Wetland Restoration Technical Guide Using Innovative Sod Structures

Santa Fe, New Mexico
2023

Our Partners

New Mexico Environment Department

Keystone Restoration Ecology

Rio Puerco Alliance

Valles Caldera National Preserve

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We also want to give a big thank you to BadDog Design of Santa Fe for their wonderful graphics illuminating the innovative sod techniques described here.

A number of organizations have accomplished significant wetlands restoration work in the East Fork Jemez Watershed, including Los Amigos de Valles Caldera, Albuquerque Wildlife Federation, the New Mexico Volunteers for the Outdoors, and Rio Puerco Alliance, aand Zeedyk Ecological Consulting. We look forward to continuing restoration work throughout the southwest with these wonderful partners.

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Front COVER PHOTO: Courtesy of Steve Vrooman.

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List of Acronyms

Acronym	Full Name
ACOE	United States Army Corps of Engineers
CFS	Cubic Feet per Second
EARTh™	Erosion Analysis and Restoration Techniques
FAC	Facultative
FACW	Facultative Wetland
GIS	Geographic Information System
KRE	Keystone Restoration Ecology
LANL	Los Alamos National Laboratory
LiDAR	Light Detection and Ranging
Los Amigos	Los Amigos de Valles Caldera
NM	New Mexico
NMED	New Mexico Environment Department
NHNM	Natural Heritage New Mexico
NPS	National Park Service
OBL	Obligate
SWQB	Surface Water Quality Bureau
Tc	Time of Concentration
UPL	Upland
U.S.	United States
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Service
VCNP	Valles Caldera National Preserve

Technique Graphics and Pictures

Introduction

The restoration techniques described in this guide have been developed in a series of projects, over the last 16 years, working on the Valles Caldera National Preserve of the National Park Service.

Restoration ecologists in the Southwestern United States have developed techniques to restore rangelands, wetlands, and streams with hand or machine-built techniques using native materials. An assortment of techniques are described in "Induced Meandering" (Zeedyk and Clothier, 2014) that were developed by Bill Zeedyk and colleagues. These techniques use the power of flowing water to re-direct the water and direct sediment deposition. The wet sediment captured and stored by restoration structures grows vigorous groundcover and grasses that attenuate floodwaters and allow the water to infiltrate soils. Over time, deposition of sediment and growth of vegetation supplants the original structure while enhancing its function, creating a positive feedback loop of aggradation of sediment, and restoration and recovery of riparian grasses and wetland species.

"These techniques all use native sod and soil."

Another effective technique for restoring channelized grasslands, wetlands, and alluvial fans is the plug and pond method. The "Pond and Plug" treatment for wetland restoration in perennial systems was initially developed by Dr. David Rosgen for application in lower elevation meadow systems in north central California (Wilcox, 2010). The method involves creating plugs (dams) of soil and vegetation at specific locations in incised channels to divert stream flow back into abandoned channels, wetlands, or alluvial fans. A pond is formed by excavating material for the plug; it then fills with water, raising the water table. The plug stops sediment that is carried in the incised channel, and back fills the channel, raising bed elevation to the floodplain or alluvial fan surface (Hammersmark 2008, 2009a, 2009b), creating a positive feedback loop of regeneration.

Projects

1.Restoring Wetlands & Wet Meadows on the VCNP

2. Continuing Restoration Work on San Antonio Creek

3. Restoring San Antonio Creek

4. Restoring Jaramillo Creek

5. Reducing Temperature and Turbidity on San Antonio Creek by Restoring Slope Wetlands on Six Tributaries

6. Innovative Restoration of Historic Wetlands along Sulphur Creek

7. Restoring Hydrologic Functioning to Rito de los Indios

8. Restoring Roads and Streams in the San Antonio Watershed Damaged by the Las Conchas Fire

9. Restoring La Jara Creek from Damage from the Thompson Ridge Fire

10. Restoration of Slope Wetlands from Wildfire in the Valle Grande

11. East Fork Jemez River Innovative Wetland Restoration Project Using Contour Swales, Sod Bowls, and Sod Berms

12. Lower Jaramillo Creek and Wetland Restoration River Stewardship Project

(13. San Antonio Creek Headwaters and Erosion Control Project)

See complete information in Bibliography.

The techniques described in this guide address erosion and incision caused by headcuts and gullying of 1st order tributaries and slope wetlands. Slope wetlands includes ground-water fed wetlands (springs) with unidirectional flow. Headwater slope wetlands are the same in the headwater position within a watershed (fens). The techniques are based on the work of Rosgen, Zeedyk, and others. Restoration of the smallest tributaries has been proven to have a significant impact on watershed function at the Valles Caldera, and begins at the top of the watershed and proceeds downslope. Watersheds have similar patterns at many scales, and these techniques have focused on working on the smallest scale possible and at numerous locations.

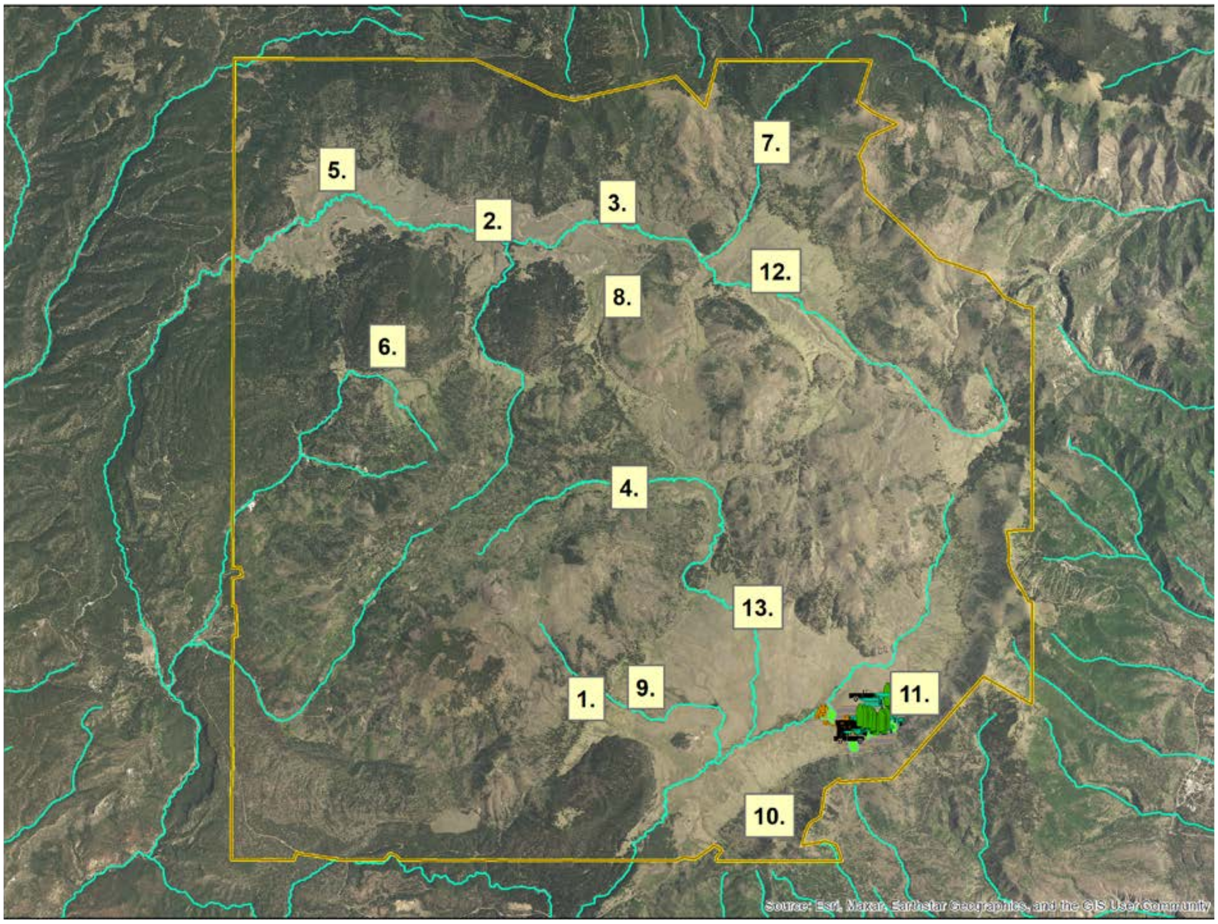
Incision and Gullying. Incision can be due to a number of factors, one of which is headcutting upward from the lowering of the base level of the "master stream." Water falling into a creek at a lower elevation begins a headcut, or "headward" cut. Headcutting proceeds upward into tributaries and slope wetlands, creating gullies, lowering the water table, and drying out the wetland surface.

Another cause of erosion is overgrazing and overall loss of soil cover, leading to an increase in runoff and a decrease in time of concentration (Tc). Additional runoff flowing quickly into channels will overwhelm the capacity of the channel or wetland and cause gullying, lowering of the water table, and additional runoff from the loss of vegetative cover from the dried-out former wetland surface.

A particular focus of this guide is stream capture, which is a phenomenon where part of the drainage of one stream is captured by another, faster eroding stream. In this case, the drainage which has captured the flow will erode due to the doubling or more of flow. The abandoned wetland or swale will dry out and change from wetland to upland vegetation. These locations can exist landscape-wide, and are usually due to livestock trails, fence lines, and old wagon roads. Most of the major gullies and headcuts on the Valles Caldera are due to this process, and old wagon roads in particular can capture many streams or wetlands and concentrate this water where the road changes grade or direction. Locating stream capture situations and treatment of these watersheds is a powerful restoration tool made much easier by modern GIS analysis techniques using LiDAR.

These techniques all use native sod and soil. Various types of ponds, swales, and diversion structures have been designed to be constructed in a relatively short time, using low-impact rubber-tracked machinery. The machinery harvests the wetland or upland sod, constructs a structure from the underlying soil, and replaces the sod on top.

Los Amigos de Valles Caldera, Keystone Restoration Ecology, and the Rio Puerco Alliance have worked (or are still working) on 13 projects since 2007 on the Valles Caldera National Preserve. We have brought in over $2,000,000 in government (NMED/USEPA, Forest



Numbers show locations of Projects listed on page 2.

Service, and State of New Mexico) and foundation support (Wildlife Conservation Society) to restore wetlands, repair streams damaged in fires, reduce temperature, restore hydrologic functioning on various streams, and more. See Projects Sidebar to the left and the map above.

This guide will outline the design process, the purpose of these sod restoration structures, and how to implement them, and will present results from the projects implemented in the Valles Caldera. This guide is part of *East Fork Jemez River Innovative Wetland Restoration Project Using Contour Swales, Sod Bowls and Sod Berms*, which was completed in 2023.

Restoration of Wetlands

Watershed restoration is a broad term including many practices, techniques, and materials. The term "restoration" itself implies that the purpose of the work is to restore the landscape or ecosystem to a condition from which it has departed. Determining this original condition is one of the major tasks of restoration, as the original watershed condition developed on the landscape over the past 10,000 years since the last ice age, and may provide habitat for a community of plants and animal species found nowhere else.

A channel or landform showing resilience for thousands of years through drought, fire, and flood should be not only the best habitat, but have the geomorphology and vegetation that best suits the site. This channel can be described as the statistically "probable natural state," the "equilibrium channel," and "naturally stable channel" (Rosgen, 1997). The practice of "Natural Channel Design" looks to re-create the stable channel form both to restore native functioning habitat and to resist erosion, fire, flood, and drought.

The question of original condition, however, is very difficult, and in the Southwestern United States, many major ecological changes have occurred that obscure the "original condition" of a channel or landform. The departure from the hypothetical "stable condition" can be thought of as being due to human influences, or large disturbance events such as wildfire, landslides, or catastrophic weather events.

Human Influences. Beaver were removed from the landscape in the 1800s as the Santa Fe Trail brought mountain men, and beaver trapping was at its peak. Many landscapes were denuded of beaver from the 1820s to 1900, when most beaver populations had declined to marginal amounts. The beaver population was trapped out long ago and even their remnant dams in the Jemez Mountains are difficult to discern (Martin, 2003).

Sheep grazing in the Jemez Mountains in the 1930s.

Grazing of sheep in huge numbers began in the late 1800s and continued through the Second World War, when the availability of sheepherders decreased as young people went to school and joined the formal labor force. Restoring to pre-1880s conditions would be ideal but little information exists to describe landscape form and function prior to this time.

Cattle became the dominant livestock on the landscape after the Second World War, and continued until the early 1990s. Over 5,000 head of cattle were grazed on the Preserve in the summer months, and these caused important and long-lasting changes to the watersheds of the Preserve (Martin, 2003).

Cattle move as creatures of habit, and tend to "trail" along behind each other on the same paths. As these paths become beaten down to dirt, they become the easiest path for both cattle and water to move downhill on the landscape. In addition, heavy cattle grazing pressure changes the native grassland plant community to one dominated by non-native grazing-tolerant species such as Kentucky bluegrass *(Poa pratensis)*, Yarrow *(Achillea millefolium)*, Dandelion *(Taraxacum officinale)*, and White Dutch Clover *(Trifolium repens)*.

Elk and cattle grazing in the Valle Grande.

Wildlife. Elk are a huge component of the biota at the Valles Caldera National Preserve, but were extirpated in the late 1800s. In 1947, elk from Colorado and Yellowstone were reintroduced, and the Elk herd grew rapidly due to limited human hunting and predation from wolves.

Elk numbers were never so high in the past, and while we know little of the past biota on the landscape, it appears that deer were the dominant grazing animal on the Preserve. Elk trailing and wallowing have large impacts on wetlands, with wallowing causing headcutting up many small spring-fed channels.

Wildfire. Fire was an important tool on the landscape used by Native American communities and continued by Spanish settlers, but began to end with the establishment of the U.S. Forest Service in 1905. By 1935, the policy was that a fire start had to be put out by 10 a.m. the following day, and wildland fire fighting began in earnest. Due to this, tree numbers and density began to climb, and plant communities maintained by fire diminished. Understanding plant community dynamics and tree numbers and how watershed yield has responded to fire would provide important information on how watersheds originally functioned, as water quantity is an extremely important part of plant community dynamics and watershed function.

Beginnings of the Thompson Ridge Fire.

In current times, the impacts of Global Climate Change are leading to extremes of both drought and precipitation, which provides an additional factor to obscure this idea of "original channel condition."

If the landscape has changed so much in the previous 140 years due to human impacts, the original stable channel form may not be stable under today's land conditions, management, and climate.

If conditions have changed too far that it is difficult to ever identify the historic condition, what can be used to replace it? The idea of a "stable, functioning channel" under current watershed conditions is one concept that can be used to lead restoration planning and implementation. Restoration can be thought of as restoring natural function, stability, and biological condition (Rosgen, 1997). The treatment of channels with natural materials mimicking natural forms and function can be used to create a channel or wetland that provides habitat, resists erosion, spreads and stores water, and provides ecological functions that are suitable to current watershed, land use, and climate conditions.

Tributaries, Sheet Flow, and Slope Wetlands

In terms of small tributary channels and slope wetlands, the original condition of the landscape can be inferred by careful observation, i.e., "reading the landscape." Many of these small channels have been gullied due to overgrazing, road building, and human activities that have degraded the landscape over time. Simple overgrazing by cattle creates a Kentucky bluegrass plant community with shallow roots, not resistant to erosion, and can lead to gullying.

The smallest gullies on the landscape can be important concerns in terms of water movement across the landscape. In this high altitude ecosystem, most of the water storage and baseflow comes from snowmelt, which builds up throughout the winter and gradually trickles out from March through late May as "interflow," the lateral movement of water in the unsaturated zone that returns to the surface or enters a stream. Interflow occurs when water infiltrates into the subsurface, hydraulic conductivity decreases with depth, and lateral flow proceeds downslope. As water accumulates in the subsurface, saturation may occur, and interflow may exfiltrate as return flow, becoming overland flow.

A small gully caused by cattle or elk trailing or a historic road or trail can be only one foot across. However, on a sloping landscape, this small gully can carry away vast amounts of snowmelt that would otherwise be infiltrated into the unsaturated colluvial sediments and returned to streams or wetlands downslope.

A channel 12 inches wide and 2 inches deep (0.16ft^2) x 4 feet per second can carry away 0.66 cubic feet per second (cfs). Over a period of a week, a moderately sized trail can carry away 5 gallons a second, 18,000 gallons an hour, or 2,993,000 gallons a week. In a week or two of snowmelt runoff, much of the snowpack on the landscape can be carried downstream to the streams and rivers rather than being stored and slowly relased through the soil.

Restoration of Geomorphology

In a dry, high mountain landscape with overlapping historic impacts, numerous gullies and trails, and loss of native wetland plants and topsoil, the landscape has lost much of its original form and vegetation. Returning the landscape to its original geomorphology would require the quarrying and movement of thousands of tons of soil that have been lost to wind and water erosion in the last 140 years.

However, restoring the natural hydrology of the site can have a hugely positive impact on vegetation, water storage, and the overall watershed. Spreading snowmelt out of gullies back on to natural landforms as sheet flow can quickly allow soil infiltration and saturation and native wetland plants to re-establish. Restoration projects working in these upper watersheds, such as the East Fork Headwaters, constructed over 200 structures over 400 acres. Many of these treatments were very small, but installed in the most effective locations to restore the original hydrology of the landscape.

Sheet Flow returned to the Headwaters of the East Fork of the Jemez River Watershed.

This guide exhibits a set of techniques that begin on the hillslopes above the smallest tributaries and work downhill to the floodplain of the small creeks on the Valles Caldera National Preserve. The use of LiDAR to design and implement a multitude of small- to medium-sized techniques using only native sod and soil has had a profound effect on wetland area and health over thousands of acres on the Valles Caldera. In addition, these techniques are very inexpensive and low impact, with some structures taking as little as a half hour to construct with a rubber-tracked excavator.

Restoration Design Process

Restoration of disturbed hydrological conditions requires understanding both the disturbance and the results of that disturbance. The Valles Caldera National Preserve suffers from historic overgrazing, livestock trailing, logging, and road building activities. These human-caused activities began erosion feedback loops that continued and expanded upstream over the last 140 years.

"Restoration of disturbed hydrological conditions requires understanding both the disturbance and the results of that disturbance."

The design process begins with seeking information about the site. A walk can be a good place to start combined with a Google LLC Earth satellite tour, to determine watershed boundaries, sources of water (springs, etc.), plant communities, and major erosional features.

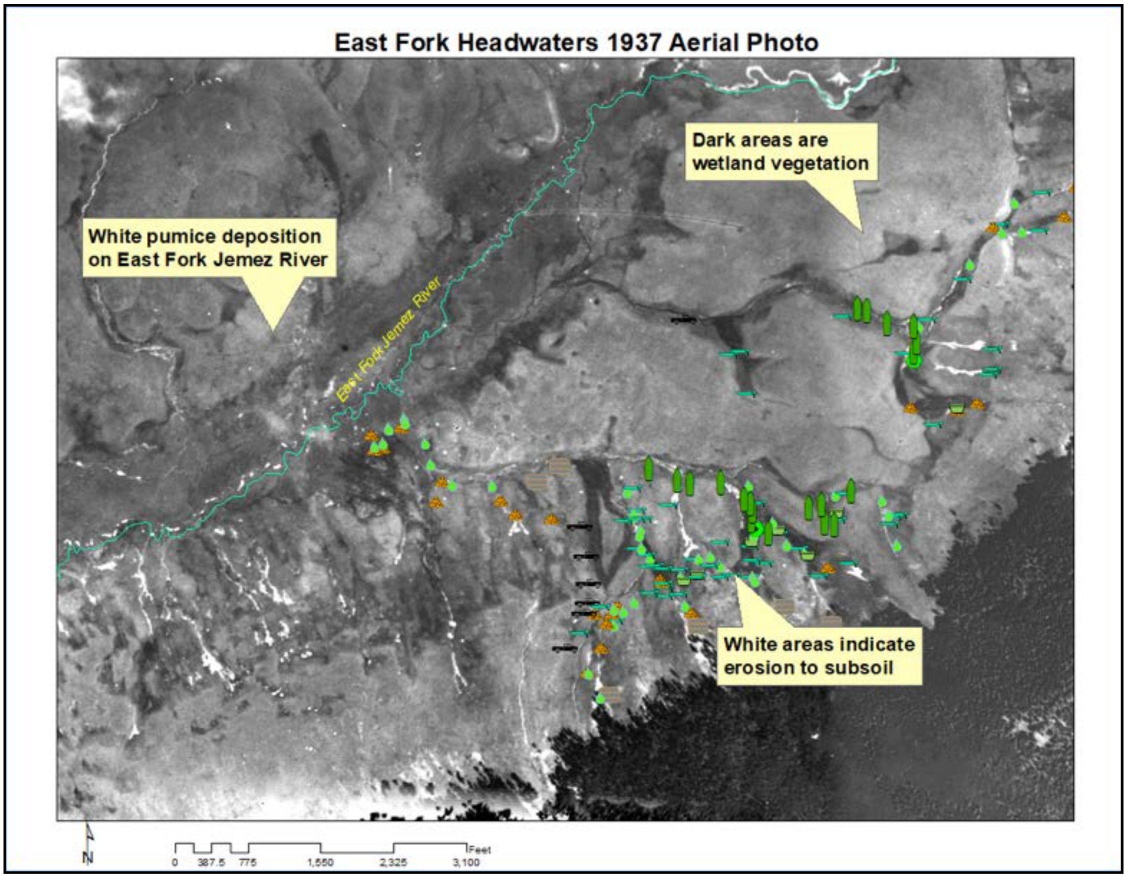
One very important tool used to understand historic conditions is a series of aerial photographs from 1935-37, some of which were taken by the famous pilot, Charles Lindbergh. These allow us to understand several important factors in watershed conditions in the past versus present times.

Channel Condition, Elevation, and Location

As seen on the map on page 9, the channels of the East Fork of the Jemez River were in many cases in a different location on the landscape in 1937. In addition, the channel form (channel width, meander length, pool-to-pool spacing) appears to have been much different in the past, with the channel being wide, shallow, and choked with sediment from overgrazing by sheep.

Roads and Livestock Trailing

Another important factor in present watershed conditions is the presence of roads or livestock trails from the past. Many of these watersheds were grazed highly by sheep from 1880 to 1940, and the herders and herds used the same trails over time, concentrating water and



1935 Aerial Photo of project area, erosion visible as white exposed subsoil.

causing gullying in many small slope wetlands.

Roads were also laid out on the landscape in locations that had more to do with the shortest distance between two points than watershed health. Moving across the landscape by horse or wagon requires a lot of energy, and few tools were available to carve roads into the hillside. Because of this, roads were placed in relatively flat locations, such as wet meadows, floodplains, and along streams and rivers. Often, these roads became the stream or channel through the wetland and created the deep gullying we can see in many locations today.

While this is conjecture, we can make some important conclusions about the landscape and the evolution of the geomorphology of the Valles Caldera National Preserve, which matches conclusions made in many similar landscapes in Northern New Mexico.

1. The presence of large numbers of animals began after the railroad came to New Mexico in the 1880s, and livestock could be exported on the railroad.

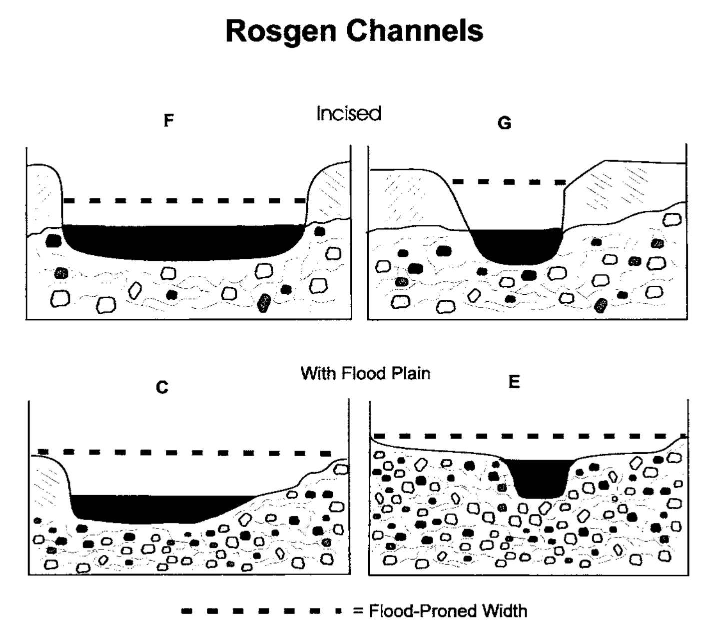
2. The estimated number of sheep on the Valles Caldera National Preserve during Bond Ranch days were between 80,000 and 100,000 sheep, many managed by small sharecroppers who owned only a portion of the herd.

3. Overgrazing led to increased run-off, widening channels, and causing channel braiding, avulsion, and channel cut-offs. Due to the

excessive sediment, the stream channels began to take a steeper course around the deposition, and began to cut deeper into the landscape, lowering the water table overall.

4. Stream channels changed from narrow Rosgen E channels to wide, braided Rosgen D channels, and then began to become gullies (Rosgen G).

5. Gullying of the major creeks led to lowering of the base elevation of the "master stream." Tributaries then began gullying upstream from the master stream, exacerbated by road building, trails, and generally poor landscape conditions due to livestock.



Rosgen, D.L, 1994. "A Classification of natural Rivers". Catena, No. 11 (3), pp. 169-199.

6. These gullies have proceeded up through the headwaters of the East Fork of the Jemez River until present times, and head cutting and gullying was continuing to drain wetlands in the East Fork Headwaters until the construction of treatments to address these issues.

Historic orthographic photos over many years can help create a more detailed understanding of landscape form and erosion over time. Aerial photos from the 1950s, and 1960s can look much different than the oldest aerial photos from the 1930s. However, additional tools exist that help read the landscape in ways that greatly expand our understanding.

LiDAR and Photogrammetry

LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure "ranges" (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of the Earth and its surface characteristics (USGS.gov). LiDAR data is post-processed (processing after other processes have been completed) to edit the image to remove surface vegetation or constructed features so you can see ground features necessary for an accurate design. LiDAR data is usually available in 1m or 0.5m resolution.

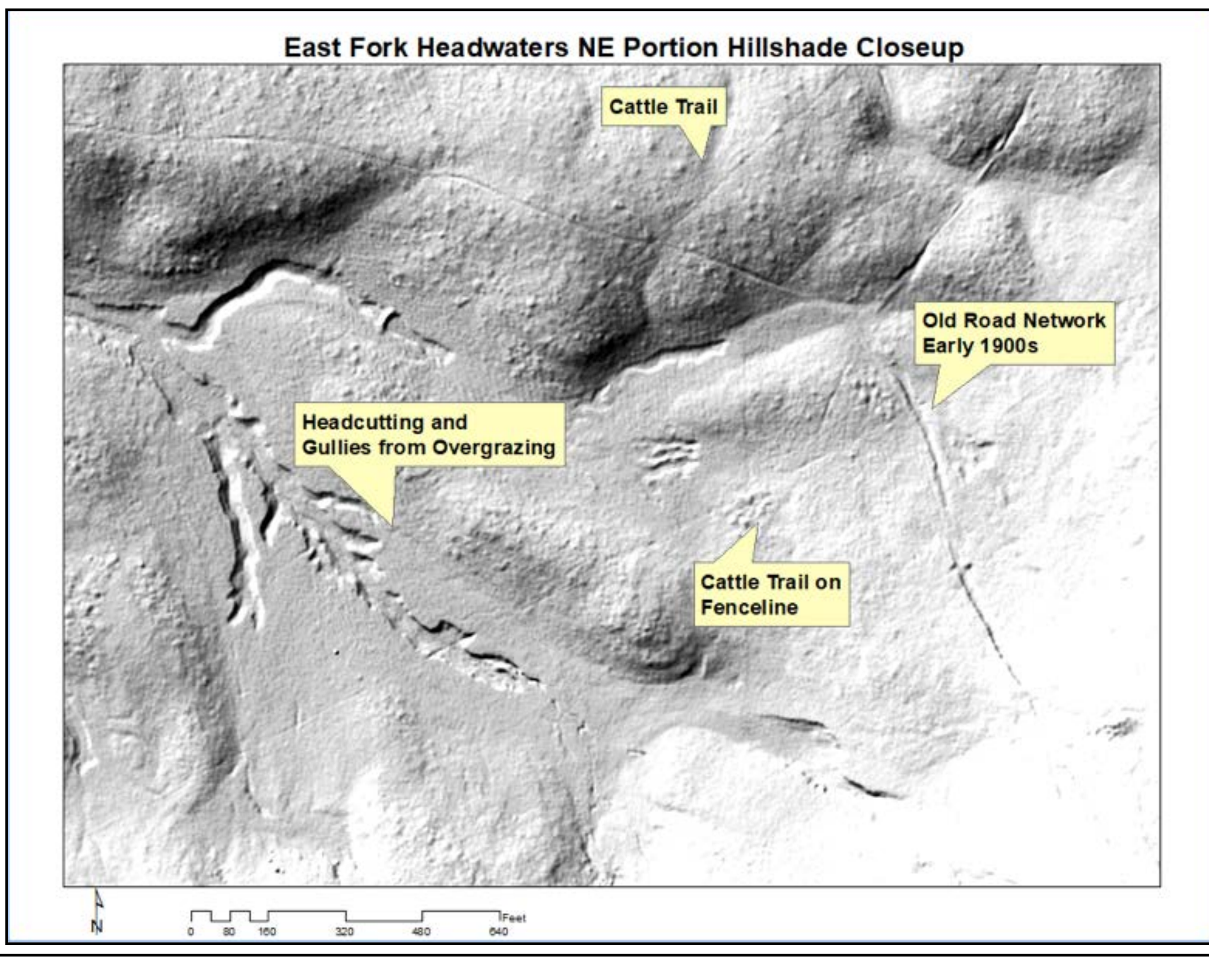
Photogrammetry, which can be taken by airplanes, or drones, triangulates with aerial photos and creates a more detailed elevation map down to 6 pixels or less, and is a very powerful tool for monitoring. However, photogrammetry is generally taken by the user, and cannot be post-processed easily to remove vegetation. In areas with tree canopies, for example, photogrammetry is hindered due to its inability to see the ground surface beneath the canopy. The National Park Service has stringent restrictions on the use of drones, and no drone imagery or photogrammetry was used during this project.

LiDAR is usually obtained in the form of a digital elevation model (DEM), a raster (a scan pattern in which an area is scanned from side to side in lines from top to bottom) dataset containing elevation values for each raster cell. This DEM is then post-processed into a number of LiDAR derivatives, such as slope, aspect, and hillshade. In addition, these data can be used to create hydrological models of flow on the landscape.

Hillshade

Hillshade, or shaded relief, is a technique where a lighting effect is added to a map based on elevation variations within the landscape. Hillshading simulates the shadows cast by the sun upon a three-dimensional representation of terrain.

The hillshade toolset in ArcGIS uses two important parameters, azimuth (the angle between North and a celestial body) and elevation.



The azimuth (lighting angle) of the sun can be anywhere within 360 degrees, but the default is 315 degrees. The azimuth of the sun should be placed to maximize the shadows cast by the gullies and rills on the landscape, and roughly perpendicular to the direction of the water flow so that the side slopes of the channels are represented by shadows.

The second parameter in the toolset is the altitude of the sun. The default is 40 degrees, and this works well for most applications. The hillshade is represented (stretched) by a function shown under the symbology tab in the layer properties. In addition, the contrast and brightness can be modified under the display tab.

In ArcPro, multidirectional hillshade can be used, which models the shading from six different directions. This is a huge improvement, especially in very steep terrain such as canyons. Vertical exaggeration can also be used to exaggerate small features on the landscape.

The hillshade technique is invaluable in reading the landscape and identifying erosional features and patterns that cannot generally be seen due to distance, deep grass, and other factors. In particular, patterns caused by old roads and cattle trailing "pop" on the hillshade, and the factors leading to erosion can be identified more easily than from on the ground.

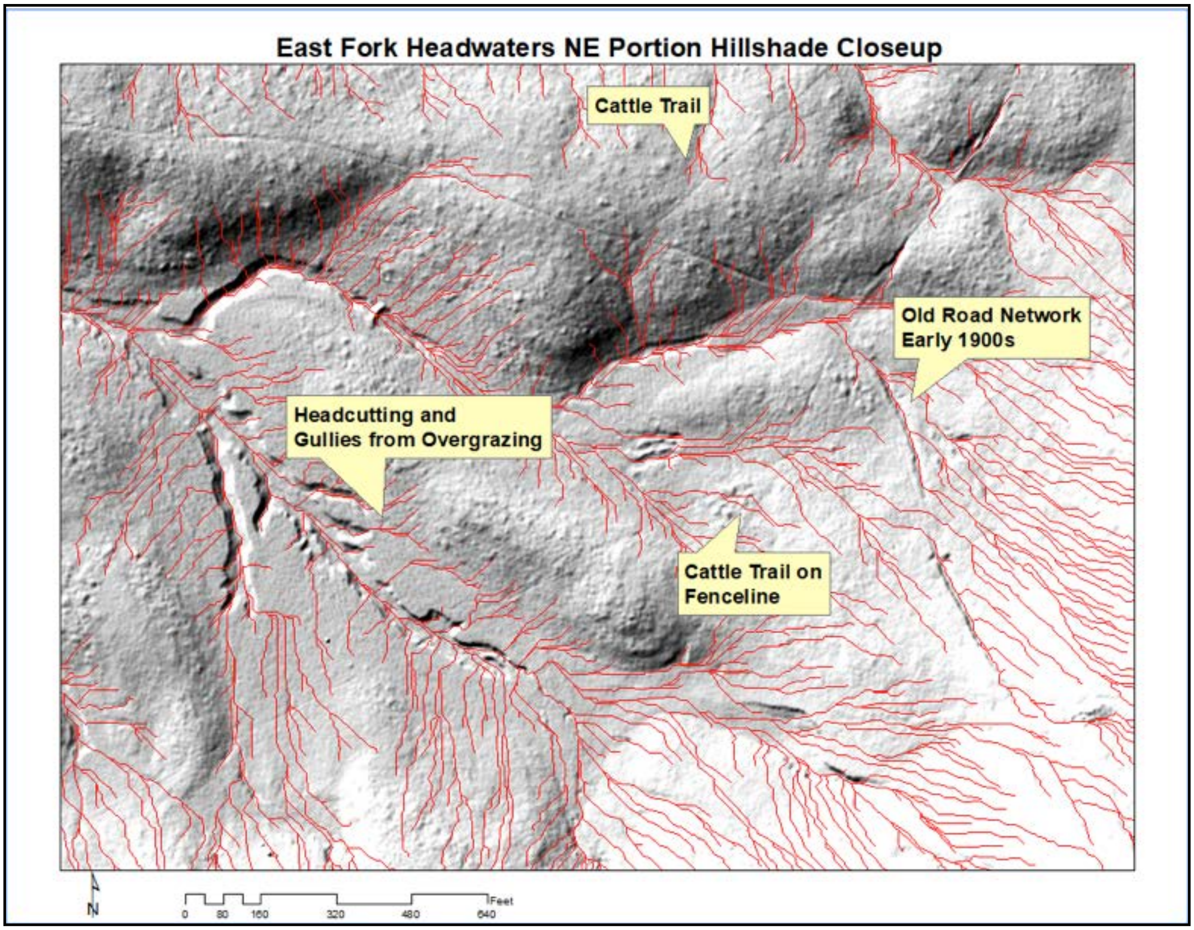
EARThᵀᴹ Toolset

Keystone Restoration Ecology has been developing a toolset using Lidar dem-based analysis for the understanding of erosion and the location of restoration techniques. The Erosion Analysis and Restoration Technique (EARTh™) toolset uses LiDAR-based flowlines for understanding flow patterns on the landscape. Flowlines are created in ArcGIS, using flow direction, flow accumulation, and other tools to create a map of water flow on the landscape at different scales.

The Flow Accumulation tool in ArcGIS calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. The slope of each cell is computed and water is modeled as flowing from the highest cell in a watershed downhill. This raster is changed to a line feature, and the minimum size of a flowline is set at 200 square meters. At the output of each 200 square meter sub-watershed, a line begins which leads into larger and larger stream features.

This process is similar to how the U.S. Geological Survey draws streams on a landscape, but with LiDAR of high resolution, the smallest rills and swales can be identified that otherwise would be invisible to the eye. Each landscape, slope, vegetation, and geomorphology would have a minimum watershed size of interest. In many places, 200 m^2 would be too small to be of interest and would be confusing to interpret.

The restoration structures used in this project are used to spread water across the landscape and to return flow from a concentrated form



in a gully to a historic flow location. Flowlines can be used to identify a historic flow location in a wetland that has been drained by a gully. A treatment can be located in order to return water to that abandoned channel or depression, and ensure that water will not return to the gully immediately below the treatment.

The use of flowlines for large-scale understanding of flow patterns allows the identification of locations where the hydrology of the landscape can be restored with minimal effort. Each structure in a sub-watershed benefits from the upstream treatments and augments the downstream ones. The provisional design is laid out on the landscape and then finalized with an on-the-ground site visit.

Ground-Based Assessment

The last step of the design process is the ground-truthing of the locations identified for treatment using the historic aerial photos, hillshade, and flowlines created in the office. Tools such as Avenza Maps®, a commercial mapping service, can be used to store multiple maps with layers such as LiDAR, 1930s aerials, 1950s aerials, hillshade, and EARTh™ analysis (flowline products). While Avenza Maps® can be used to take data and design treatments, the sheer number of maps can cause these data points to be difficult to post process, and pictures are particularly difficult to download and organize.

ArcGIS Field Maps is the latest mapping solution from Esri, and can easily take data in the field that will upload to ArcGIS online from either the field or office with an Internet connection. Photos are easy to handle, but base maps are most easily created from the Esri base map layer, leaving the aerial photos and Lidar derivatives to be brought along as either a printed map or an Avenza pdf map®.

> **"The season of design is important and many of these ephemeral channels and swales only run with water during very wet monsoons or adequate snowmelt."**

The field assessment and design involves visiting proposed design locations on the ground and deciding which treatment or series of treatments can restore flow to abandoned wetlands and spread water on the landscape. The process begins at the top of the watershed and proceeds downhill, as the effects of each treatment in a series must be considered in the design of the next treatment downhill.

The season of design is important and many of these ephemeral channels and swales only run with water during very wet monsoons or adequate snowmelt. In the Valles Caldera National Preserve, the initial snowmelt in March runs on the surface of the ground and is infiltrated. It may be several weeks until "interflow" of water on shallow colluvial sediments leads to water in the slope wetlands on the hillslopes. A previous project using shallow groundwater wells identified that runoff ended on April 5th, and flow in channels and on top of wetlands began by April 21st. During the interlude, very little water was seen on site, which could be interpreted incorrectly as a dry winter leading to no shallow groundwater storage.

From that point, it may be as long as a month into early May, when the water carried by Interflow meets the perennial streams and runoff and flooding begins in the tributaries to the larger creeks. These "pauses" in flow are noticeable and each year has a differing pattern depending on overall wetness, temperature, and precipitation. Correct timing of site visits for design changes from year to year can be only gained by experience on a particular landscape.

Understanding the pattern and amount of flow in different seasons can be combined with an understanding of vegetation species composition for maximum restoration effectiveness. Spreading water onto coarse soils with colluvium dominated by Parry's Oatgrass (*Danthonia parryi*) may store water in the soil that will return as interflow downhill, but will not change that plant community to wetland plant species. However, many relict wetlands can be identified by small clumps of Baltic rush (*Juncus balticus*) or *Carex sp*. in a matrix of Kentucky Bluegrass and other non-native species. These areas have fine soils and will more quickly respond to the additional runoff water from a treatment uphill and return to a wetland plant community in several years.

East Fork Headwaters Assessment

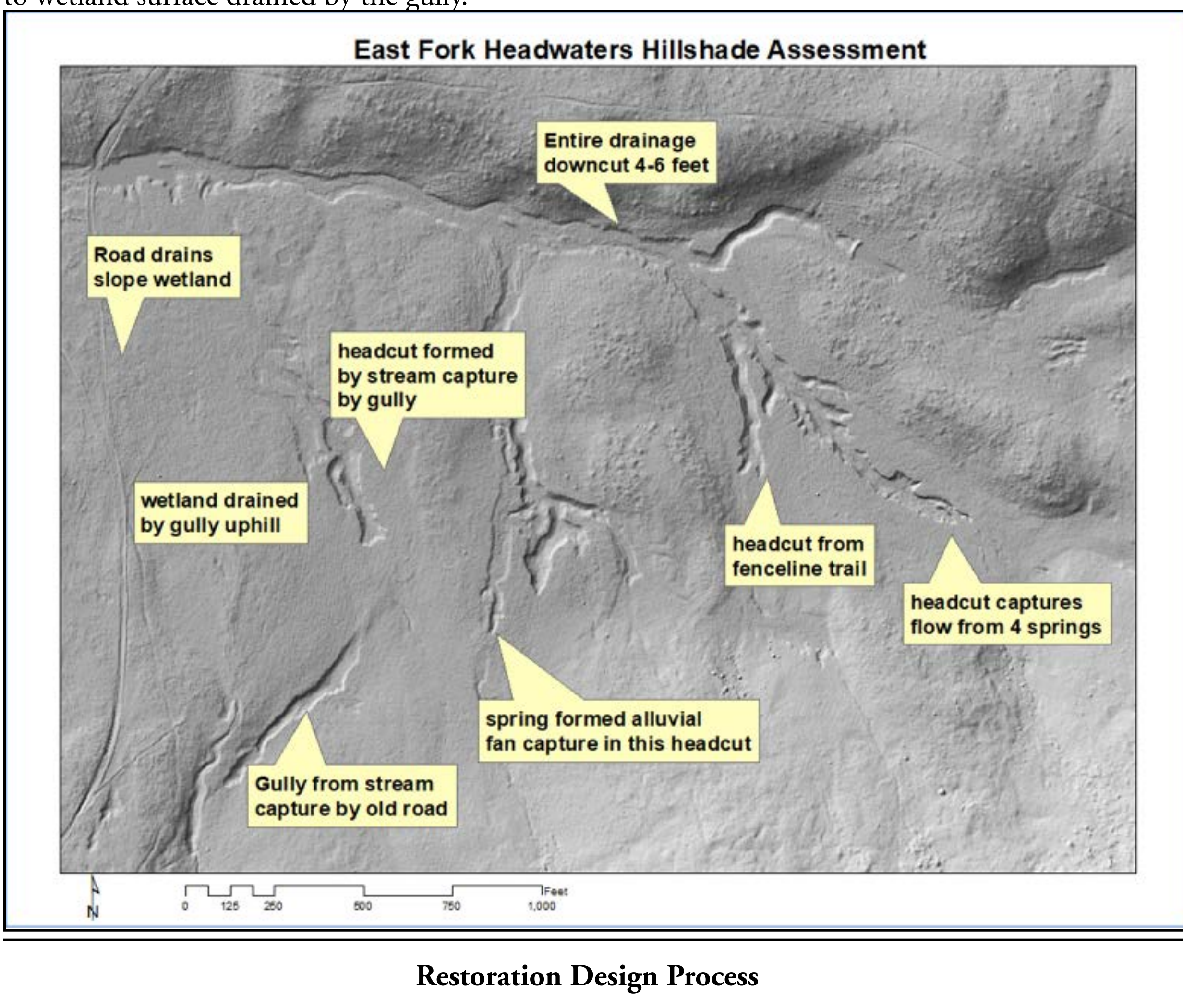
The 1937 aerial photos, hillshade, EARTh™ toolset flowlines and ground-based assessment are combined into a conceptual picture of the landscape patterns and the erosional processes that have created those patterns. A close up of the Southeast corner of the East Fork Headwaters project is presented below with just some of the landscape features and erosional issues identified.

The overall conceptual picture of this small watershed is that enormous amounts of soil have been lost due to a number of factors including livestock overgrazing, road-building, stream capture, and headcutting. Understanding of the patterns created by these processes allows for a design that restores hydrology to as much of the former wetland surface as possible.

1. Restoring the stream captured in the gully to a drained wetland also helps prevent the excessive flow that created the head cut downhill.

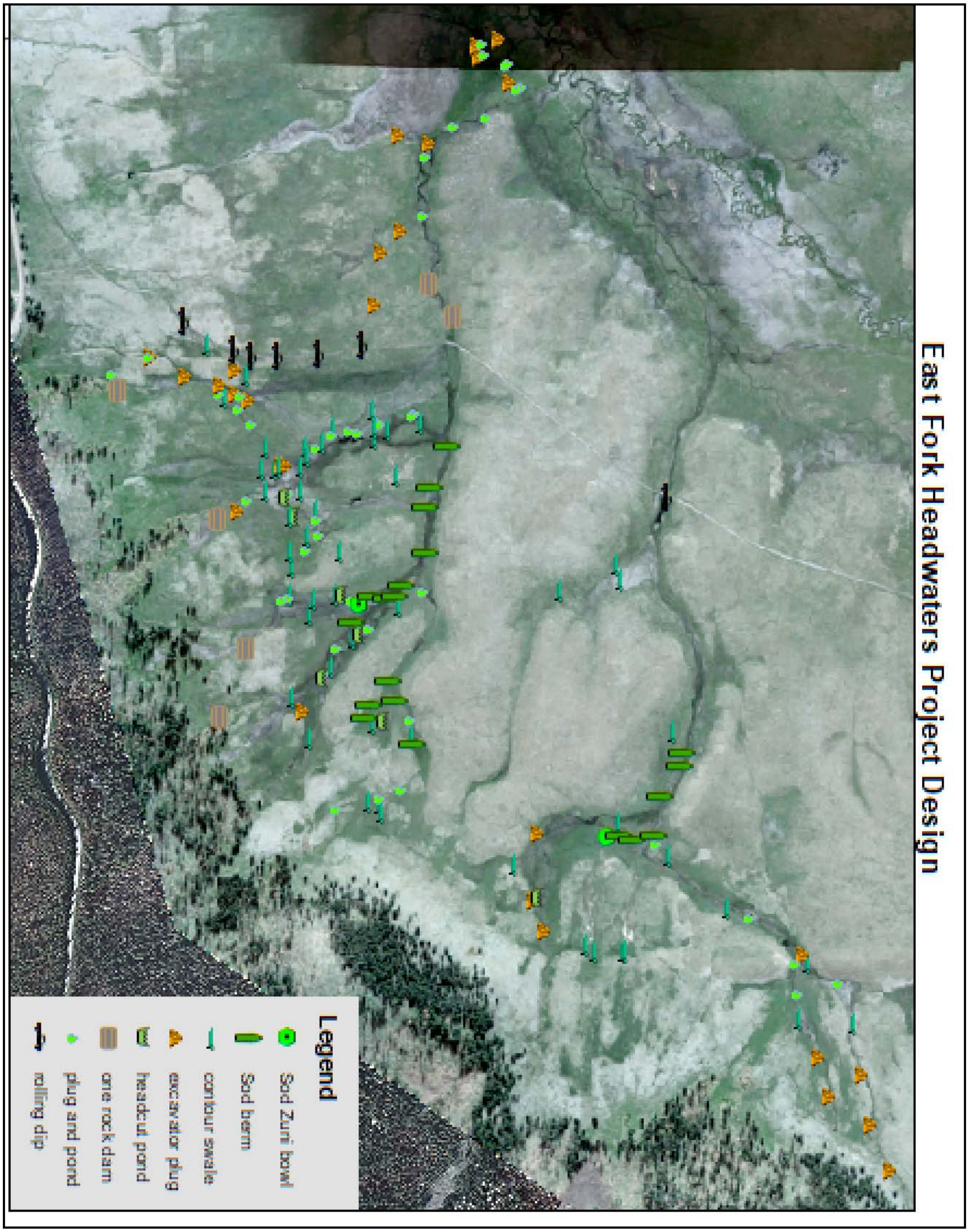
2. A spring was returned to the alluvial fan by a series of contour swales.

3. The large headcut at right of picture was treated with a series of head cut ponds, plug and ponds, and contour swales to restore hydrology to wetland surface drained by the gully.



4. Sod berms in the bottom of main gully were designed to spread water across the breadth of the gully.

Over 200 treatments were implemented in the 400-acre project area. The project design map is shown below.



Restoration Techniques

The techniques described in this section focus on using wetland vegetation for restoration. Just as rocks and logs are used in restoration, wetland vegetation lends itself to repairing and enhancing wetland areas, with the added bonus that it grows on-site. Wetland vegetation has the additional benefits of vigorous growth, deep and trailing roots, and complete soil coverage with a mat-like growing structure. These wetland species have evolved to withstand saturated ground and the flowing of water, making them ideally suited to wetland and riparian restoration.

> **"...WETLAND VEGETATION LENDS ITSELF TO REPAIRING AND ENHANCING WETLAND AREAS, WITH THE ADDED BONUS THAT IT GROWS ON-SITE."**

Native wetland plants found on-site are the ideal restoration material.

•The ecotype of native plants has been adapting to that specific location for over thousands of years.

•Each sod tile is made of a community of plants and includes a seed bank, allowing it to adapt to the post-restoration hydrological conditions, with some plants dominating and others being replaced by either drier or wetter adapted species.

•Sod tiles can be moved in less than 10 minutes to at most several days, leaving even the flowers blooming after the construction of the sod and soil treatment.

•Moderately wet is the ideal condition, as soil compaction is minimized and sod tiles are not too wet to "hold together" after handling.

Using native sod in wetland restoration creates a structure that gets stronger over time, as the wetland plants grow stronger in the increasingly wetted area and additional species from nearby areas colonize the swale, pond, or ditch. Unlike structures of other native materials such as rock or wood, only native sod can be found on-site,

Sod Tiles

For the past decade these sod techniques have been refined, and the species most commonly used is *Carex utriculata*. At the time of this publication, there is little research on comparing wetland species and how they perform. *Carex utriculata* grows vigorously in very wet sites and is commonly dug from the bottom of the gullies that are then plugged. In addition, *Juncus balticus* has a very tough, comb-like root structure, and holds together well in sod tiles. *Juncus balticus* is more commonly found in drained wetlands or marginal wetland areas, and is more commonly used in structures higher on the landscape in drier conditions.

Sod tile being removed with rubber-tracked loader and added to sod tiles harvested before restoration structure is built. The wetland sod that is removed and replaced is placed in a "runway," so that the water that flows out of the structure irrigates this area and helps with re-vegetation and compaction of the soil. See further description on p. 26.

grow immediately, and continue to improve the stability and function of the restoration structures over time as it grows into restored landscape form.

Certain considerations are made to ensure wetland vegetation will be successful as a restoration material. In essence, vegetation is transplanted using small machinery. Therefore, the time of year the restoration is done is important as well as re-establishing soil contact with roots.

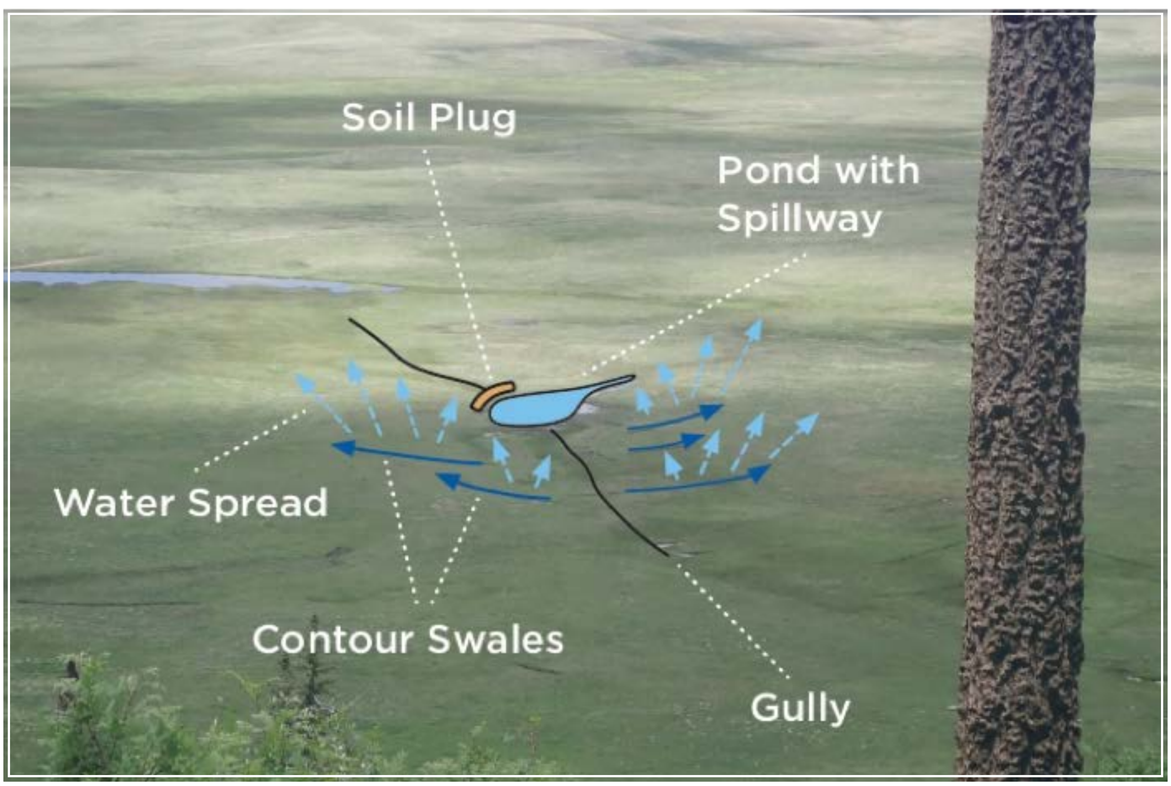
Using rubber-tracked machinery is also important. When used with low-impact practices, the rubber tracks have less compaction and allow vegetation to rebound quite well after transplanting.

The suite of sod techniques described in this guide are rarely used alone. To address the needs of the landscape, multiple techniques will work together to enhance wetland and riparian areas. (See photo on page 19.) Restoration structures will affect and impact the landscape below them and thereby the structures placed downstream/below them. As always start at the top of the watershed, valley, or slope wetland and move downhill. Many times a huge erosion issue at the bottom of the drainage can be treated best by multiple techniques working in concert above it and, less disturbance will be needed at the valley bottom.

For the purposes of this guide, each technique will be described individually below.

Technique	Landscape Position	Purpose	Size
Contour Swale	High in watershed	Diversion from sheet flow or small gully to sheet flow on wetland	Small to medium
Headcut Pond	Above headcut	Move flow from headcut to sheet flow on wetland	Medium
Plug and Pond	Below headcut	Capture flow in gully and return to sheet flow in wetland	Medium to large
Excavator plug	High in watershed	Plug trail or small gully and return flow to wetland	Small to medium
Sod berm	Low in watershed inside large gullies	Change channelized flow in gully to sheet flow across entire width of gully	Small
Sod bowl	At headcut	Restore small headcut with little flow and revegetate	Small

In the picture below, several techniques are implemented together to restore hydrology impacted by an old wagon road. Flow is now dispersed by contour swales before reaching the gully and then ponds at the plug and pond structure location. The spillway returns to higher elevation terraces, restoring the hydrology of an old remnant wetland. Subsurface flow that enters the gully is captured behind the plug and pond and diverted back to former wetland surfaces.



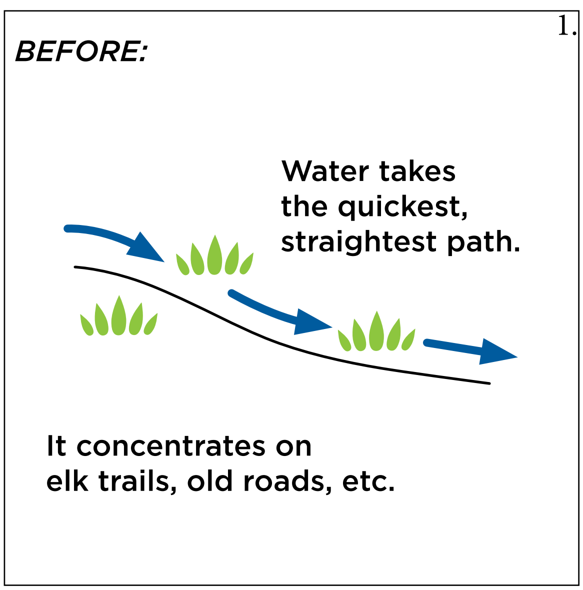
CONTOUR SWALES

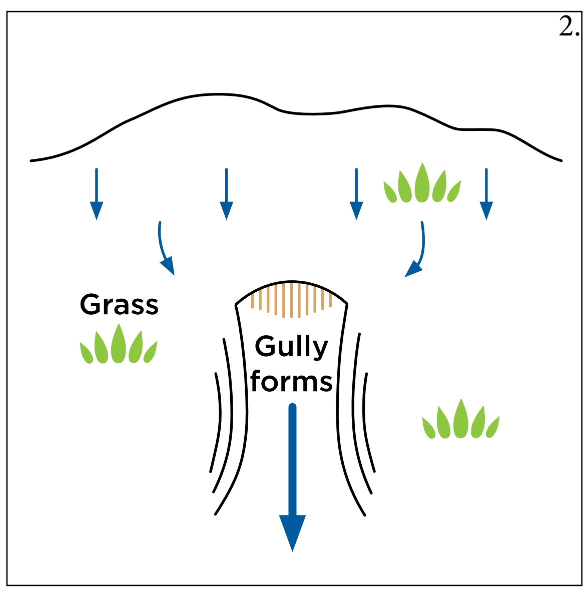
Often at the top of the watershed or slope, where the landscape transitions from convex to concave, contour swales offer opportunities to spread water and divert it from contributing to an erosive feature. Using contour swales before water flow has concentrated deprives a headcut of erosive energy or reduces flow in a gully.

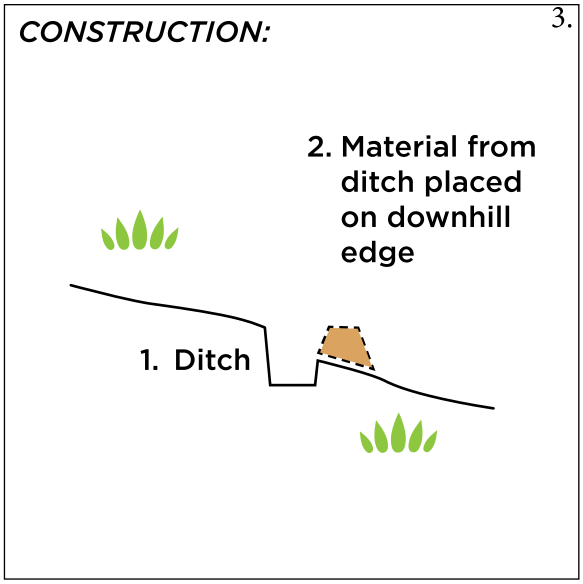
A contour swale is a shallow depression with a sod tile placed on the downhill edge. The depression is set slightly off contour so water slowly flows from one direction to the other. Stormwater runoff and snowmelt will catch on the lip of the swale and either infiltrate or flow to the end of the ditch, thereby changing water flow directions and dissipating erosive energy. Contour swales route the flow away from headcuts, onto former wetlands de-watered by the headcuts. Swales can also be used with a plug and pond when a simple spillway or berm would not be sufficient to keep flow from returning to the gully.

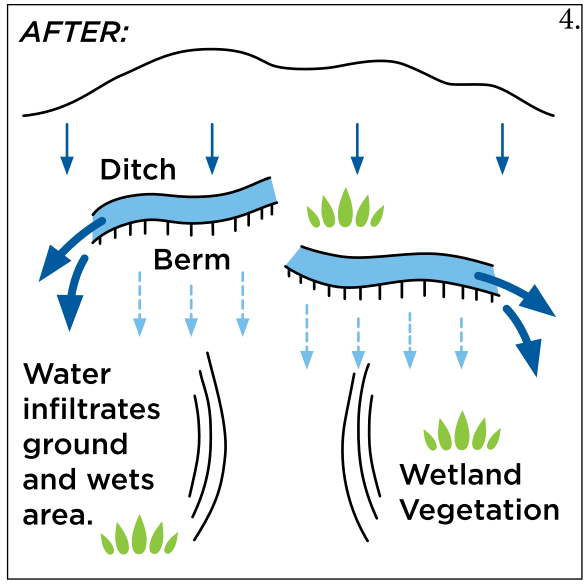
To construct a contour swale, the area is marked out with pin flags and a laser level. The slope or grade of the ditch will be minimal, roughly 0.5% or ½ inch over 10 feet, enough to have water pool, infiltrate, and slowly flow in a particular direction. An excavator bucket is used to dig the shallow ditch, generally 8-12 inches deep, just deep enough to remove a sod tile. Once the bucket removes the sod tile, it is placed on the downhill edge of the ditch, creating a low berm. It is important to re-establish soil contact with the roots of wetland vegetation, and the excavator bucket works nicely to apply pressure to the sod tile. Swale lengths will vary by conditions on-site and the location in the landscape.

Contour swales are a variation of the spreader swale which spreads water all along the downhill edge of the swale. These spreader swales were being damaged from elk and wildlife trampling, causing the water to exit the swale in the compacted area and no longer spread. By diverting water

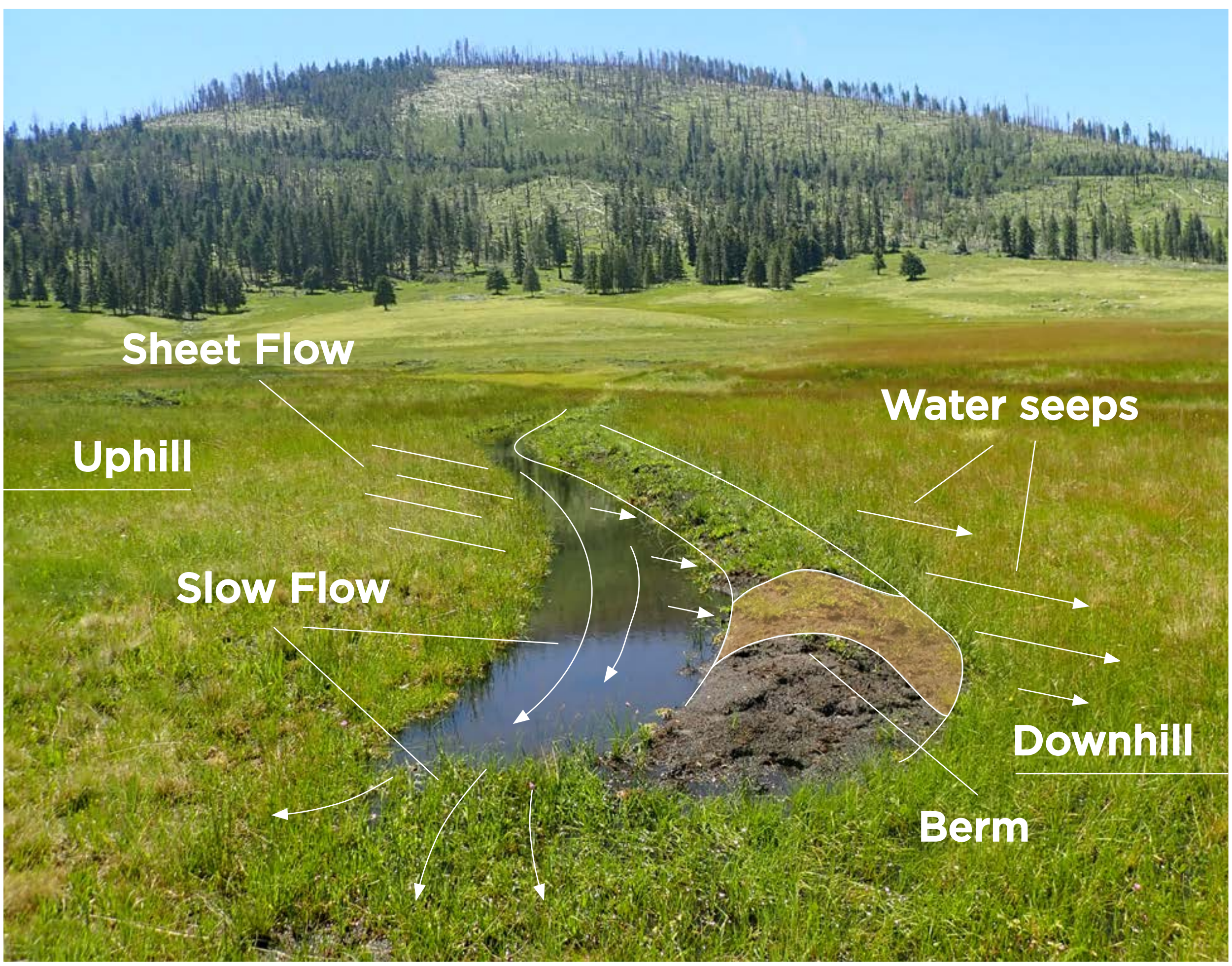








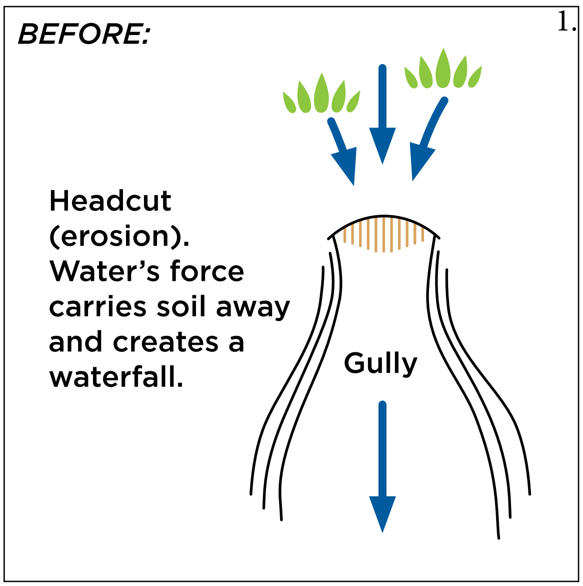
in a particular direction and adding the downhill berm, less damage to swales was done and the structures performed successfully in the long term.

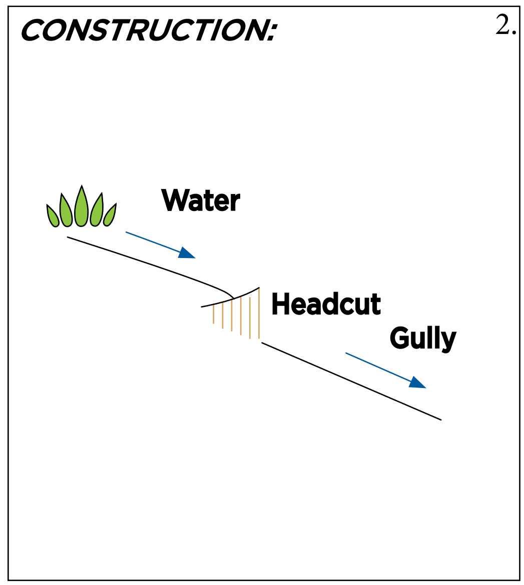


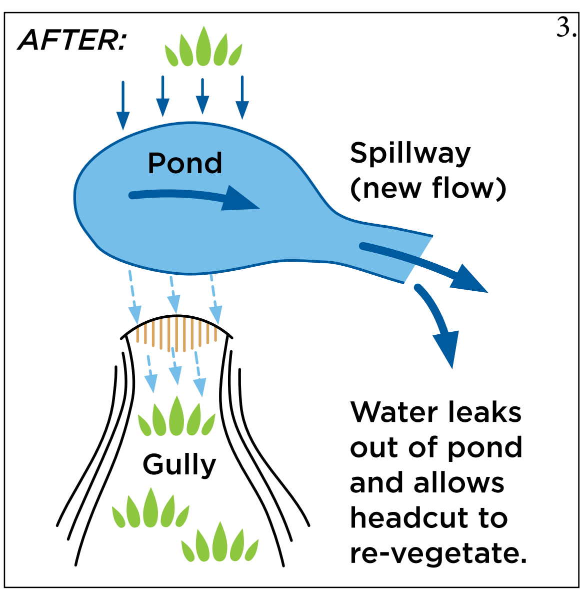
HEADCUT POND

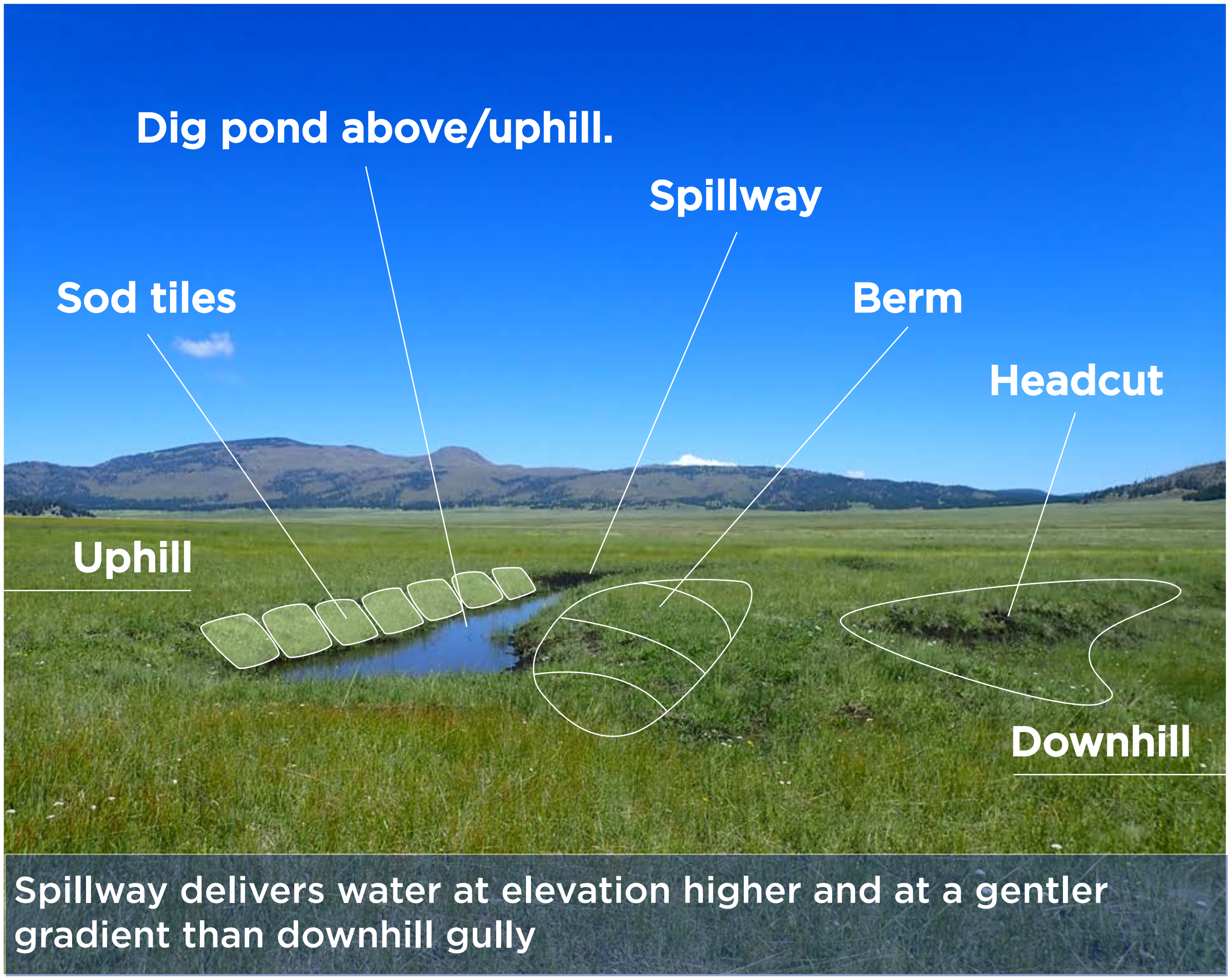
The headcut pond is a variation of the plug and pond technique. Its main purpose is to deprive a headcut of "flowing water," reduce soil erosion, and preserve surrounding wetlands. The "pond" is created upstream or above the headcut on stable ground. The pond's spillway diverts flow around the headcut area and onto former wetland areas. This technique works well for minor headcuts that do not pose a threat of eroding up valley. It is ideally suited for areas where the pond's spillway will be able to flow onto former wetland surfaces and not return to the gully with the headcut.

The native vegetation is first removed and saved. The spoils from the pond are used to create the "plug" which is built around or above the headcut to prevent water flow over the headcut. The spillway elevation is lower than the top of the "plug" and spreads water from the pond slowly as sheetflow onto higher elevation wetland or former wetland areas. This variation uses the "plug and pond" to deprive the headcut of water, which arrests the erosion and re-hydrates surrounding vegetation. This sod technique provides another low impact tool to addressing erosive headcuts.









Headcut pond treatment at a Volunteer Workshop at the Valles Caldera in June 2023.

EXCAVATOR PLUG

A much smaller version of the plug and pond (see next Technique) is the excavator plug. This small plug is constructed using only an excavator, and is used in gullies less than 2 feet deep and 5 feet across. The excavator plug can be constructed in less than 1 hour and many of them built in the course of a day. More time can be spent tracking the excavator to each site than in actual construction.

The excavator is used to remove the sod from both the pond and bay areas and place it within reach. The bay is dug out and a small plug built as in the plug and pond structure. The sod is placed on top of the plug and any excess sod placed on the sides of the pond.

Excavator plugs are ideal for plugging the smallest gullies such as old roads, cattle trails, fence-line cattle trails, and even small rills.

Like the plug and pond, they are placed in a location where the least amount of work can be done to spread water over the largest area. In addition, the smallest pond possible is built, and water runs downhill out of the pond to the former wetland surface.

[Above] Excavator Plug structure in early spring after snowmelt. The water is flowing toward the person downslope.

PLUG AND POND

The plug and pond structure is constructed in a gully to restore the hydrology of the gullied wetland. The gully is plugged with an earthen berm to create a pond, and the flow is captured in the pond and returned to a former wetland surface nearby.

This technique raises the water table by returning flow to a higher elevation. Other benefits include: retaining runoff and releasing it slowly as sheetflow, increasing wetland areas, and restoring wetland vegetation on the former wetland surface, both upstream and downstream of the pond.

This plug and pond structure is based on the Rosgen Priority 1 Plug and Pond and modified for use in slope wetlands. The construction described here is not for plugs being built on perennial streams. This technique has been implemented on tributaries and slope wetlands where flow can be ephemeral or intermittent.

To construct a plug and pond, native sod is salvaged from the work area and placed aside for further use. Then, a "bay" is dug in the side of the gully to provide fill material to construct a plug. The bay can even extend into the shape of a swale so that the water leaving the plug and pond runs downslope onto a former wetland surface.

The plug, or earthen berm, spans across the entire gully and as soil is deposited, it is compacted with machine tracks or the excavator

Plug and Ponds returning hydrology to slope wetlands in the East Fork Headwaters.

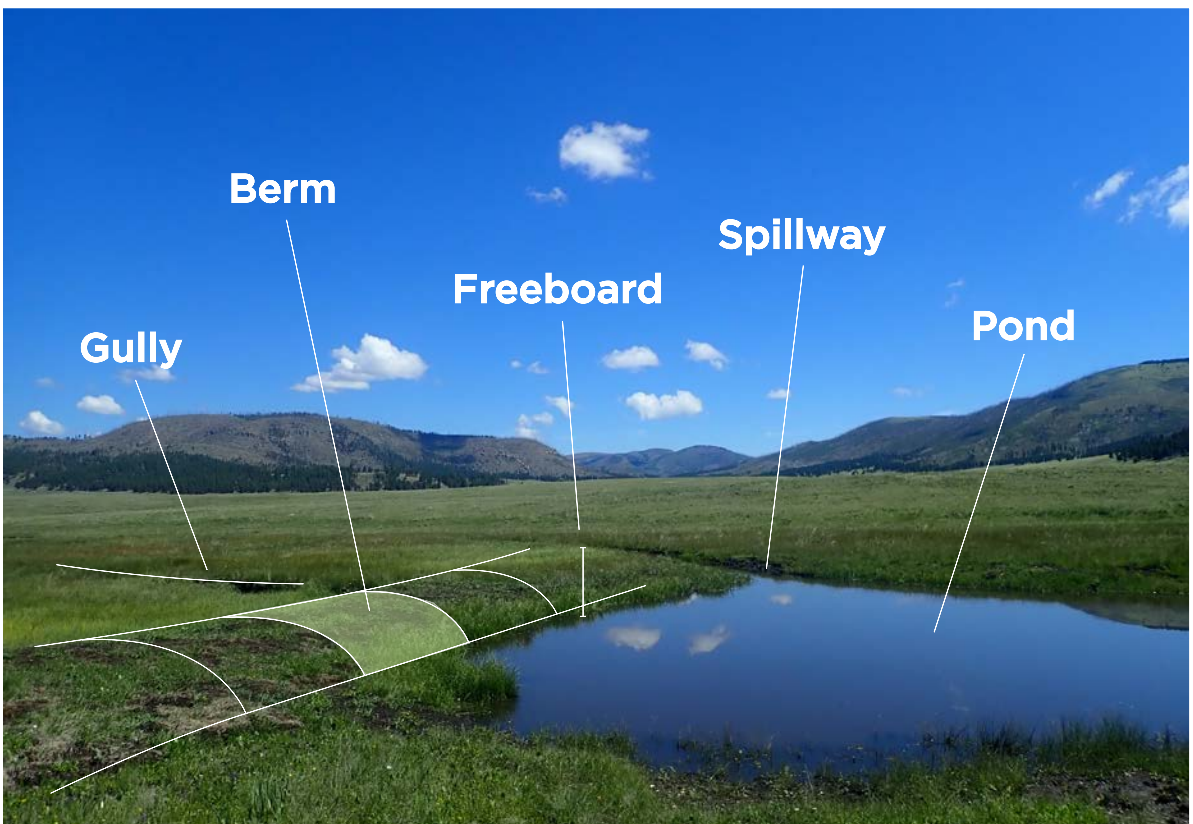
PLUG AND POND (CON'T)

bucket. The slope of the plug will be roughly 2:1 to provide stability. The height of a plug is determined by the spillway elevation.

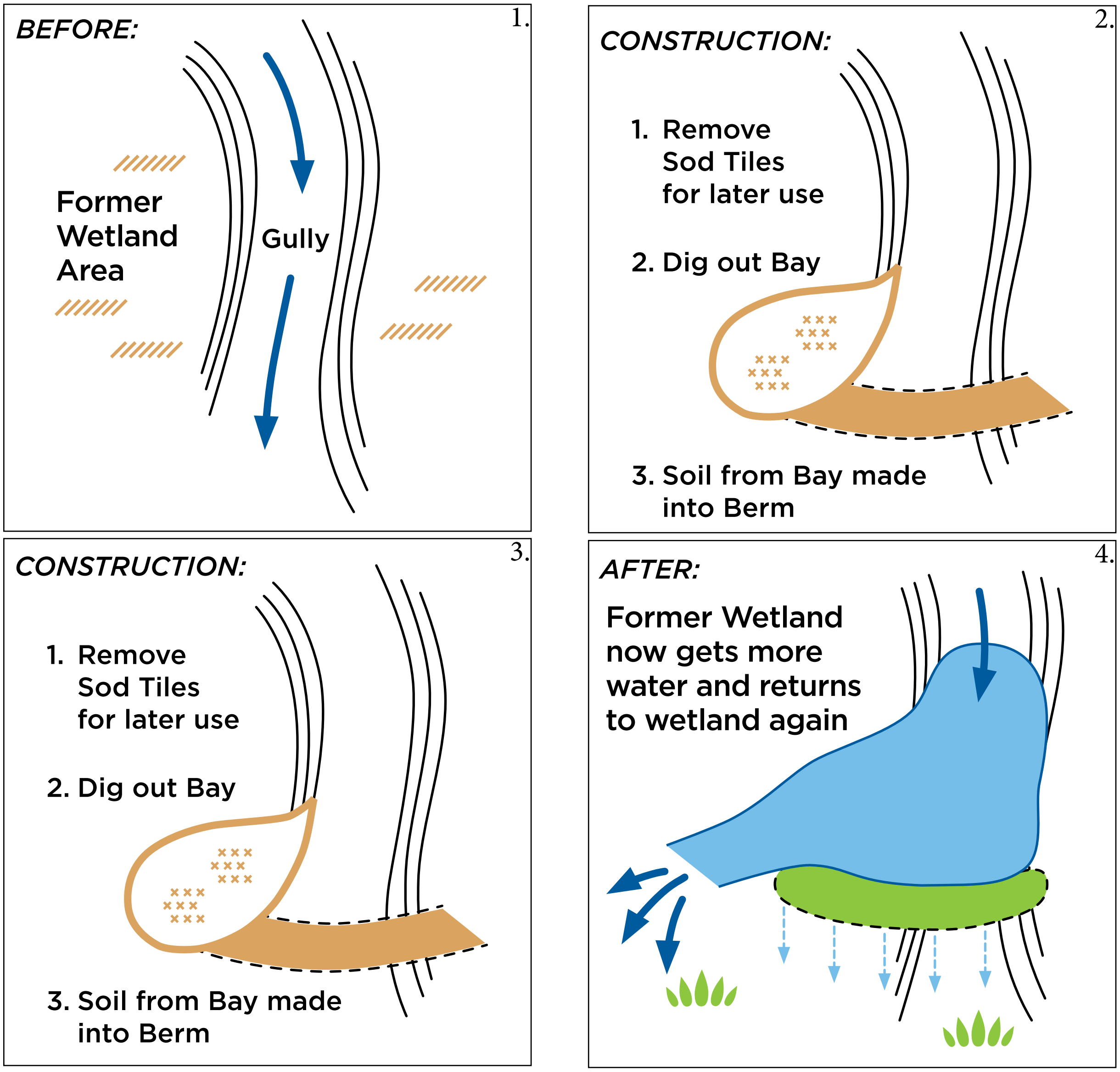
Freeboard, the distance between the water and the top of the plug, preserves the integrity of the structure. The top of the plug should be a minimum of 2 feet higher than the spillway. Wildlife will use the top of these plugs as trails and continually compact the saturated plug.

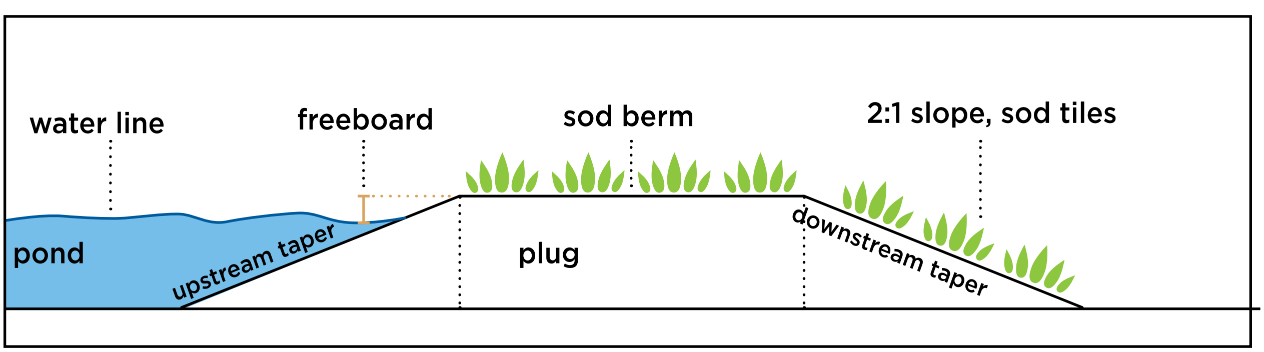
Once the plug is completed, it is faced with the salvaged sod so that it re-vegetates very quickly. Water fills the pond then spills out onto the former wetland or channel through a spillway. The spillway is a wide, level area created to spread overflow from the pond to a vegetated surface. Wide and level grade ensures that the flow will be spread slowly and not erode the area.

The wetland sod that is removed and replaced is placed in a "runway" usually at the outlet of the pond, so that the water that flows out of the plug irrigates this area and helps with re-vegetation and compaction of the soil. Secondly, the rubber-tracked machinery used is only turned around in areas that will be either re-vegetated or under water once the pond is filled by runoff. This prevents the "shear" from turning machinery, which will kill grass much more quickly than compaction will.



Former wetland area restored with water from spillway

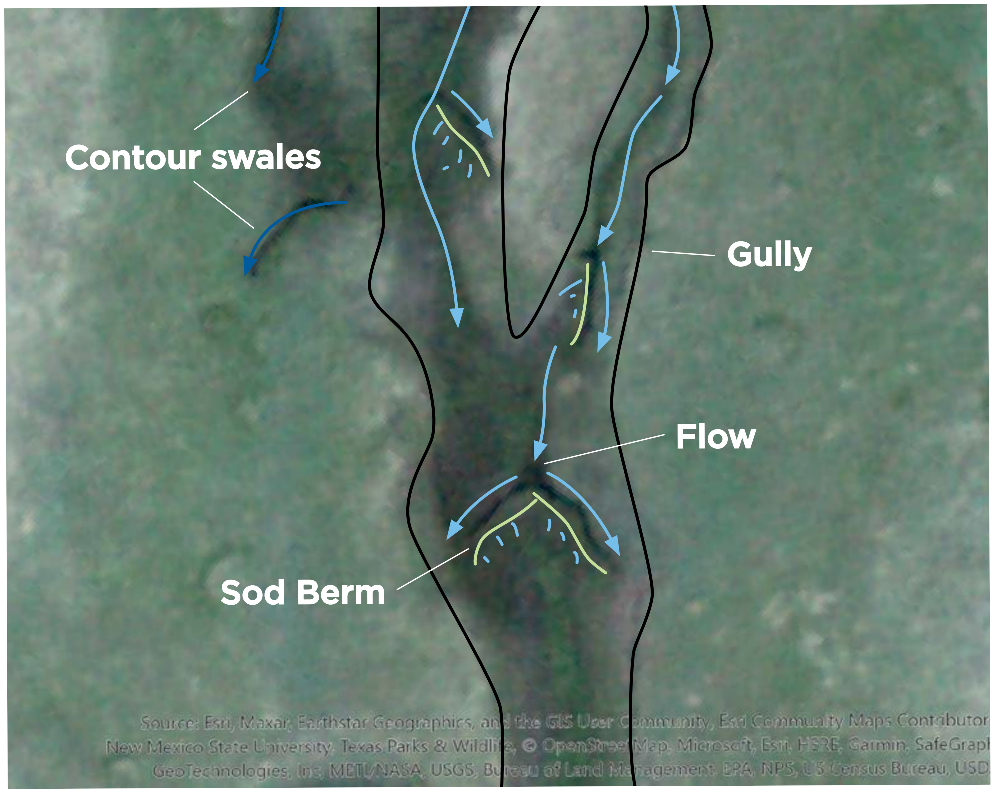




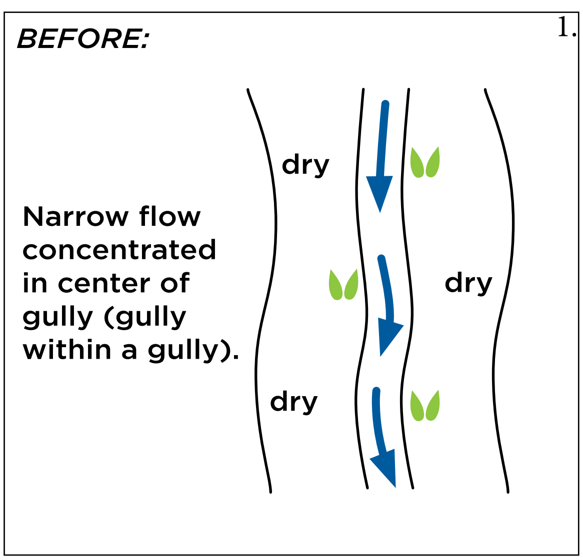
PLUG AND POND LONGITUDINAL PROFILE

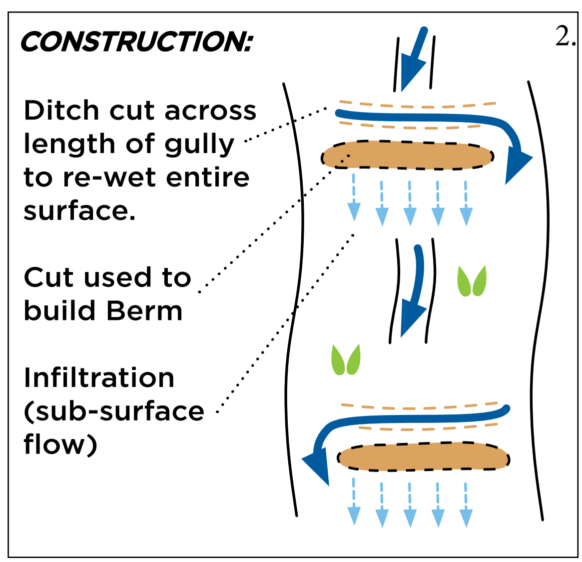
SOD BERMS

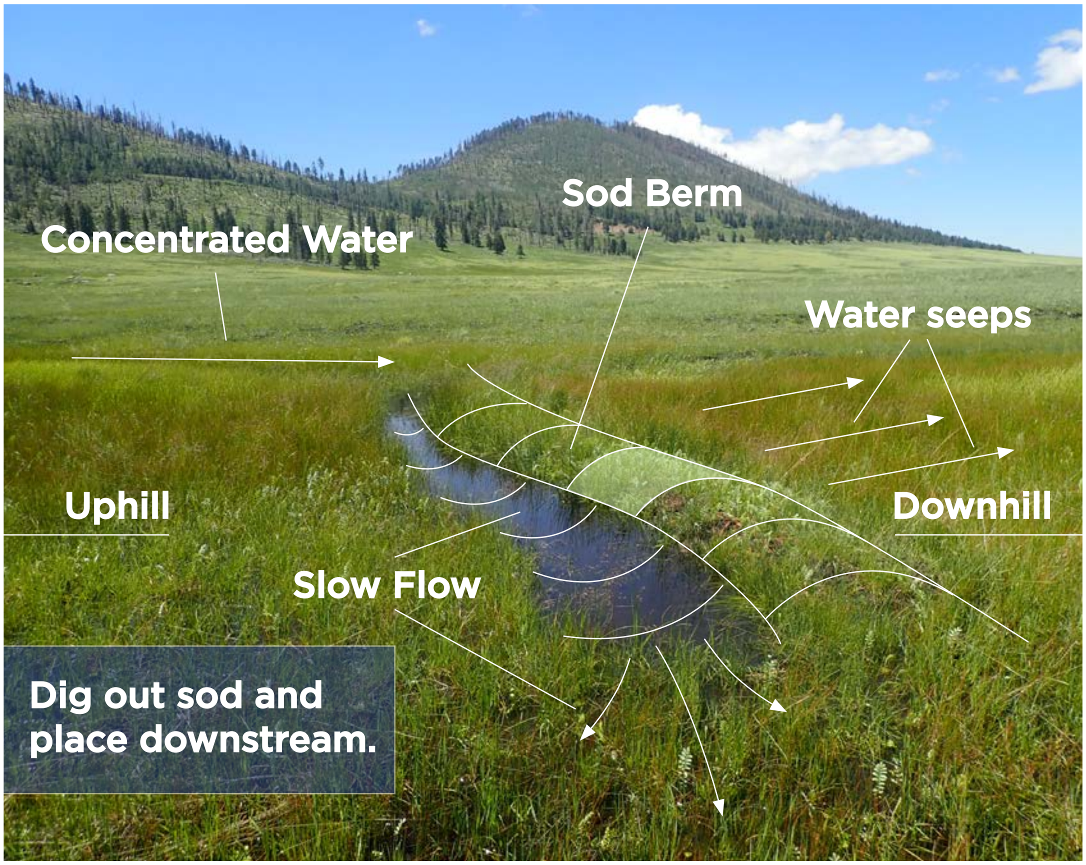
The larger channels at the East Fork Headwaters project are gullied 3-6 feet deep into the landform along their entire length. These gullies are a remnant of the overgrazing by sheep in the early part of the 20th century, and headcuts have proceeded uphill from these gullies into the former slope wetlands on the hillsides.



The intermittent flow in the bottom of these gullies is itself captured in a small, 12-inch wide channel at the bottom of the gully which is 15-30 feet across. The obligate wetland vegetation (*Carex*) is



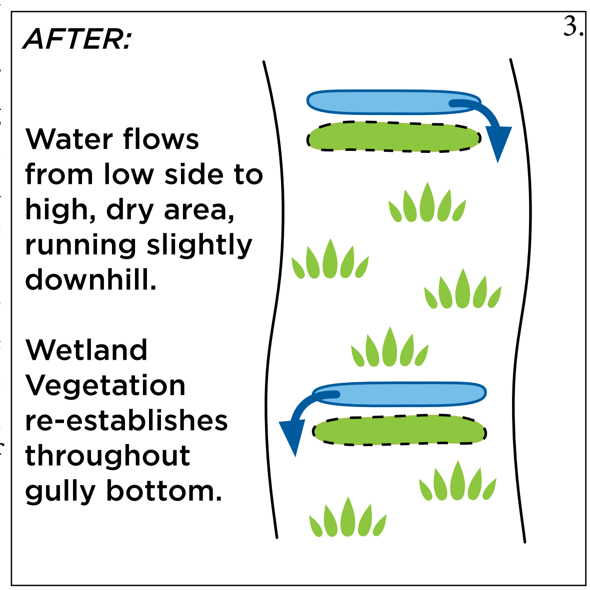




mostly confined to this narrow channel, with facultative species such as *Juncus balticus* growing throughout the rest of the gully, which remains dry most of the year.

Sod berms are installed in a series to spread and infiltrate flow across the bottom of the gully with the outlet of the berm leading water to the drier and higher side. The slope of the sod berm is at 0.5%, and the water runs downslope towards this dry side. Sod berms are created using a narrow excavator bucket to dig shallow and short ditches running perpendicular to the water flow. The berm can also be created using excess sod tiles on top of the existing grade. The berm is at most 6 inches in height. Sod berms are used in a series to keep water spreading across the width of the gully.

The patterning of the vegetation in these deeply incised channels leads to the design of the sod berms. Berms are constructed at the top of the narrow areas of *Carex*, before the slope of the channel increases. Spreading water before a steep section of channel helps wet the entire width of the gully.

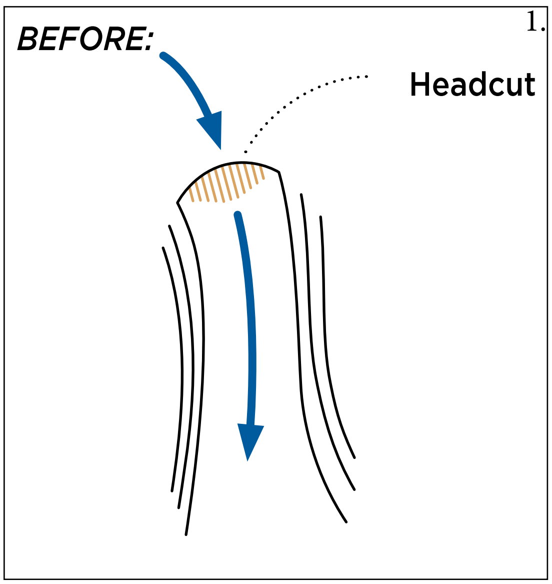


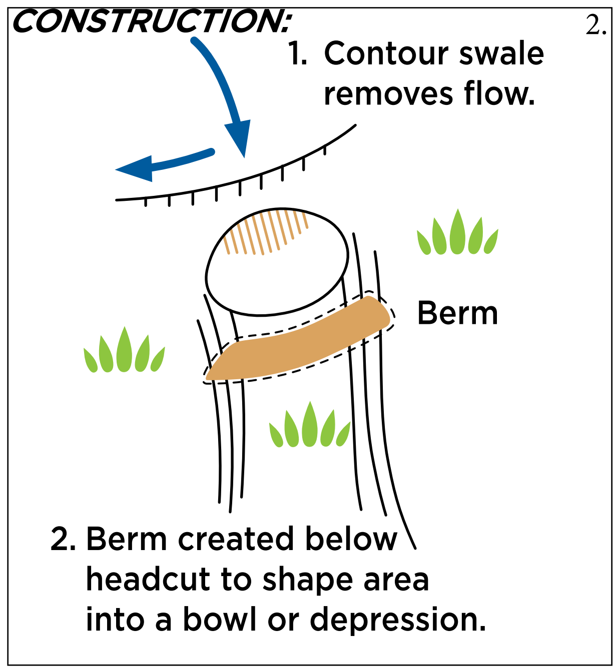
SOD BOWLS

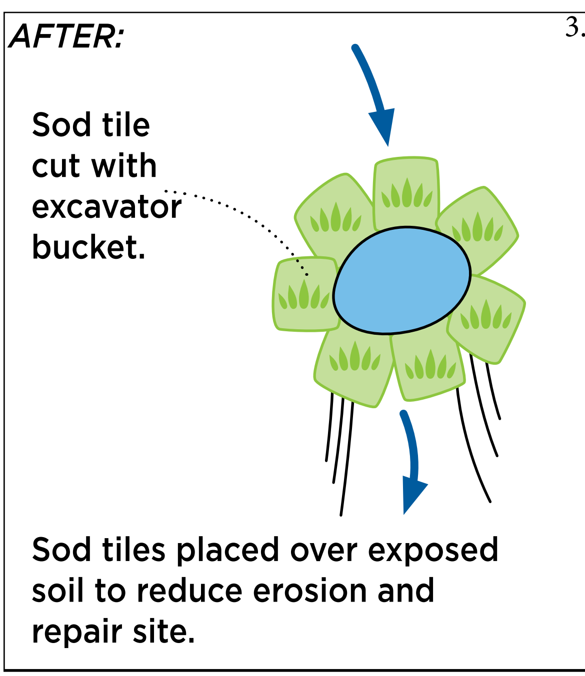
A sod bowl or sod Zuni bowl is used to treat a headcut located at a low point in the landscape. Diverting water away from the headcut with a pond or swale is not feasible, as all water is concentrated into the low spot, which is the headcut location. The sod bowl is a modification on the rock Zuni bowl structure. Instead of rocks, existing wetland vegetation is used to cover exposed soil and decrease erosion.

The headcut is widened and the slope of the headcut reduced to 3:1 or less. The material removed from the widening is used to construct a berm about ½ the height of the headcut downslope. The bowl and berm are lined with sod tiles. During periods of active flow, water flow is slowed by the roughness created from the vegetation, and the water held in the bowl wicks upward to irrigate the sod tiles. Splash erosion is reduced as the sod tiles provide a gradual slope and create an absorbent mat for water to gently pool, dissipating erosive forces. Over time, the vigorous roots of the wetland vegetation will bind soil into place and continue to reduce soil erosion at the site.

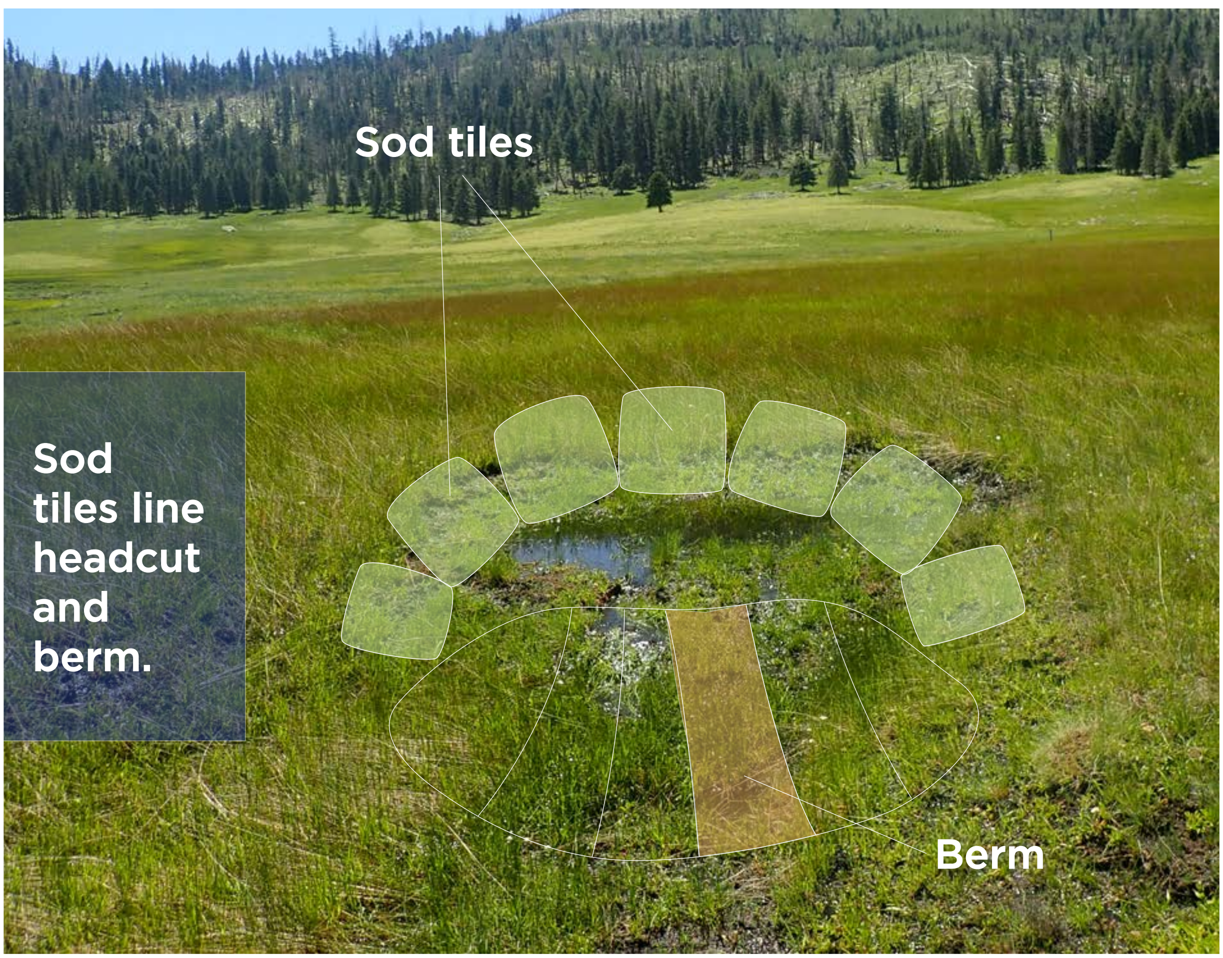
Sod bowls can be built with either a rubber-tracked excavator or manually with hand tools. Either way it is essential to compact the sod tile into existing soil for successful transplanting. The bucket on an excavator is an excellent tool for establishing soil contact with existing wetland vegetation roots on the sod tile.

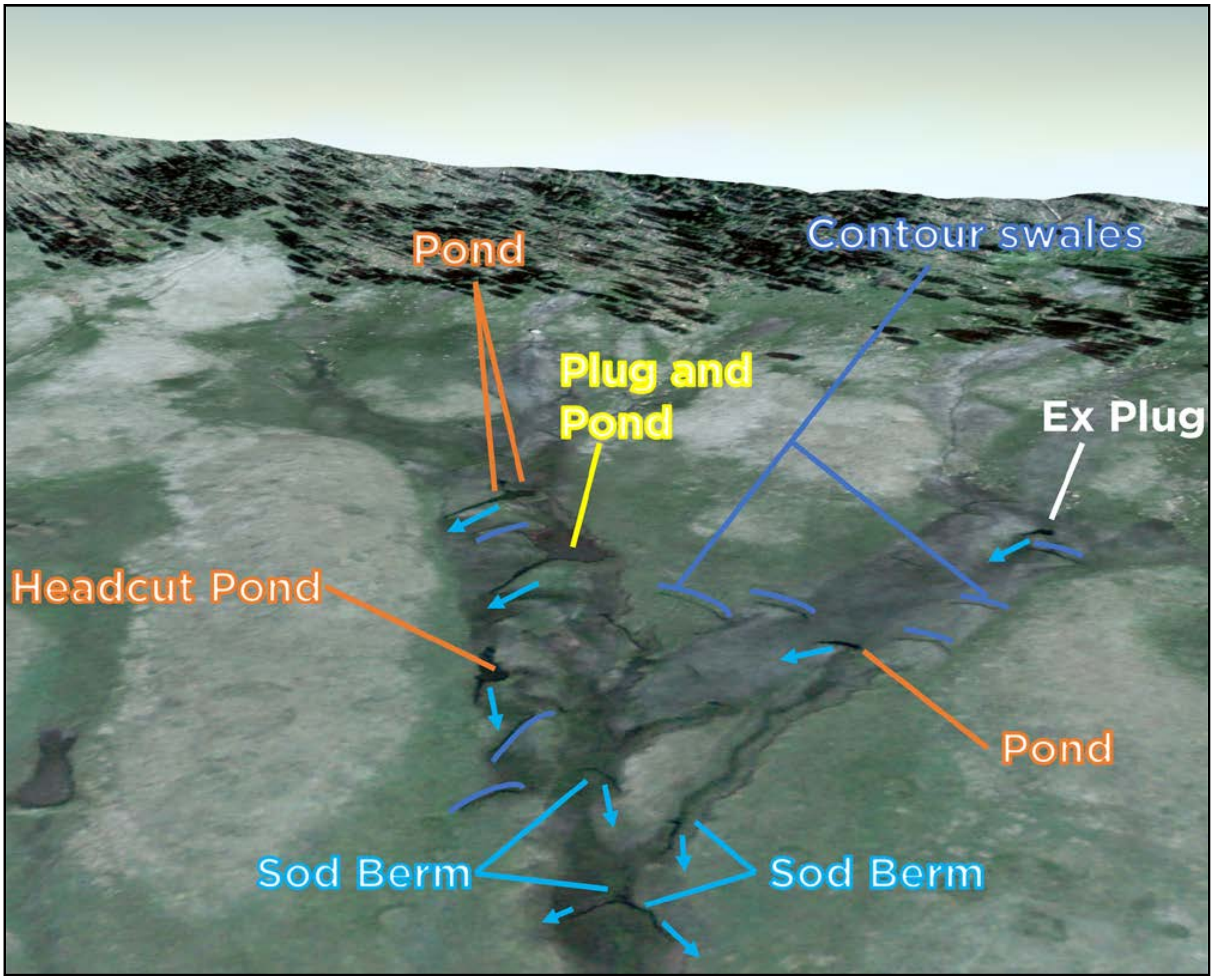






[Above] A portion of a constructed sod bowl. A Northern Leopard Frog is the small tan object in the center of pond.





[Above] Aerial photo of eastern hillside portion of East Fork Headwaters. The dark grey color is water making its way downhill. Several different types of sod restoration structures were constructed to restore hydrology to this slope wetland. Starting at the top contour swales re-distributed sheet flow across the top of the hillside. Headcut ponds treated a headcut at the top of the picture, followed by a large plug and pond. Contour swales continue to spread sheet flow to the area. Towards the bottom of the hillside (right hand side) a series of sod berms spread water across the entire bottom of the gully.

Conclusion

These sod techniques implemented together reduce erosion and restore hydrology to degraded wetlands and are rarely used alone. The aerial photo shows a portion of the eastern hillside of the East Fork Headwaters project. Several different types of sod restoration structures were constructed to repair erosion and also continually spread and infiltrate water across the hillside. The dark gray is water being spread or diverted as it moves downhill through a series of contour swales, headcut ponds, plug and ponds, excavator plugs, and finally sod berms at the bottom of the gully. Sod vegetation recovers quickly and responds to the wetland conditions created or enhanced by restoration structures.

Efficacy Monitoring

Monitoring restoration projects validates the beneficial effects these structures have on the landscape. It also provides insight on how to improve design and construction. Over the years a variety of different monitoring techniques have been used to document the response or changes from restoration work: photo points, shallow ground water wells, line point vegetation sampling plots, and wetland delineation, and they all have their challenges and limitations. Two of the most effective and efficient techniques to use to see changes in hydrology are wetland delineation and vegetation transects (line point intercept sampling).

"Wetland hydrology monitoring provides documentation of the change in hydrology of the project site before and after implementation."

Wetland Delineation

Wetland hydrology monitoring provides documentation of the change in hydrology of the project site before and after implementation.

The wetland delineation technique using U.S. Army Corps of Engineers (ACOE) standards is the baseline for this monitoring technique (Western Mountains, Valleys and Coast Region Supplement). For over 12 years, Keystone Restoration Ecology has adapted this technique to focus on hydrology and vegetation indicators, which can respond to wetland restoration techniques and the restoration of the hydrology at the project site. It allows wetlands to be delineated before and after restoration implementation and show the response within one to two years post-implementation. Hydrology indicators, in particular, respond immediately to restoration techniques, as soon as the next heavy rainfall or spring snowmelt.

This method is time sensitive, and usually performed from the last week of April to the middle of May on the VCNP, when runoff is occurring and the growing season has begun. If the budget allows, it can be paired with vegetation transect sampling as a further indicator of the wetland changes.

Vegetation indicators used are hydric plant communities listed as Obligate, Facultative Wetland, and Facultative. (Obligate [OBL] is almost always is a hydrophyte, rarely in uplands. Facultative Wetland [FACW] is usually a hydrophyte but occasionally found in uplands. Facultative [FAC] commonly occurs as either a hydrophyte or non-hydrophyte.) If these plant communities are present and dominate the area (compose 50% of the vegetation present on-site), then the area is also mapped as wetland (ACOE Western Mountains, Valleys and Coast Region Supplement).

Soil indicators are not recommended as they may take up to five years to develop after the restoration of the wetland (Fiedler, et al, 2007). In addition, the process of digging soil pits at 30-50 small wetland sites and analyzing soils can be too time consuming and expensive, and each soil pit would potentially disturb archaeological resources.

Many of the soils on lower slopes at the Valles Caldera National Preserve are histosols, which formed in cold wet conditions. For histosols in degraded wetland areas drained by gullies, the hydric indicators may still indicate the soil as formed under hydric conditions even if the hydrology and vegetative indicators are no longer present. This false positive, so to speak, can be confusing when analyzing soil samples and is another reason soil indicators are not used with this Wetland Delineation monitoring technique.

Wetland Delineation Indicators

The survey area is assessed for hydrology indicators early in the growing season, which begins in May in the Valles Caldera. Weather station data are analyzed for an approximate date determined to be the "start of the growing season." This is determined by soil temperature readings at the nearest weather station. In this case, the Valles Caldera has a weather station located in the same area as the East Fork Jemez Innovative Wetland Restoration Project, about three miles away.

The growing season has begun on a site in a given year when two or more different non-evergreen vascular plant species growing in the wetland or surrounding areas exhibit one or more of the following indicators of biological activity:

a) Emergence of herbaceous plants from the ground.

b) Appearance of new growth from vegetative crowns (e.g., in graminoids, bulbs, and corms).

c) Coleoptile/cotyledon emergence from seed.

d) Bud burst on woody plants (i.e., some green foliage is visible between spreading bud scales).

e) Emergence or elongation of leaves of woody plants.

f) Emergence or opening of flowers.

Hydrology Indicators

The U.S. Army Corps of Engineers (2005) provides a technical standard for monitoring hydrology on such sites. This standard requires 14 or more consecutive days of flooding or ponding, or a water table 12 in. (30 cm) or less below the soil surface, during the growing season, at a minimum frequency of 5 years in 10 (i.e., a 50 percent or higher probability).

The following table for wetland hydrology indicators is used. (See **bold** sections.)

Table 12. Wetland Hydrology Indicators for Western Mountains, Valleys and Coast Region

Indicator	**Category**	
	Primary	**Secondary**
Group A – Observation of Surface Water or Saturated Soils		
A1 – Surface water	**X**	
A2 – High water table	**X**	
A3 – Saturation	**X**	
Group B – Evidence of Recent Inundation		
B6 – Surface soil cracks	**X**	
B7 – Inundation visible on aerial imagery	**X**	
B9 – Water-stained leaves	X	
B11 – Salt crust	X	
B12 – Biotic crust	**X**	
B13 – Aquatic invertebrates	X	
B1 – Water marks	X	X (riverine)
B2 – Sediment deposits	X	X (riverine)
B3 – Drift deposits	X	X (riverine)
B10 – Drainage patterns		X
Group C – Evidence of Current or Recent Soil Saturation		
C1 – Hydrogen sulfide odor	**X**	
C3 – Oxidized rhizospheres along living roots	**X**	
C4 – Presence of reduced iron	X	
C6 – Recent iron reduction in tilled soils	X	
C7 – Thin muck surface	**X**	
C2 – Dry-season water table		**X**
C8 – Crayfish burrows		X
C9 – Saturation visible on aerial imagery		X
Group D – Evidence from Other Site Conditions or Data		
D3 – Shallow aquitard		X
D5 – FAC-neutral test		X

Hydrophytic Vegetation Indicators

Hydrophytic vegetation is present when the plant community is dominated by species that tolerate prolonged inundation or soil saturation during the growing season.

Lighter green vegetation is a mix of Carex utriculata/Carex praegracilis. Darker green vegetation is Juncus balticus responding to increased wetness.

According to the Western Mountains, Valleys and Coast Region Supplement (p. 13), if more than 50 percent of the dominant plant species across all strata are rated OBL, FACW, or FAC, the area is a wetland. This is called the "dominance test" and is the primary technique used to delineate hydrophytic vegetation. If the plant community fails the dominance test, but indicators of hydric soil and wetland hydrology are both present, the prevalence test is used (Indicator 2).

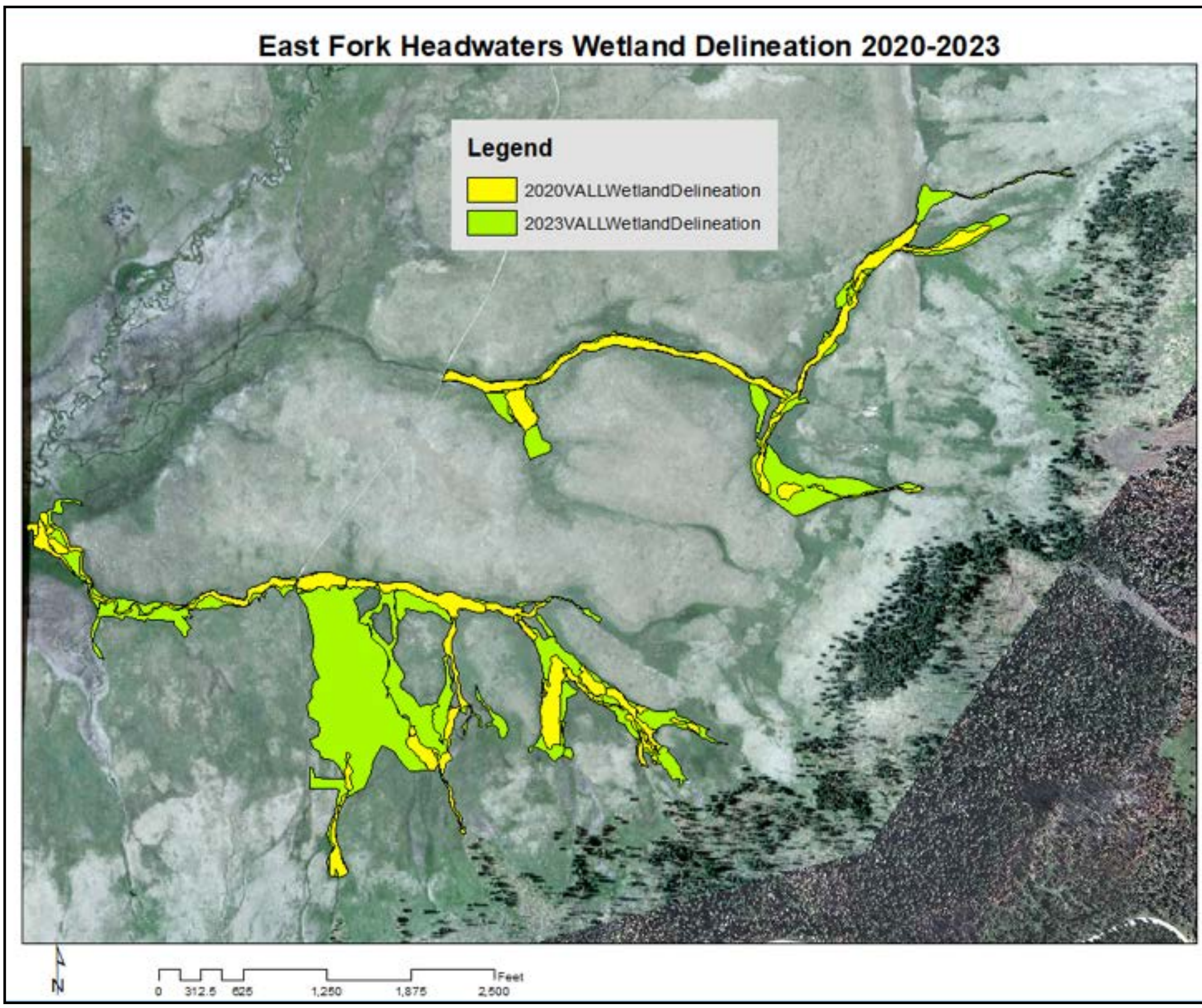
To calculate the prevalence index, at least 80 percent of the total vegetation cover on the plot (summed across all strata) must be of species that have been correctly identified and have an assigned wetland indicator status (Reed 1988 or current list) or are upland (UPL) species.

Once the major vegetative units are identified, the boundaries between wetland and upland communities are mapped with a sub-meter GPS. To assist in identification of the boundary, one technician walks ahead with "pin flags," marking the boundaries of each wetland unit. The second person follows behind with the GPS and walks the boundary. This two-step process has been found to help reduce errors such as mapping the same site twice, or missing small clumps of wetland vegetation.

Post-Implementation Re-Survey

Once the site has been delineated for wetland vegetation and hydrology, the project is usually implemented in the fall of that year or spring of the following year. Since the major vegetative units have already been mapped, a GPS map of the delineated wetlands is used to guide the post-implementation delineation. The first indicator that appears is the wetland hydrology indicator; this may occur as soon as 1-2 months after implementation, depending on rainfall. Surface water, drift lines, and a high water table can all be seen.

Hydrophytic vegetation may take 2-3 years after implementation to meet the dominance test. However, several vegetative features may show hydrology of the site has been restored. Kentucky bluegrass (*Poa pratensis*) and Dandelion (*Taraxacum officinale*) are very prevalent at the Valles Caldera National Preserve, and both bloom in profusion in May-June with the addition of more water. In year two after implementation, remnant wetland vegetation such as *Juncus balticus* begins to dominate and the Kentucky Bluegrass and Dandelion may begin to die off, leaving areas of bare soil between the *Juncus balticus* stems.



Wetland Delineation Comparisons

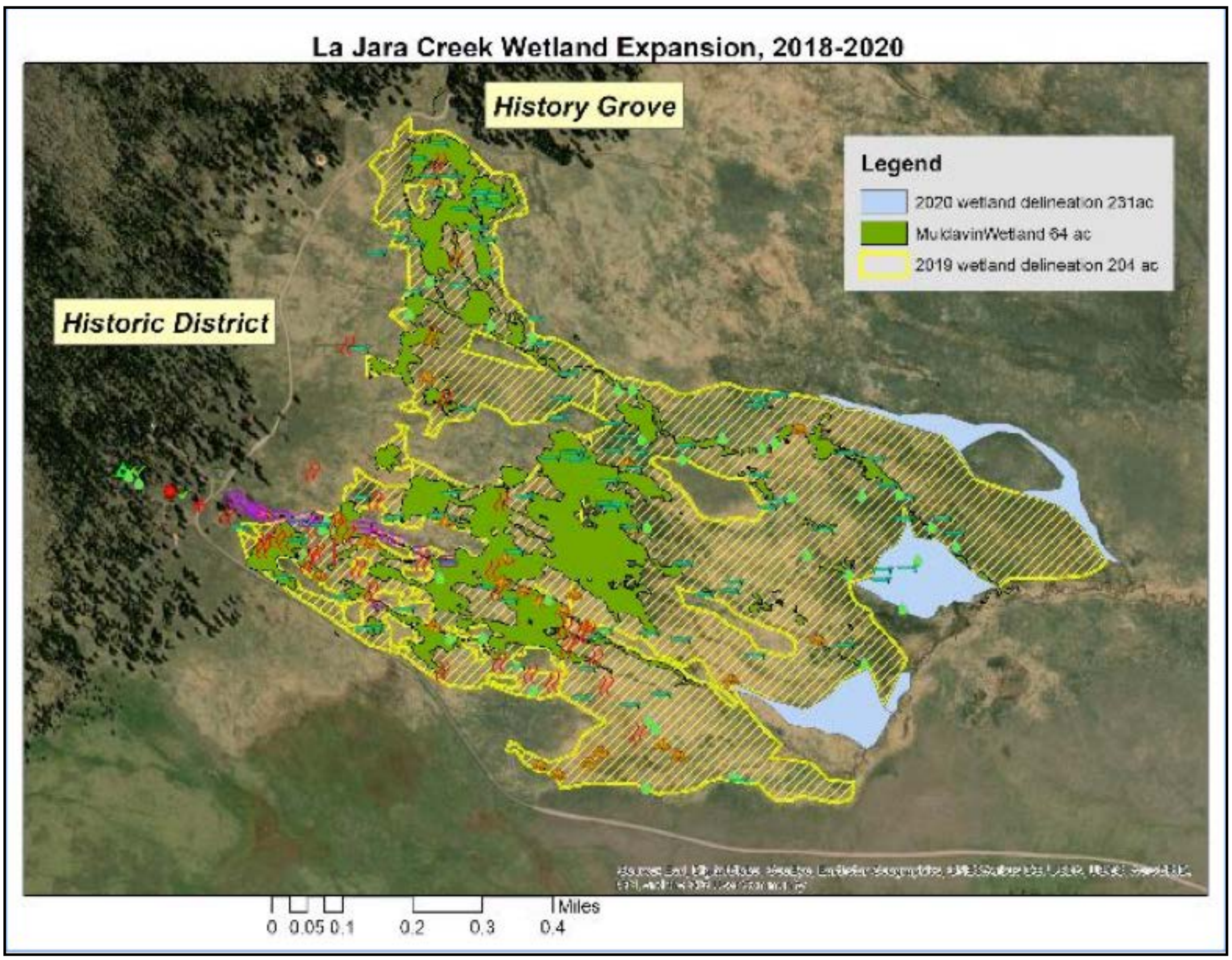
The wetland delineation monitoring technique was conducted on the East Fork Headwaters project in the spring of 2020. The hydrology and vegetative indicators were used to map the area. The total amount of wetland acres was 33.8 acres (shown in yellow on the map on page 37). In 2023 the project area was mapped again with the same technique and the wetland acres totaled 98.8 (shown in green).

The change in wetland acres is an increase of 65 acres between 2020 and 2023. This project area has a relatively steep grade (approximately 4% on the hillsides) for the slope wetlands and the wetlands are spring fed.

In other project areas in the Valle Grande, where the East Fork Headwaters project is located, projects have expanded, enhanced, or created new wetlands.

Three years after restoration project wetland delineation comparison showed an increase of 167 acres.

The La Jara Creek wetland restoration project *(Restoring La Jara Creek from Damage from the Thompson Ridge Fire)* was implemented in 2017 and was a one square mile slope wetland fed by La Jara Creek. A wetland delineation was performed on a subset of 60 acres of the project area by the Valles Caldera National Preserve vegetation crew



prior to project implementation. This delineation matched an aerial vegetationassessment performed by the New Mexico Natural Heritage (Muldavin and Tonne, 2003). The wetland area in the NM Natural Heritage data was mapped as 64 acres prior to implementation.

When the wetland delineation was repeated in 2019, wetland acreage had increased to 204 acres and in 2020 the wetland area was 231 acres. (See map on page 38.) These slope wetlands were less steep and fed by La Jara Creek, a perennial stream, and an un-named perennial stream near the History Grove. Since the area was once almost entirely wetland and fed by perennial streams, the impacts of restoration treatments were phenomenal.

A restoration project on lower Jaramillo Creek in the Valle Grande, a tributary to the East Fork, was completed in 2021. A year later, in 2022, the project area was delineated again and there was an increase of 111 wetland acres (43.8 acres before project and 146 acres after implementation. See map on page 40.).

This project involved stream restoration as well as wetland restoration treatments on the floodplain and terraces of the lower Jaramillo Creek.

The most effective stream restoration technique for wetland expansion was stream realignment to a historic channel. By plugging the Creek and restoring it to an abandoned channel, Jaramillo Creek was reconnected with its floodplain. Winter snowmelt was able to spread over many acres of former wetland that had been abandoned by downcutting and erosion.

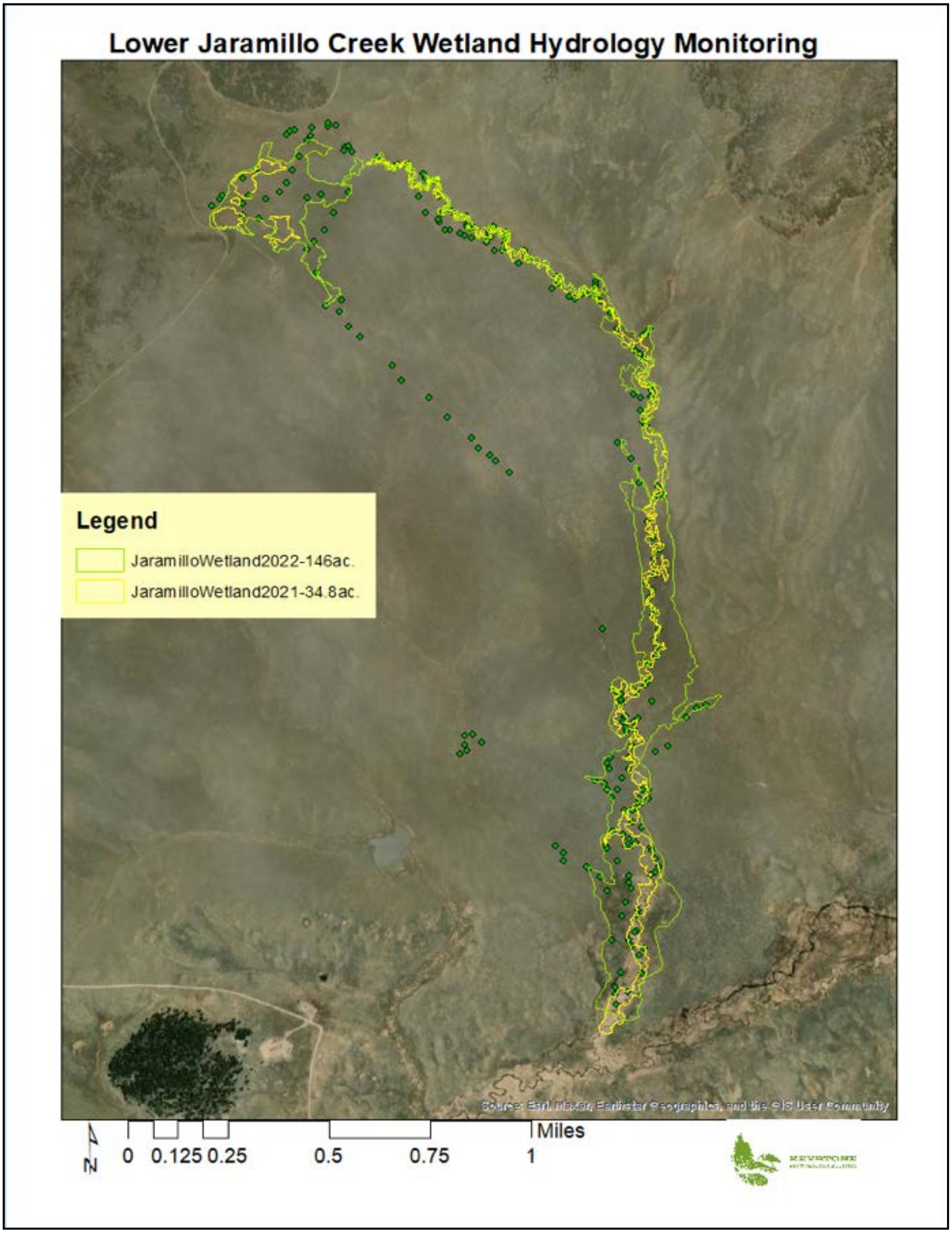
Vegetation Monitoring Transects, Line-Point Intercept

In addition to the wetland delineation monitoring, the Valles Caldera National Preserve vegetation survey crew completed vegetation transects before (2020) and after project implementation (2021, 2022) on the East Fork Headwaters Project. While wetland delineation offers a broad-brush assessment of wetland areas, vegetation transect data provide specific vegetation comparison between restoration treatment sites and control (reference) sites.

Three treatment-monitoring plots were installed and sampled before restoration activities took place in 2020 and again in 2021 and 2022, post-restoration. Each treatment plot consisted of three 100-foot transects running parallel to each other. The location for these lines was determined on site by Keystone Restoration Ecology and laid out perpendicular to the direction of water flow expected after construction. These vegetation plots are in locations that capture plant community changes resulting from wetland restoration.

There are numerous reference sites from which to compare

Wetland delineation comparison showed an increase of 111 acres a year after project implementation.



against in the watershed and elsewhere across the Valles Caldera National Preserve. The control plots that were selected as references for this monitoring project were installed in 2001 as part of a rangeland and riparian monitoring program. The control sites for this project consist of one riparian and two wet mountain meadow sites in areas with similar landforms to the treatment sites but with existing wetland vegetation composition. The control sites were also sampled in 2020, 2021, and 2022.

Methods. Each treatment monitoring plot consists of three 100-foot transects while each control plot is made up of three 100-meter transects. Vegetation data were collected using the line-point intercept sampling method where data were recorded at each foot or meter along each transect for a total of 100 points per line. Measurements were taken with the use of a thin rod, 1.2 meters in length by 1 cm in diameter. The species of every live plant touching the rod, or intersecting the vertical line drawn by the rod from the top of the plant canopy down to the ground surface, was recorded to species level in most cases.

The surface substrate touched by the base of the rod at ground level was also recorded and used to determine basal litter coverage. If one species occurred more than once at a particular point, only its highest appearance was recorded. Canopy height measurements, estimated to the nearest centimeter, were recorded as the height of the point at which the tallest plant intersected the sampling rod. Two photos were taken of each transect line with the measuring tape present on the ground for a total of six photographs per site per year.

Selecting Control (Reference) Sites. Ideally control (reference) sites would be degraded wetlands left untreated within the project area, which would show restoration effects on degraded wetlands and control for variables such as rainfall and hydrology. However, in the Valles Caldera National Preserve several established monitoring sites are available as part of a long-term monitoring program. The reference sites chosen for the East Fork Project were healthy wetland sites.

Table 1: Vegetation Transect Monitoring Plots

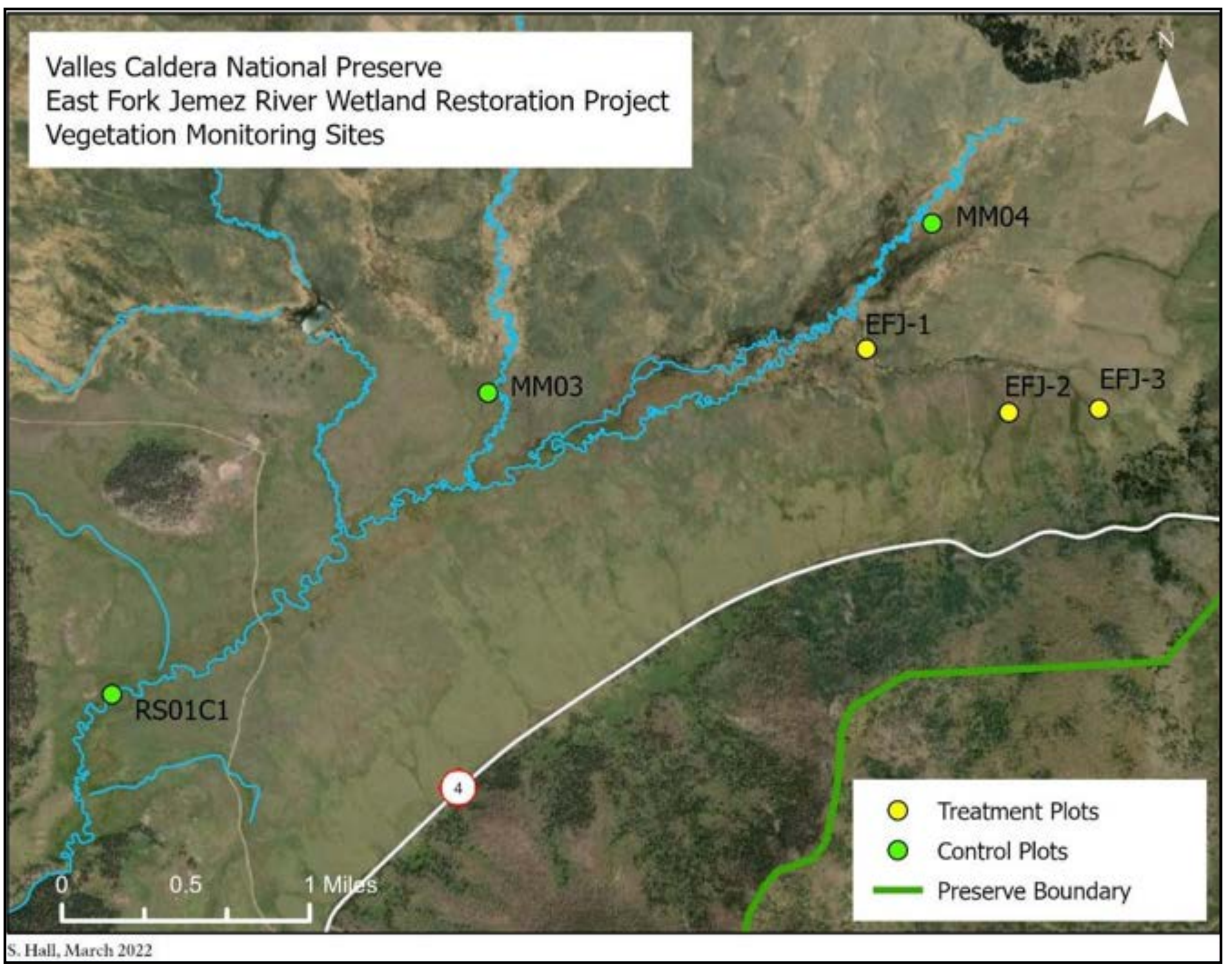
Plot Name	Treatment Type	Habitat Type
EFJ-1	Treatment	Slope Wetland
EFJ-2	Treatment	Slope Wetland
EFJ-3	Treatment	Slope Wetland
MM03	Control	Wet Mountain Meadow
MM04	Control	Wet Mountain Meadow
RS01C1	Control	Riparian

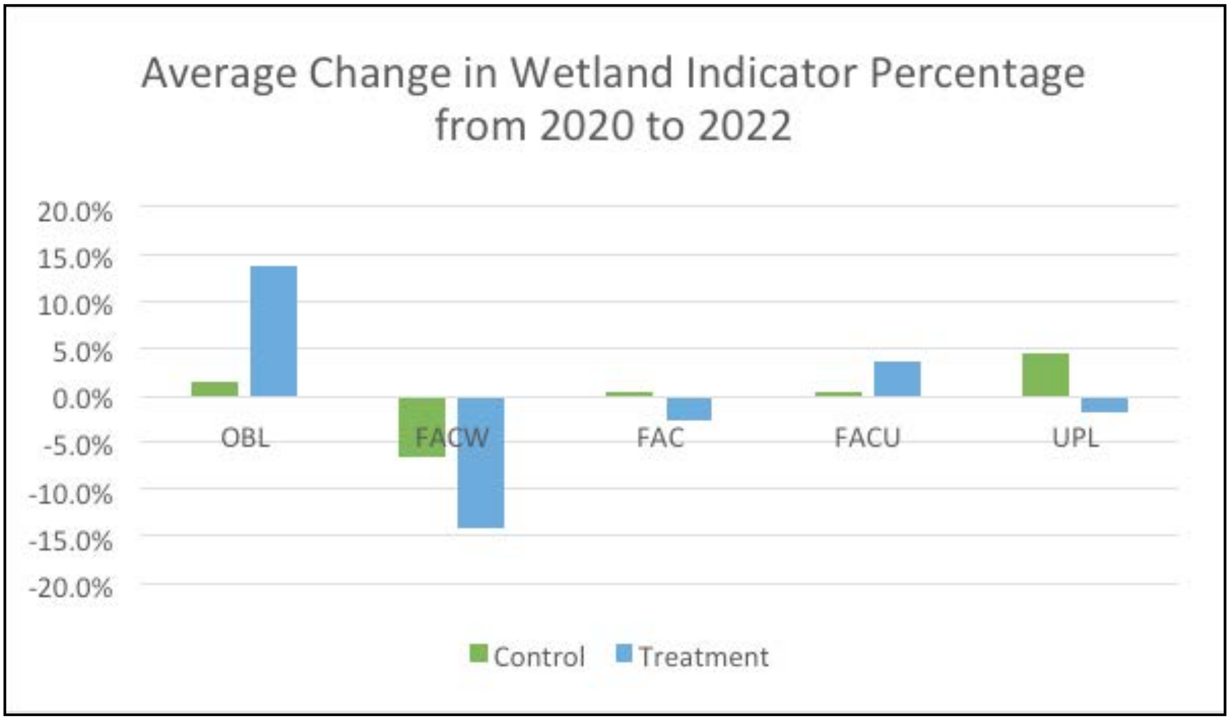
In general, the most common plants in the treatment plots were *Juncus* species, Kentucky bluegrass, and *Carex* species. The Preserve was an active ranch for many years before being sold to the federal government so it's not surprising to find pasture grasses in these plots.

The most common plants found in the control plots were similar in that they also had *Juncus* species, Kentucky bluegrass, and *Carex* species at the top, as well as yarrow. The most common rush species in all plots was *Juncus arcticus ssp. littoralis* (syn. *Juncus balticus*), which is considered a facultative wetland species. *Carex praegracilis*, a facultative wetland species, was a relatively common sedge found in most sites, especially the treatment sites. Other *Carex* species such as *Carex utriculata* and *Carex aquatilis*, both obligate wetland species, were not present in past years but were present in 2022 in both treatment and control sites.

The results indicate that the treatment sites showed an increase in obligate species and a decrease in facultative wetland species compared to

Map shows the location of control and treatment plots located in the Valle Grande on the southeastern border of the Valles Caldera National Preserve.





pre-restoration. Two out of three treatment sites saw a decrease in facultative species, while facultative upland species mostly remained the same and upland species declined. Compared to healthy wetland control sites, two out of three saw a decrease in obligate species with facultative species remaining the same and upland increasing.

One control site did show an increase in obligate and facultative species and a decrease in facultative wetland and facultative upland while upland species remained the same.The wetland indicator percentages were averaged across plots--separately, for treatment and control sites and then the difference between 2020 and 2022 was calculated. As expected, the control plots did not change as much as the treatment sites. Interestingly, the treatment sites saw an overall increase in obligates and decrease in facultative wetland species. Treatments also saw minor decreases in both facultative and upland species with a small increase in facultative upland species.

Prevalence

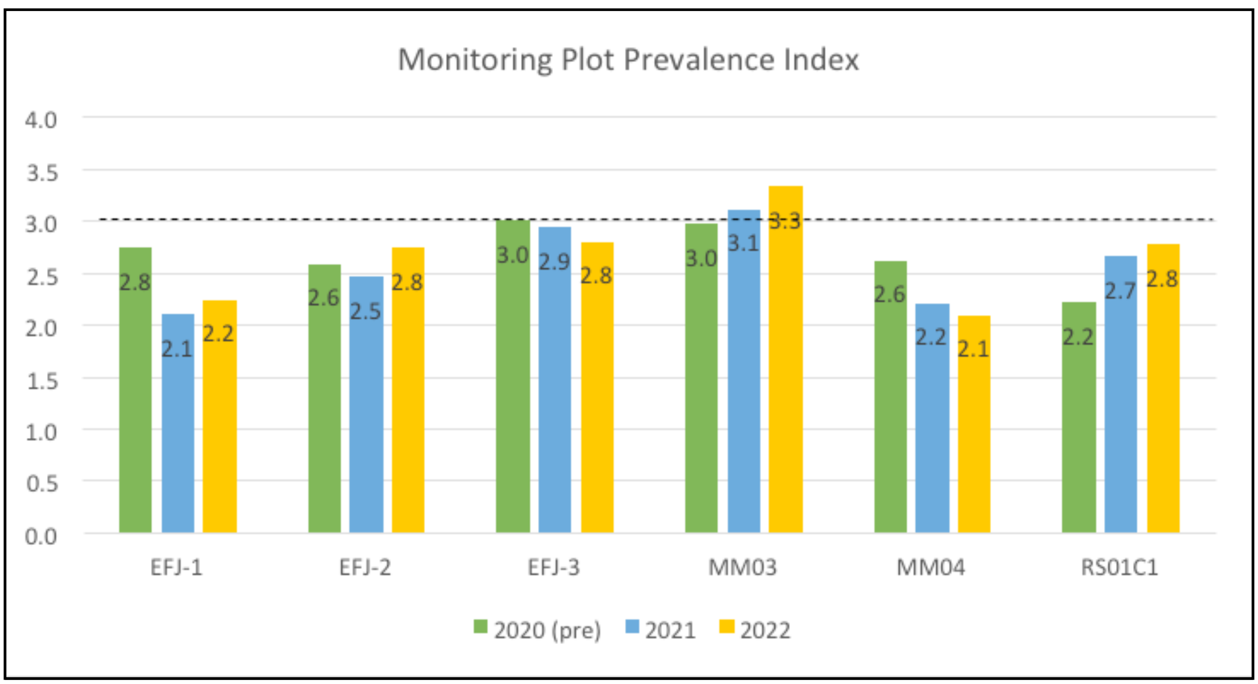
The ACOE Western Mountain, Valleys, and Coast Regional Supplement states that the most accurate way to use point-intercept sampling to measure for hydrophytic vegetation is by prevalence index. All species hits (one per species per point) are totaled and then categorized by wetland indicator status. For this project, data were grouped by plot. The vegetation community is considered hydrophytic if the prevalence index is 3.0 or less. The following formula was used to determine prevalence index:

where:

$$PI = \frac{F_{OBL} + 2F_{FACW} + 3F_{FAC} + 4F_{FACU} + 5F_{UPL}}{F_{OBL} + F_{FACW} + F_{FAC} + F_{FACU} + F_{UPL}}$$

PI = Prevalence index
FOBL = Frequency of obligate (OBL) plant species
FFACW = Frequency of facultative wetland (FACW) plant species
FFAC = Frequency of facultative (FAC) plant species
FFACU = Frequency of facultative upland (FACU) plant species
FUPL = Frequency of upland (UPL) plant species

As seen from the graph below, all plots except for control site MM03 could be considered hydrophytic in 2022. There are multiple factors beyond ecological restoration activities that could affect a change in vegetation. The monsoon season produced more rain in 2022 than in 2021 and 2020. On the other hand, there was a smaller snowpack during both the 2020-2021 and 2021-2022 winter than in previous winters. Vegetation takes multiple growing seasons to establish after disturbance caused by the restoration process. Therefore, it is important to monitor for multiple years post-restoration.



Valle Seco Vegetation Results

The project *Innovative Restoration of Historic Wetlands along Sulphur Creek, Valles Caldera National Preserve* began in 2013 and was completed in 2017. Vegetation data was collected using the line point intercept protocol (Herrick, et al, 2005). A total of seven transects were established; 4 transects at treatment sites and 3 at control sites. Treatment sites were established downstream of treatment locations where runoff water would be spread and infiltrate onto abandoned wetland surfaces. Control sites were located on former wetland surfaces that were left untreated.

Total numbers of vegetation "hits" identified are represented on the Y axis of Figure 5. Each point on the line-point intercept can have multiple species due to vegetation layers. The total percent of vegetation cover was compared before treatments were implemented (2013) and after (2017) at both the treatment and control sites.

Results of the linear regression models shows a significant difference (P-values: 2017 = 0.0248 *) in the change in the percentage of cover between control sites and treatment sites at Valle Seco between 2013 and 2017. Total cover at control sites was slightly lower than at

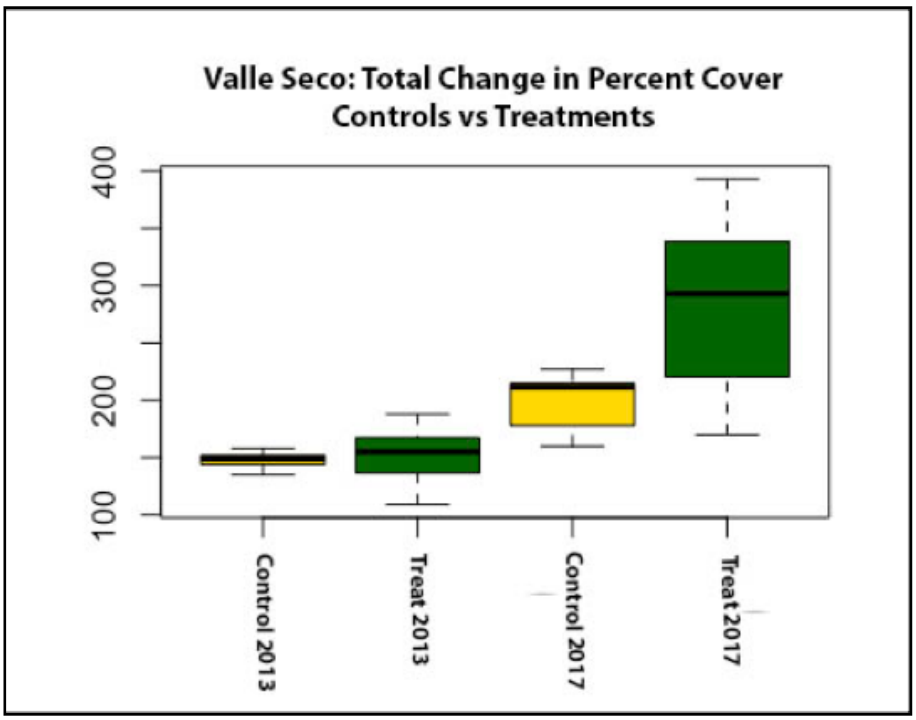


Figure 5. Comparison of vegetation changes in percent cover along Valle Seco treatment and control transects.

treatment sites in 2013, but by 2017 total percent cover increased at both control and treatment sites. However, vegetation cover at treatment sites increased by over 100 percent and only increased by approximately 50 percent at control sites, indicating that treatments had a significantly positive effect on total percent cover. The increase in total percent cover at control and treatment sites between 2013 and 2017 is likely due to the removal of cattle from the landscape between 2014 and 2017.

Figure 6 (below) provides a more detailed description of total cover and total wetland cover at control versus wetland sites. This graph represents the difference (change) between percent cover between 2013 and 2017. While total cover increased for all sites, including control sites, in most cases total cover increased more at treatment sites, with the exception of site 5 transect 1. Total wetland cover decreased along three transects at two different control sites and increased at all treatment sites. Overall, the total increase in wetland cover at treatment sites was higher than at control sites.

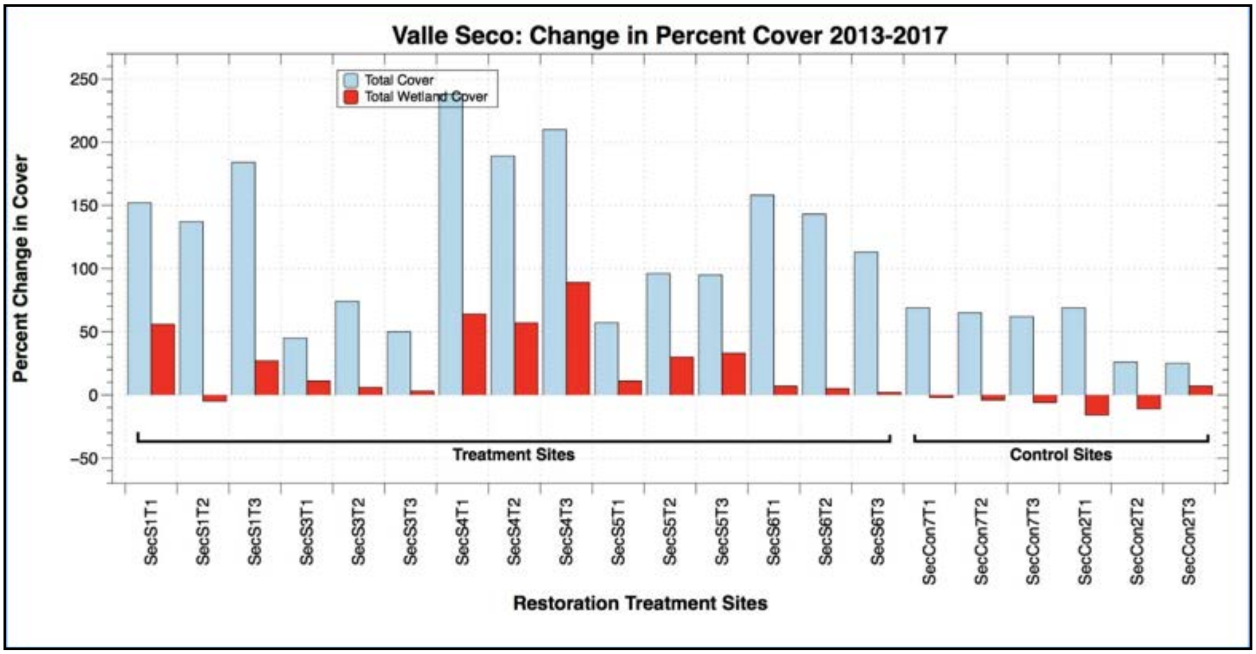


Figure 6. Comparison of vegetation changes in percent cover and wetland species cover along Valle Seco treatment and control transects.

Figure 7 (page 47) clearly shows an increase in wetland species cover at all treatment sites and a reduction of wetland species cover at control sites. Results of linear regression models indicate a high level of significant difference between control sites and treatment sites (p-value: 0.02094). This shows that treatments are increasing wetland cover even in years when wetland cover is naturally decreasing due to low amounts of precipitation.

Figure 8 (page 47) provides a detailed analysis of the percent change in cover between 2013 and 2017 for specific FAC, FAW and OBL species at treatment vs control sites. Results showed the most significant increase for *Poa Pratensis* (p-value: 0.007645), which is a facultative wetland species. Similarly, all *Carex* species (FAC and OBL) increased relative to control sites (p-value: 0.02094) and the increase in *Juncus arcticus* (OBL) was noticeable, but not significant compared with control sites (p-value: 0.782).

Overall, these results provide an interesting comparison with

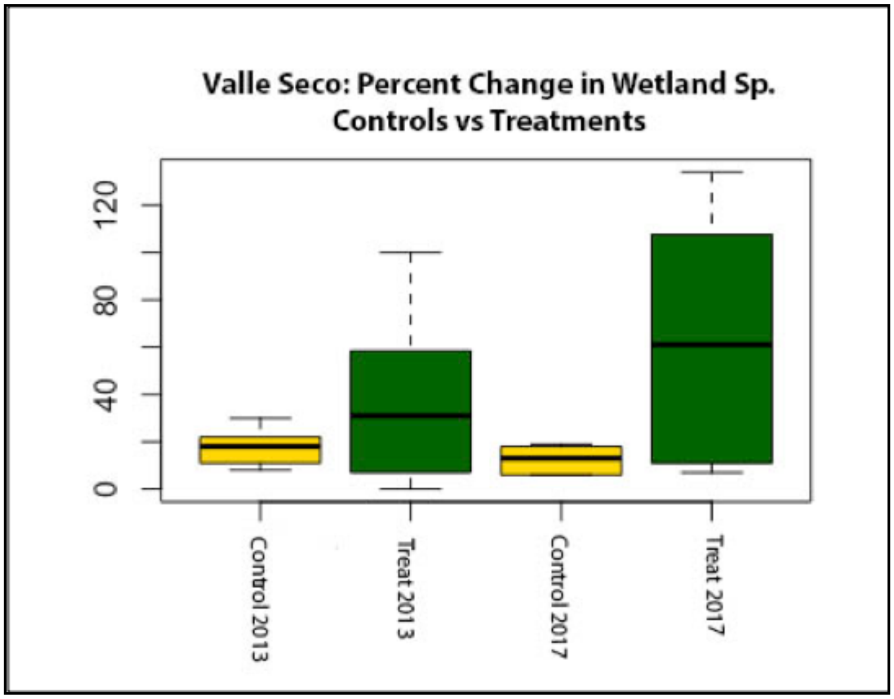
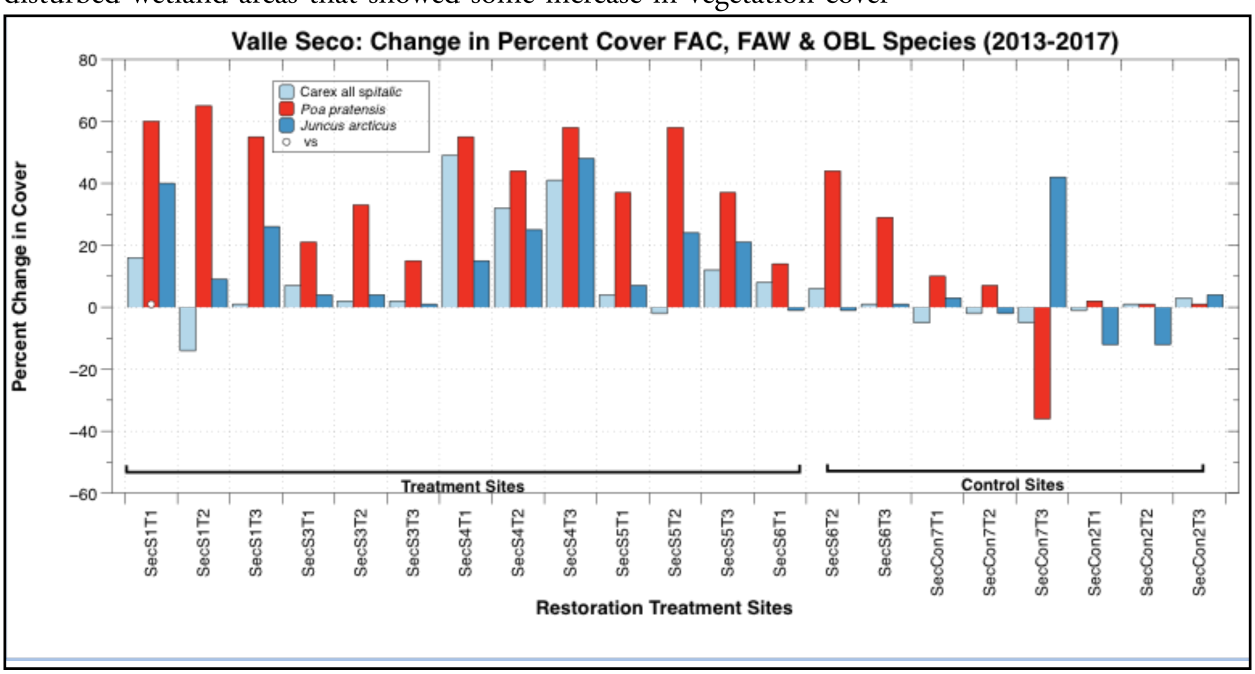


Figure 7. Comparison of change in wetland species along Valle Seco control versus treatment transects.

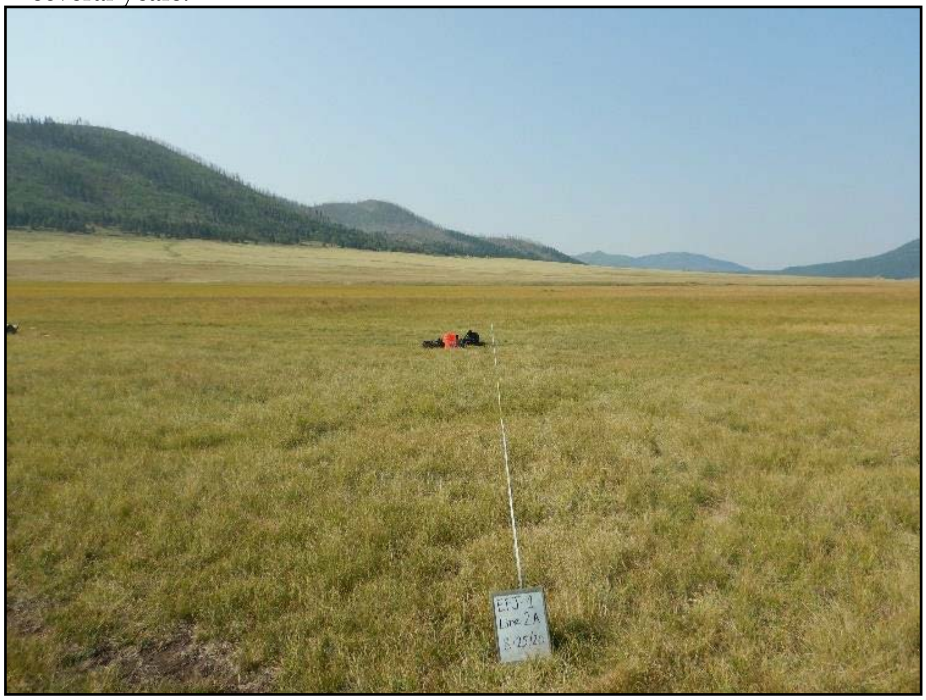
the East Fork Headwaters Line-Point Intercept Monitoring. The East Fork Line-Point Monitoring used control transects that were existing wetlands, and the monitoring results showed that the treatments and controls were similar, both showing hydrophytic vegetation in 2022, two years after treatment. The Valle Seco project showed a significant increase in wetland species in treatment versus control. Controls were untreated, disturbed wetland areas that showed some increase in vegetation cover

Figure 8. Percent cover of FAC, FAW, and OBL species along Valle Seco control versus treatment transects.



due to a cessation of cattle grazing during the project. Both project results show the effectiveness of wetland restoration treatments over several years.

Examples of the photos taken by the Valles Caldera Vegetation survey crew during their transect monitoring. The top is 2020 and the bottom is the same spot in 2022.



Conclusion

The use of these techniques at the watershed scale on small incised tributary wetlands and alluvial fans has restored hundreds of acres of wetlands across thousands of acres of the Valles Caldera National Preserve. Construction costs for the work has been between $500 to $2,000 per acre of wetland restored, which is extremely cost-effective.

Locations for these techniques can easily be identified through LiDAR analysis and confirmed through ground-based assessment. Working at the watershed scale on 1st order streams allows for treatment of hundreds of acres for the cost of a single restoration project on a stream or river, and leads to landscape-wide benefits for wildlife and ecosystem stability.

Most of the treatments demonstrated in this guide work on the same principle of diverting water captured in a gully back to its natural and historic flow path. The concept of looking for stream capture on the smallest scales and restoring natural flow paths can be done anywhere, and the techniques are merely a way to achieve that goal. A desert project, for example would most likely use rock in the structures rather than sod, which would not grow on-site.

Oxidation and Reduction (Redox) Dynamics and Nutrient Buffering at Plug and Pond Restoration Sites in the Valles Caldera National Preserve

These wetland restoration techniques are being studied on the Valles Caldera National Preserve as a treatment for post-fire flooding, sedimentation, and nutrient pollution. The Las Conchas Fire in 2011 burned 150,000 acres, including most of the eastern Jemez Mountains. About one-third of the Valles Caldera National Preserve was burned in the Las Conchas Fire, resulting in enormous losses to forests, fisheries, and wildlife.

Since 2015, a partnership with Los Alamos National Laboratory's Earth Systems Operations Group (EES-14) on multiple projects has studied stable isotope analysis to address questions of nutrient transport, sediment capture, and hydrology. The study goals are as follows:

1) Understand if restored wetlands are functioning similarly to existing wetlands and have reducing conditions (where soils saturated with water use up all available dissolved oxygen resulting in an alteration of the soil chemistry to hydric).

2) Understand how restoration of wetlands can address wildfire flooding and pollution and protect resources from damage.

3) Study the source of water on the landscape and understand how these restoration projects can attenuate snowmelt and maintain baseflow.

"Detailed geochemical depth profiles generated from diffusion cell samplers in constructed ponds showed frequent occurrence of strongly reducing conditions in the established restoration watershed, and reducing conditions also developed within six months in the two newly treated watersheds."

Wetland Restoration and Creation

A number of techniques were utilized to study restored versus healthy wetlands and understand if reducing conditions were being created in the restored wetlands. Detailed geochemical depth profiles generated from diffusion cell samplers in constructed ponds showed frequent occurrence of strongly reducing conditions in the established restoration watershed, and reducing conditions also developed within six months in the two newly treated watersheds. The amount of reducing conditions appears to depend on the construction of the pond; pond dams built out of clay have reducing conditions deep into the soil, while ponds built on porous sediments only have reducing conditions in a 20 cm muck layer at the bottom of the pond (Jacobs, et al, 2016).

Water Source, Residence Time

A number of water samples were taken from intermittent creeks and shallow groundwater wells placed in restored wetlands, and a number of stable isotopes were analyzed, in particular hydrogen and oxygen (δ^2H and δ^{18}O). The slope of the meteoric water line can show a difference in the source of water (from snowmelt or rainfall) and whether there have been significant amounts of evaporation. The data from all sites show that the source of stream and spring waters is predominantly snowmelt with some rainfall infiltration and interflow through soils from summer monsoons (Jacobs, et al., 2016).

An investigation on a large wetland restoration project on La Jara Creek (see *Efficacy Monitoring* section, p. 33) was performed to see if the implementation of 206 restoration structures in a large wetland fed by La Jara Creek caused significant evaporation or water loss. A small set of stable isotope samples (δ^2H and $\delta^{18}O$) were collected after construction and below most of the restoration activities to assess potential evaporation loss. The data from La Jara are essentially indistinguishable from precipitation data and show no evidence of an evaporation effect.

The purpose of these structures is to spread snowmelt and runoff across wetlands drained by small and large gullies and to store that water underground, so it can flow as "interflow" downstream to springs and streams. These techniques have evolved to make the "ponds" as small as possible, and to limit the amount of water in ponds that might be subject to evaporation. At the La Jara Restoration Project, two of the samples were collected from shallow ponds just above the drainage channel near the La Jara 7 stream discharge measurement site. These would be expected to have the most evaporative isotopic values but they show no evidence of significant evaporation.

Due to funding constraints, the residence time of water on the landscape using isotopes such as tracers has not been directly studied. However, spreading water across the landscape and saturation of shallow sediments should lead to attenuation of snowmelt and storage of water underground where it will not evaporate. This should help maintain baseflow and provide water supplies to users downstream.

Wildfire Flood Protection

The reducing conditions that develop can help buffer transport of nutrients to downslope areas and streams, and the extent of reduction observed suggests such ponds may be effective for reducing concentrations of some redox sensitive contaminants. Sampling at restoration sites even showed restored wetlands can process slurry from fire retardant that was captured in a plug and pond structure. The nutrient spike occurred after a heavy rainfall event, and levels returned to baseline in one month's time in the highly reducing environment sub-surface (Newman, et al, 2018).

Plug and pond and other restoration structures could be utilized as a protective measure for post-fire flood management, either immediately after the fire, or preventively, before a watershed burns. The installation of a series of plugs could capture a great amount of the sediment and nutrient produced by post-fire flooding and use this sediment to restore gullied wetlands and alluvial fans while protecting downstream resources such as water quality, wildlife, and infrastructure.

Wildlife

While considerable monitoring and research have been conducted on the response of vegetation and hydrology to plug and pond treatments, such treatments can also have a positive impact on vertebrates, insects, and soil microbes. At our project sites, the colonization by amphibians such as the endangered Northern Leopard Frog (*Lithobates pipiens*) was observed at treatment sites within a few days after pond construction and filling with water. Small excavator plug ponds off of the main channel with water were found to be full of tadpoles, and provide a refuge from trout predation.

Northern Leopard Frog Tadpoles in Excavator Plug.

Bibliography

Fiedler, S., Vepraskas, M.J., Richardson, J.L. (2007). Soil Redox Potential: Importance, Field Measurements, and Observations, Editor(s): Donald L. Sparks, *Advances in Agronomy,* Academic Press, Volume 94, Pages 1-54.

Hammersmark, C. T., Rains, M. C., & Mount, J. F. (2008). Quantifying the hydrological effects of stream restoration in a montane meadow, northern California, USA. *River Research and Applications*, 24(6), 735–753.

Hammersmark, C. T., Dobrowski, S. Z., Rains, M. C., & Mount, J. F. (2009a). Simulated Effects of Stream Restoration on the Distribution of Wet-Meadow Vegetation. Restoration Ecology, 18(6), 882–893.

Hammersmark, C. T., Rains, M. C., Wickland, A. C., & Mount, J. F. (2009b). Vegetation and water-table relationships in a hydrologically restored riparian meadow. Wetlands, 29(3), 785–797.

Herrick, J., VanZee, J.W. & Havstad, K. (2005). Monitoring manual for grassland, shrubland and savanna ecosystems. Vol. I: Quick start.

Herrick, Jeffrey & Zee, Justin & McCord, Sarah & Courtright, Ericha & Karl, Jason & Burkett, Laura. (2017). Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems, Volume I: Core Methods.

Jacobs, E., Heikoop, J., and Newman, B., CY2016 Final Report: Watershed Restoration from Wildfire at the Valles Caldera National Preserve, Surface and Alluvial Groundwater Chemistry.

Martin, C. (2003). Valle Grande: A History of the Baca Location No 1. Los Alamos NM: All Seasons Publishing.

Muldavin, E., Tonne, P. (2003). A Vegetation Survey and Preliminary Ecological Assessment of Valles Caldera National Preserve, New Mexico. New Mexico Natural Heritage Program

Newman, B.D., Heikoop, J., Musa, D., Koger, J., Perkins, G., Kelly,R., and Vrooman, S. Stable Isotope and Geochemical Investigations at Plug and Pond Restoration Sites in the Valles Caldera National Preserve, New Mexico. USA Report on the Valles Caldera Watershed Restoration NMSBA Leveraged Small Business Assistance Project 12/19/2018.

Reed, P. B., Jr. (1988). National list of plant species that occur in wetlands: 1988 national summary. Biological Report 88(24). Washington, DC: U.S. Fish and Wildlife Service.

Rosgen D. (1997). A Geomorphological Approach to Restoration of Incised Rivers. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision.

Valentin, C., Poesen, J., & Li, Y. (2005). Gully erosion: Impacts, factors and control. Catena, 63(2-3), 132–153.

US Army Corps of Engineers (2010). Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys and Coast Region (Version 2.0). Wetlands Regulatory Assistance Program.

Wilcox, J. (2010). The Plug and Pond Treatment for Stream and Meadow Restoration: Resource Effects and Design Considerations. A Briefing Paper for Plumas National Forest Resource Specialists and Managers, V 1.0.

Zeedyk, B. and Clothier, V. (2014). *Let the Water Do the Work - Induced Meandering, an Evolving Method for Restoring Incised Channels.* Chelsea Green Publishing.

Zeedyk, B. and Vrooman, S.S. (2017) The Plug and Pond Treatment: Restoring Sheetflow to High Elevation Slope Wetlands in New Mexico. New Mexico Environment Department, Surface Water Quality Bureau Wetlands Program.

Projects on the Valles Caldera National Preserve

Los Amigos
Restoring Wetlands and Wet Meadows on the Valles Caldera National Preserve; through EPA Assistance Agreement with NMED CD#366449-01. 2007-2011: $143,130.

Continuing Restoration Work on San Antonio Creek FY10-C . State of New Mexico Professional Services Contract No. 10-667-5000-0012. 2009-2012: $167,498.

Restoring Jaramillo Creek. Contract No. 11-667-5000-0041 FY 11-G. 2011-2014: $171,897.

Restoring San Antonio Creek, RERI 2009-201: $116,000

Reducing Temperature and Turbidity on San Antonio Creek by Restoring Slope Wetlands on Six Tributaries. NMED PSC# 12-667-5000-0013. 2011-2014: $165,400.

Secure Rural Roads Program - *Restoring Roads and Streams in the San Antonio Watershed Damaged by the Las Conchas Fire*, funded through USDA Forest Service Agreement #11-CS-11151000-008 between Los Amigos, the Valles Caldera Trust, and the USDA Forest Service. 2014-2015: $49,884

Restoring La Jara Creek from Damage from the Thompson Ridge Fire, Valles Caldera National Preserve. River Stewardship Program Contract #17-667-2060-0013. 2017-2019: $160,000.

Restoring Hydrologic Functioning to the Rito de los Indios, Valles Caldera National Preserve, NMED Contract #15-667-2000-0024. 2015-2018: $172,000.

Innovative Restoration of Historic Wetlands along Sulphur Creek, Valles Caldera National Preserve, NMED Professional Services Contract # 17 667 2060 0027. 2012-2017: $196,203.

Restoration of Slope Wetlands from Wildfire in the Valle Grande of the Valles Caldera National Preserve, funded through a December 1, 2016 Wildlife Conservation Society Climate Adaptation Fund Grant Agreement. 2016-2018: $170,000.

Rio Puerco Alliance
East Fork Jemez River Innovative Wetland Restoration Project Using Contour Swales, Sod Bowls and Sod Berms, CWA Section 104(b)(3) Wetlands Program Development Grant Assistance Agreement CD #01F39601-0 (FY2018). 2018-2021: $191,490.

San Antonio Creek Headwaters and Erosion Control Project. River Stewardship Program FY2021 RFP # 10-66700-21-27670 2022-2025: $259,214.

Keystone Restoration Ecology
Lower Jaramillo Creek and Wetland Restoration Project, River Stewardship Program. 2020-2023: $227,493