most direct treatment is to relocate and or realign the offending road segment to a less offending site on the wetland surface or out of the wetland entirely.

POROUS FILL, LOW WATER CROSSING

A road culvert has been replaced with a porous fill, low water crossing in the Grassy Creek drainage of the Comanche Creek Watershed. The low water crossing allows the creek to flow over the road and connect with the wetland below. The porous fill keeps the road from functioning as a dam. During precipitation events resulting in high water volume and velocity, the porous fill of the crossing allows for some dispersal of flow rather than concentrated flow though a culvert.

@Craig Sponholtz, Watershed Artisans, Inc., 2014

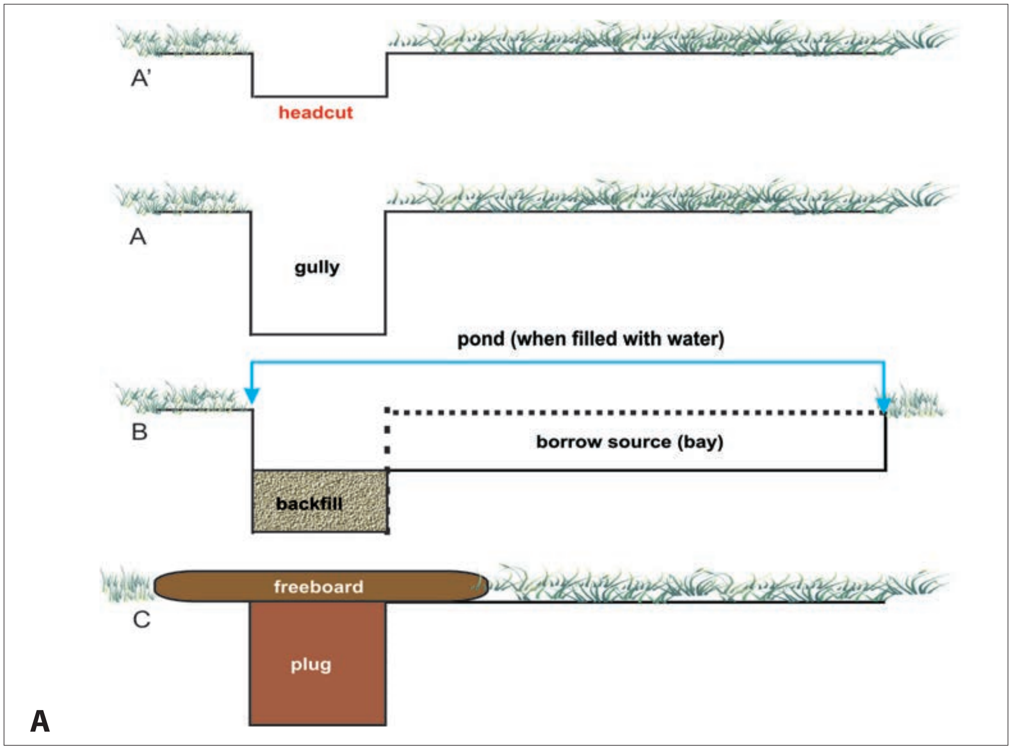
@George Long, USFS, Questa Ranger Distric, 2014

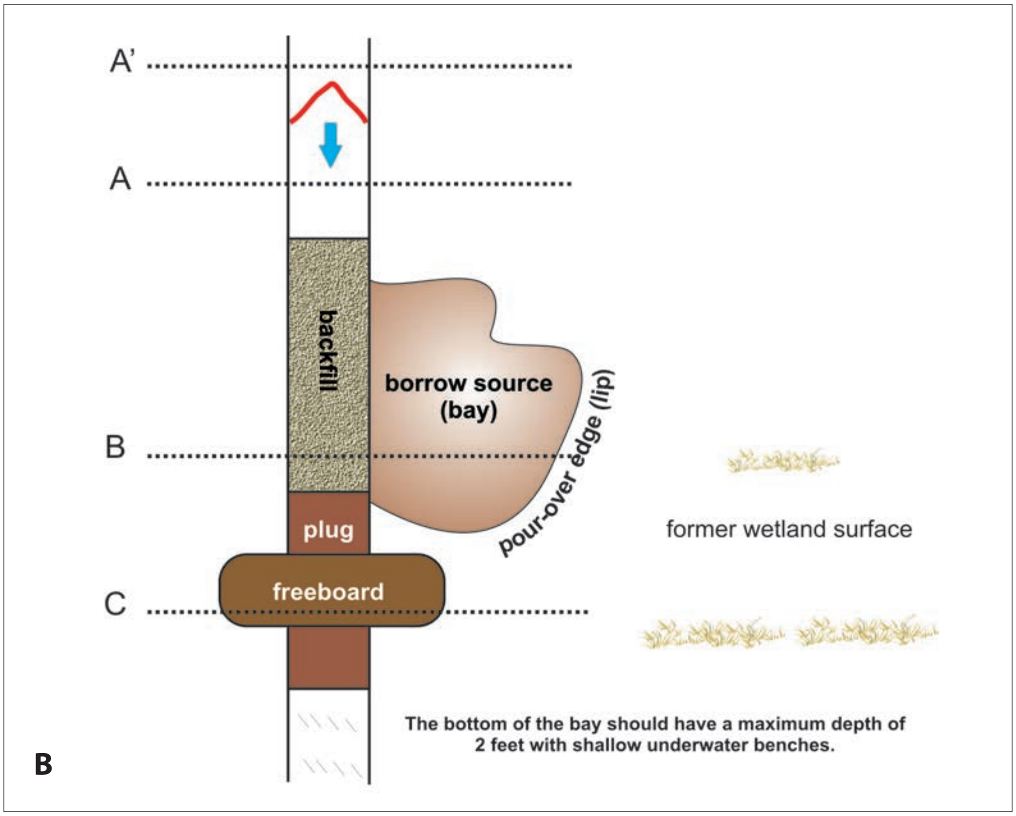
TREATMENTS FOR GULLY AND HEADCUT CONTROL

Plug and Pond

The plug and pond treatment is an ideal tool for headcut control purposes under certain conditions. In this case, the plug is installed and the borrow area is excavated so that the pour-over edge of the outlet bay is at the same elevation as the edge of the headcut (Figures 71 A and B). The resulting pond inundates the headcut and prevents further erosion of the scour pool at the base of the headcut. It also stimulates plant growth and the formation of a delta.

This treatment is only appropriate where water diverted by plug and pond can be safely returned to the downstream gully without creating a new headcut. Often this can be accomplished through the installation of another plug and pond or a drop structure, such as a Zuni bowl.





Figures 71 A and B. These schematics show a cross section view and a plan view of plug and pond components.

Zuni Bowl and One Rock Dam

The Zuni bowl is a frequently used headcut control structure. It is a rock basin built by machine or hand, using properly sized rock at headcuts ranging between 1.5 to 6 feet in height. The Zuni bowl is built on the step-falls or step-pool principle and designed to create two or more drops replacing the single drop of the original headcut.

The bowl is lined with rock to harden the bed against the erosive, scour effect of falling water. Water pooled within the bowl blunts the shear stress of the falling water, further reducing erosion of the bed and walls of the headcut (Figure 72).

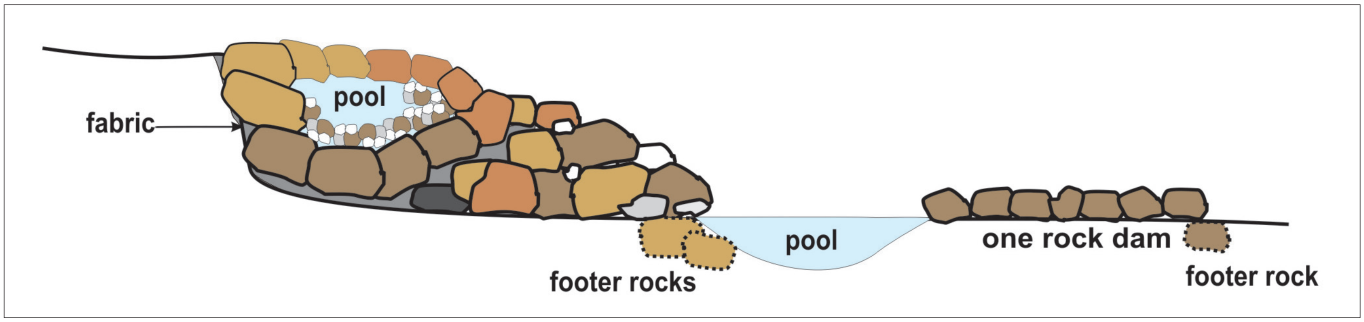


Figure 72. This schematic shows a Zuni bowl with one rock dam (Zeedyk and Clothier, 2009).

The second purpose of the bowl is to preserve soil moisture in the banks and protect the face of the headcut from drying out by promoting grass root growth. Water temporarily stored in the pool has more time and opportunity to saturate the banks and stimulate vegetation growth (Figure 73).

Figure 73 is a Zuni bowl constructed by volunteers in the Grassy Creek slope wetlands in the Comanche Creek Watershed. The one rock dam can be seen in the photograph. Below the pool is a sod plug which is helping to slow water flow through the incised channel below the headcut and rewet the slope wetland surface.

A Zuni bowl up to 3 feet in height with a single bowl can be built by hand using 10 to 50 pound rocks. Zuni bowls larger than this must be built with heavy equipment. Angular rocks are preferred and care should be taken to properly place them so that the will key into each other. Construction begins with shaping the base and walls of the headcut to remove loose material, rocks, roots, etc. The sides and back wall are laid back on an approximately 2:1, slope and a footer trench is dug. Flatter rocks are placed in the trench as an apron to dissipate the force of water pouring out of the bowl.

Next, a rock dam is built with its downstream edge resting on the upstream edge of footer rocks. The dam can be from 1.5 to 2 feet tall and 3 to 4 feet through, tightly fitted bank-to-bank. After the dam is built, the bottom of the evolving bowl is lined with rock. Finally the sides and backslope of the bowl are lined with rock to the height of the cut but not higher. It is critical that each layer of rock is fully supported by the rocks below and that each layer lean into and be partially supported by the banks.

A Zuni bowl, 6 feet wide by 10 feet long by 4 feet high and creating a single step fall, will require about 3 cubic yards of rock to build. A second pool is created by installing a simple one rock dam downstream from the Zuni bowl. The upstream edge of the one rock dam should be approximately 6 to 8 times the height of the falls downstream from the footer rocks in the bowl.

Log and Fabric Step Falls

Log and fabric step falls can be built as an alternative to a Zuni bowl, particularly if a sufficient numbers of freshly cut green logs are available. In addition to logs, geotextile fabric, smooth wire, staples, and steel T-posts are required (Figure 74).

This type of structure is practical for headcuts up to 4 feet in height and can be built by hand using 3 to 4 tiers of logs, 8 to 12 inches in diameter. Logs on the bottom tier can be 10 feet long; second tier, 8 feet long; third tier 6 feet, etc. The top tier should be a bit longer and should overlap the natural surface elevation above the edge of the headcut.

To keep the backslope moist and to capture finer soil particles, a layer of geotextile fabric is placed between the logs and the face of the cut in successive layers. The logs should be wired together and anchored in place with at least 4 steel T-posts driven into the banks. It is important to place the upper tier of logs in such a manner that flood flows are focused to fall on the structures and not go around it. If constructed of green aspen logs or a decay-resistant species such as Douglas fir, structures can be expected to function for 20 years or longer.

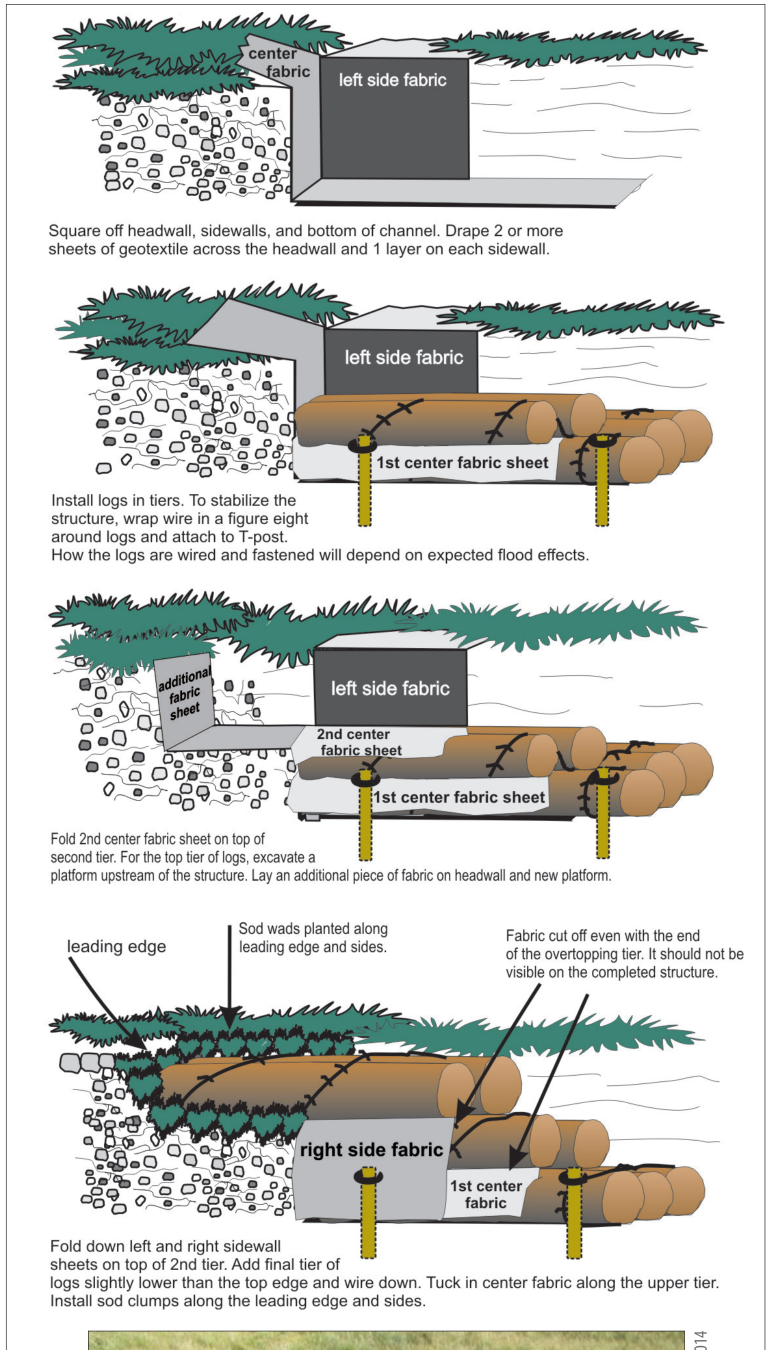


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Figure 74. The log and fabric step falls schematic shows the detail of material placement (Zeedyk and Clothier, 2009). The log step fall in this photograph was built by volunteers in the Grassy Creek slope wetlands.

Rundowns

Rundowns, whether rock, log, or log and rock, are used to halt the upstream progression of shallow headcuts usually less than 2 feet in height. Rundowns achieve the two primary objectives of a successful headcut control structure, to 1) prevent formation of the scour pool, and 2) maintain the health and vigor of grass and grass-like vegetation at the edge of the pour-over, protecting the soil from further erosion. The first objective is met by creating a hardened surface for falling water to spill onto, thus preventing erosion of the scour pool. The second is met by sheltering soil at the edge of the falls from the drying effects of sun and wind, therefore protecting the soil and holding it intact.

Rock rundowns usually extend some distance downstream of the headcut, usually 10 to 20 feet, and fill the gully from edge-to-edge in order to accommodate water flow of any magnitude. Spaces between the rocks accumulate sediment, organic debris, and seeds, which produce mulching effect that promotes rapid revegetation. The same is true for other types of rundowns.

Log and Rock Stepdown. A log and rock stepdown is a headcut control structure that converts the vertical face of a headcut into multiple low "steps" that stop headcut erosion by bridging the area above the headcut to the incised channel and dissipating flow velocity. This treatment is particularly useful where there is a steep grade change at the toe of a slope wetland, which if not stabilized, results in a headcut that will drain the water stored in wetland soils.

Each step is constructed with a log that spans the incised channel at a wide angle (approximately 60 degrees) so that the upstream portion of the log is the lowest part of the step and the downstream portion of the log is the highest part of the step. The logs can be anchored into the banks by placing small boulders where the logs overlap or by using rebar to pin the logs together. This structure is a long-term solution to headcut stabilization that blends well into the surrounding environment (Figure 75). Ultimately, this type of structure will allow large amounts of vegetation to establish around and between the logs, creating stable and gradual steps where a headcut had been.

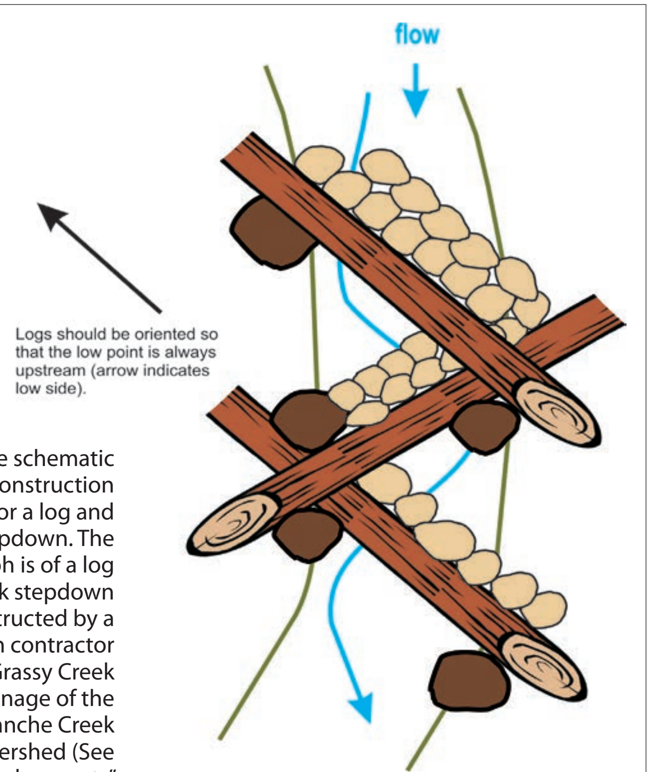

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Figure 75. The schematic shows construction details for a log and rock stepdown. The photograph is of a log and rock stepdown constructed by a restoration contractor in the Grassy Creek drainage of the Comanche Creek Watershed (See "Acknowledgements" page 66).

Rock Rundown. The rock rundown is the simplest and most basic of all headcut control structures but for wetland purposes, its use is generally limited to headcuts less than 2 feet deep. Its purpose is to prevent further erosion by armoring the face of the headcut and the bed of the channel at the front where the falling water impacts the bed.

Rocks used to armor the bed must be large and heavy enough to resist being washed away. Rocks are usually placed in a single layer reaching from bank to bank and extending downstream 6 to 8 times the height of the drop (Figure 76). Installing a row of footer rocks at the downstream end of the structure is recommended.

Headcuts progress up valley as the vegetation protecting the soil at the edge of the pour-over weakens and dies. As the plants die, their roots no longer bind the soil, which crumbles and dries in the sun, becoming more vulnerable to erosion. Rocks should be carefully placed with their top surfaces flush with and tightly against the edge of the pour-over. This will conserve moisture, reduce evaporation, maintain plant vigor, and hold the soil in place, thus stopping headcut progression.

Figure 76. This rock rundown was constructed in an arid environment; however, the same design and construction principles would apply for a slope wetland stabilization treatment.

Log Rundown. Like the rock rundown, the log rundown can be simple to build and highly effective if properly installed. It is most suited to incised channels and gullies through slope wetlands with headcuts less than 2 feet tall (Figure 77).

Figure 77. Log run downs may be used when the headcuts are shallow and in low energy systems. These log run downs are used to stabilize slope wetlands in the bottom of a gently sloping valley.

To build a log rundown, logs up to 12 to 14 inches in diameter should be cut into lengths of 6 to 10 feet, if handled manually, or longer if handled by equipment. Logs are placed side-by-side across the gully and flush with the face of the headcut. It may be necessary to trim the edge of the headcut and face with a pick or shovel to secure a tight fit. Leaving branch stubs up to 1 foot long attached to the logs will help to anchor logs in place while also trapping sediment during runoff events. Usually logs should be only a single layer deep and wedged tightly together.

Depending on the timing and intensity of flow events, vegetation will quickly become established between the logs, along the banks, and at the pour over edge. Vegetation will trap and retain sediment and debris, and form a binding sod that will prevent further headcut migration.

HOOF-SHEAR REMEDIATION FOR DAMAGED FENS

Fens are damaged mostly by animal trailing (see page 41, Figure 49 A, B, C and D in Chapter 5). Any headcut in a fen may be stabilized by the structures listed in the sections above. Within a slope wetland, prioritizing stabilization of the fen component of the complex is essential. The techniques described below are largely preventative. They are ways to “rest” the surface of the fen so that hoof-shear does not result in headcutting, thereby draining the artesian source of water that creates and maintains fen structure and vegetative composition.

Hoof-shear, resulting in pedestaling and hummocking, can be extremely damaging to fens in particular, as well as to saturated wetlands and streamside areas. Fens are composed of peat (highly organic soils). Hoof-shear causes the peat to be cut into isolated clods and lifted above the fen surface, where it is subjected to drying and oxidation by sun and wind. Oxidized peat disintegrates into carbon dioxide and simply blows away. It is not washed away by erosion (Cooper et al., 2005).

Various techniques are modestly effective in preventing hoof-shear. No treatments have proven fully effective in restoring damaged sites to the pre-disturbance condition. However, a combination of many of the treatments listed is showing promise in the early stages of fen restoration in the Grassy Creek slope wetland complexes in Comanche Creek Watershed.

A remedial treatment has been attempted which involves salvaging individual clods and placing them in shallow pits or in close proximity to other clods so as to reduce air circulation and prevent further drying and oxidation. At some locations, it has been possible to reflood the damaged surface so as to restore anaerobic conditions in the subsurface soil layers. The results of such treatments will be evaluated in the coming years.

Coverings

Treatments used to limit animal access to prevent or reduce further damage include covering damage sites with brush or tree limbs or installing drift or exclosure fencing. Often when a hoof-shear area is covered, another will be created as elk and cattle begin to use an adjacent area. This treatment has a limited effectiveness, but may allow recovery in areas where grazing can be intensively managed (Figure 78).

Brush used for coverings has the advantage of decaying back into the landscape over time. Of course, this is also a disadvantage, if deterrents to livestock and elk use are needed for longer periods of time. In this instance, drift and exclosure fencing are the recommended options.

Photo Series ©Mollie Walton, Quivira Coalition, 2013

Figure 78. Cut trees and brush are used as a livestock and elk deterrent in the Springwagon Creek slope wetland complex, where livestock and elk overuse is damaging the fens.

Drift Fence

Figure 79. The photograph shows a drift fence constructed to discourage use of an existing trail across a slope wetland near Gunnison, Colorado.

A drift fence is used as an obstacle to livestock movement to prevent trailing in or alongside a slope wetland complex. Drift fences are not exclosures: livestock still have access to graze the wetland vegetation but the habit of trailing up and down the bottom of the valley from prime grazing area to water sources is blocked. Because livestock trails in the bottom of the valley tend to evolve into gullies, drift fences are a useful tool for both stabilization and restoration of slope wetlands. Because drift fences are obstacles, they need not be cattle or wildlife proof and can be built to a different standard than the typical four-wire pasture boundary fence (Figure 79).

The most important features of the drift fence is that they are highly visible and resistant to damage by cattle and elk. A three-strand, smooth wire fence has proven successful with wires placed approximately 20, 30 and 42 inches above ground elevation. Wires are mounted to T-posts driven at 12 foot intervals with two highly visible wooden stayes placed at 4 foot intervals between adjacent T-posts. All drift fences to date have been 100 to 300 feet long to span the width of the valley.

In addition to being highly visible, drift fences should be properly placed in relation to travelling behavior of cattle and to a lesser extent elk, especially the ends of the fences. This means that each end of the fence should terminate on a flatter rather than steeper land surface such, as a bench or terrace where livestock might normally trail. Cattle tend to select for the flattest and easiest grade. Finally, it is important not to locate fences where terrain would cause cattle to be "bunch up" and "mill around" by preventing their easy access up and down valley.

At a restoration site near Gunnison, Colorado, following installation of a drift fence, immediate positive results were observed (Figure 80). Cattle have stopped moving up and down the valley bottom and long-used trails have begun to revegetate. Even though cattle are not excluded from areas between adjacent drift fences, grazing intensity diminished and utilization of wetland vegetation was greatly reduced.

A variation on the drift fence concept could be a short spur fence built perpendicular to a pasture fence where cattle had been trailing along the fence. Such a spur can force cattle to change their habits to avoid a key area, such as a spring or evolving headcut.

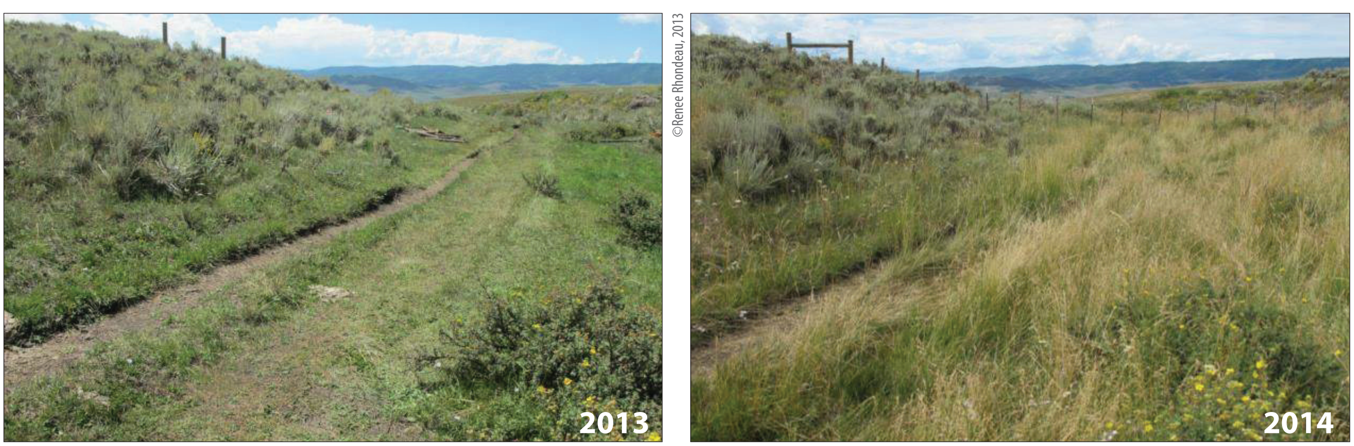

Figure 80. These photographs show a slope wetland area before the 2013 installation of a drift fence and after recovery in 2014 (Gunnison Sage Grouse habitat restoration project, Gunnison, Colorado).

Exclosure Fence

Exclosure fences can be used to exclude livestock—and to a lesser extent elk—from wetlands or a key area within a more extensive wetland, such as a spring or fen. Because an exclosure fence must be livestock proof, including sheep, goats, and calves, exclosures should be built of woven wire or to the same standard as a pasture fence (Figure 81). If the goal is to exclude elk, it may be necessary to construct a taller woven wire fence. In many instances, if an area is not excluded from grazing, many stabilization and restoration structures will ultimately fail to yield the desired results in the absence of managed grazing.

Figure 81. This photograph is of a cattle exclosure in the Springwagon Creek drainage in the Comanche Creek Watershed.

The primary concern with exclosure fences is the obligation to commit to annual maintenance and repair on a long-term basis. Exclosures may also present a hazard to wildlife, such as deer, elk, wild turkey, and other species especially if woven wire is used in their construction. Exclosures are often necessary, but long term maintenance may be an issue.

Exclosure fences have been used to protect wetlands in many areas such as Navajo Nation National Historic sites. Small exclosures used to protect springs and spring seeps have been commonly used on National Forests, Bureau of Land Management lands, and elsewhere. Recently, fens have been protected with exclosures on the Valles Caldera National Preserve.

CHAPTER 7 **CONCLUSION**

The characterization of the myriad of slope wetland types represented in the New Mexico landscape is in its early stages. The restoration of slope wetlands and alluvial fans is recent and innovative in concept and technique. While there is much research on the reconnection of stream systems and their floodplains, the restoration of dispersed flow across slope wetlands and alluvial fans is key. Capturing, slowing, spreading, and infiltrating water as high up on the landscape as possible is essential to headwater slope wetland stabilization and restoration. The slope wetlands that are the subject of this publication are linked to, or have their origins, as alluvial fans. Characterization of headwater slope wetlands, as contained in this publication is the beginning of a process that will actively encourage more scientific research and analysis. The restoration of slope wetlands and alluvial fans in mountainous and in arid environments is crucial in the role they play influencing the quantity and quality of downstream hydrologic systems, supporting sustainable ecosystems, as well as buffering the effects of climate change.

Ecological and geomorphic benefits derived from wetland restoration treatments are cumulative and interactive as one proceeds down valley. Water spread across the wetland surface is recaptured and redirected by the next structure downslope, multiplying the benefits. Therefore, when designing a project, structures should be located, sized, and shaped so as to function in support of each other or as a complex—not independently as a series of unrelated structures.

A holistic approach should be implemented including appropriate management of roads and trails, timing, intensity, and duration of grazing use; and removal of incompatible barriers such as abandoned ditches, berms, culverts, etc. The reality of restoration work is that success is completely dependent on the next rainstorm, timing and intensity of successive grazing episodes, and many other conditions that will differ from site-to-site and time-to-time.

Once incision exceeds a given depth, treatment options become heavy equipment based, increasingly expensive, and more problematic to implement. It is recommended that priority be given to stabilizing less damaged sites first. Some can be addressed successfully with currently known stabilization and restoration treatments; others cannot. Some can be accomplished by hand, using the services of enthusiastic volunteers.

Continued advances in the science and art of restoration are called for, particularly with regard to alluvial fans. Treatment should focus on preventing further incision, protecting and reestablishing dispersed flow where feasible; controlling or eliminating new or evolving stressors, where possible, and monitoring results. The primary goal of restoration is to reestablish dispersed flow across historic slope wetland surfaces while recharging the shallow groundwater aquifers associated with them. By understanding the processes that govern water flow in alluvial fans and slope wetland complexes, restoration practitioners will be better able to address the critical water storage functions that these landforms provide while sustaining a broad range of ecosystem services into the future.

POST-TREATMENT ASSESSMENT AND MONITORING

Post-treatment assessments of the landscape in general and stabilization and/or restoration structures in particular is an essential component of any project. In order to do a post-treatment assessment, it is necessary to have baseline data. Most often, these data are in the form of pre-treatment photographs. It is important to remember that the treatment for wetland stabilization or restoration has to do with spreading water out over the landscape and returning the system to one with dispersed flow rather than channelized flow. Assessing treatment efficacy requires the establishment of photopoints that show a landscape level view and not just photopoints at treatment structures.

Often funding sources do not provide enough money to pay for detailed pre-and-post project monitoring Therefore photopoints are the most cost effective way to document change as a result of treatments. A post-treatment photograph alone does not provide enough information on stabilization or restoration structure functionality. There is no substitute for field observation and assessment.

Structures should be revisited after one full year of exposure to the hydrologic cycle. In any system there will be mostly minor adjustments that are necessary for the structure to function as intended. Proper training and design and building skills are critical to the function of any restoration or stabilization structure. Restoration practitioners and volunteers need oversight and training. Water has a mind of its own and may not choose the path that the restoration team intended for it to follow. Minor adjustments can be made to structures to correct for this.

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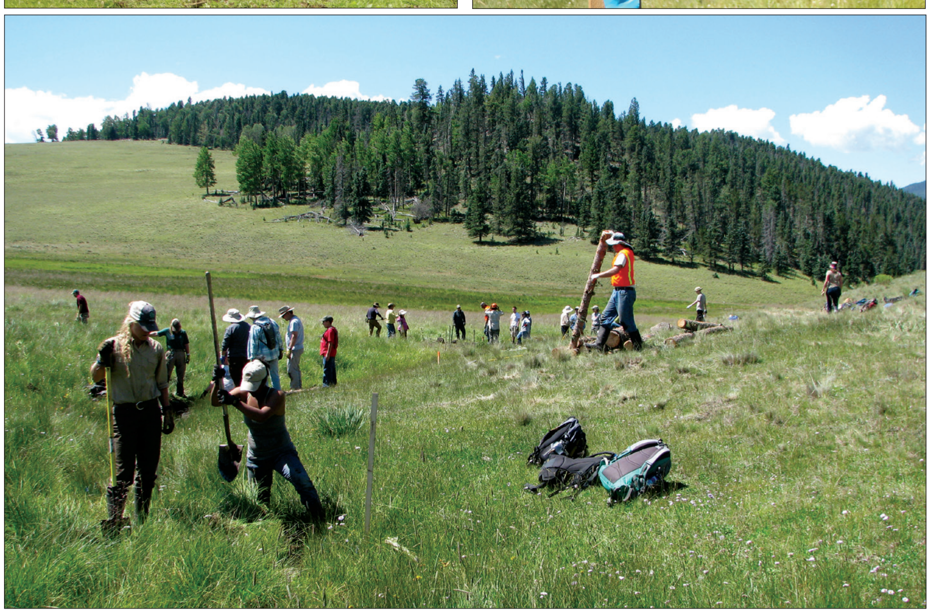
Photo Set ©Virgine Pointeau, Quivira Coalition. 2013



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