The Plug and Pond Treatment: Restoring Sheetflow to High Elevation Slope Wetlands in New Mexico

A Restoration Project in the Valle Seco of the
Valles Caldera National Preserve, Jemez Mountains

November 2017

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The Valle Seco restoration project within the Valles Caldera National Preserve, with the plug and pond treatment as its primary tool, was contracted to Los Amigos de Valles Caldera, a non-profit organization, through the New Mexico Environment Department, Surface Water Quality Bureau (NMED-SWQB), Wetlands Program. Planning and design began in 2013. Construction was implemented in 2015-2016. Mechanized construction was contracted through Stream Dynamics, Inc. and Keystone Restoration Ecology, LLC. Hand work was donated by volunteers serving Los Amigos de Valles Caldera and the Albuquerque Wildlife Federation. Planning, design and construction oversight was provided by Zeedyk Ecological Consulting, LLC under contract to Los Amigos de Valles Caldera. Vegetation monitoring was by Keystone Restoration Ecology, LLC.

Cover:

Plug and pond treatment, Valles Caldera National Preserve, 2017
Photo: W.D. Zeedyk; Layout: T.E. Gadzia

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CHAPTER 1 — VALLE SECO PROJECT OVERVIEW

"POND-AND-PLUG"?

This publication describes the application and initial results of using the "**plug and pond**" treatment, and related ancillary treatments, to preserve and restore high elevation slope wetlands within Valles Caldera National Preserve in the Jemez Mountains of northern New Mexico. In 1995, the stream and meadow restoration technique commonly known as "**pond-and-plug**" was first implemented in perennial systems on the Plumas National Forest in California (Plumas National Forest 2010) and the treatment was initially described by Dr. David Rosgen (Rosgen 1997). More recent publications use both terms "pond-and-plug" and the alternative, "plug and pond," describing the same basic concepts. "*The term 'pond-and-plug,' though catchy, is a poor moniker for the treatment because the treatment's primary restorative element is not the series of ponds and plugs but the re-connection of the stream channel with its floodplain*" (Plumas National Forest 2010). Here in New Mexico this method of wetland restoration has evolved under the "plug and pond" label and is now generally accepted by that term. For the sake of maintaining consistency, here in the Southwest, the term plug and pond will be applied throughout this text.

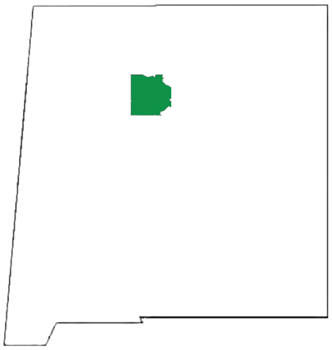

Figure 1. Map of New Mexico showing approximate location of Valles Caldera National Preserve.

"PLUG AND POND" TREATMENT IN NEW MEXICO

In New Mexico, the plug and pond treatment has been used to preserve and/or restore wet meadow landforms damaged by channel incision (gullying) due to historic overgrazing, animal trailing, poorly built or poorly maintained roads, and the impact of severe wildfires of recent origin. The plug and pond treatment benefits adjacent wetlands primarily by raising the water table to pre-disturbance levels and reconnecting previously saturated wetland landforms with seasonally appropriate flood flows attributable to snow melt or monsoonal storm events. The plug and pond treatment functions by raising incised channels back to, but not exceeding, the pre-incisional elevation at the point of treatment. The plug and pond treatment can be used to 1) reconnect seasonal flows to wetland and formerly wetland surfaces, 2) control advancing headcuts, 3) reconnect existing (active) channels with abandoned channels no longer accessible due to channel incision, and 4) move flood flows back and forth between parallel gullies or gullied landforms.

Restoration treatments were applied within the Valle Seco, a bowl shaped historic lake bed (now a valley or valle) between two volcanic domes (Goff 2009), situated within the west-central portion of the Valles Caldera National Preserve (Figures 1, 2 and 3). The Valle Seco is approximately 500 acres in size, lies within the Sulphur Creek Watershed and is a principal watershed tributary

Figure 2. Valle Seco. (©Google™ earth, Keystone Restoration Ecology, LLC)

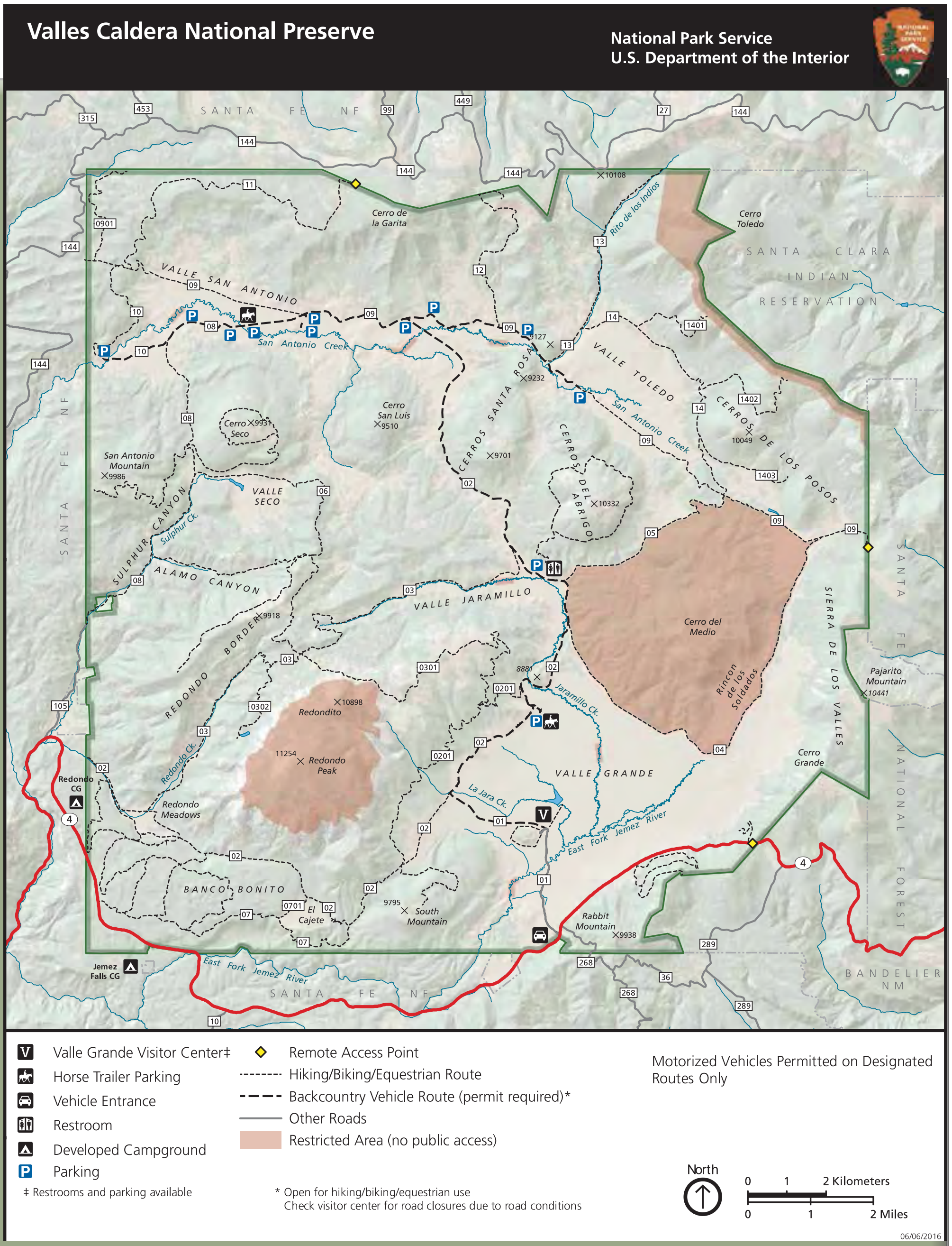

Figure 3. Map of Valles Caldera National Preserve and location of project areas that used the plug and pond treatment to restore slope wetlands.

THE VALLES CALDERA NATIONAL PRESERVE was previously known as the Baca Location, a Spanish Land Grant property dating to 1860 (Martin 2003). Approximately 89,900 acres in size (140 square miles), the property was intensely managed for sheep grazing (up to 20,000 head) on a share-cropper basis beginning in the 1880s and subsequently up to 12,000 head of cattle (Martin 2003). The western one third, including the Sulphur Creek Watershed, was drilled extensively to explore for thermal resources by Union Oil Company ending in 1988. The thermal resources were not developed although well pads and associated roads remain. The Baca Location was purchased by the federal government in 2000 and was managed on a for-profit basis until 2015 by the U.S Department of Agriculture (USDA) as the Valles Caldera National Preserve (VCNP) under legislation specific to the site. The Preserve was subsequently transferred to the National Park Service (NPS), U.S. Department of the Interior on October 10, 2015. Legislation enabling possession and management by the NPS addresses three primary objectives for the science and education program, one of which "provides for improved methods of ecological restoration and science-based adaptive management of the Preserve…" (*http://www.webcitation.org/6Uzyzl7eW* pg. 1269). Restoration of streams and wetlands falls under this objective. Since 2002, other wetland restoration projects have been completed or are currently underway elsewhere on the Preserve.

for the Jemez River. Elevations within the Valle Seco range from 8,700 to 9,500 feet. The Valle Seco watershed area is approximately 2,100 acres with a predominately north-facing exposure. Precipitation is equally divided between winter snows and summer monsoonal events, but stream flows are sustained primarily by a prolonged snowmelt season extending from mid-March through mid-May. Snow melt discharge sustains both hydric and mesic landforms.

Figure 4. Site 21, August 7, 2016. A plug and pond on a perennial channel fills soon after construction. (©S. Vrooman)

Previous wetland restoration efforts in the Valles Caldera National Preserve have been conducted in association with road construction/reconstruction projects including: East Fork of the Jemez River (VC01, VC02), San Antonio Creek (VC08, VC09), Santa Rosa Creek (VC03), Sulphur Creek (VC06, VC07, VC08), Jaramillo Creek (VC03), Nina's Spring, Alamo Canyon, and Upper San Antonio Creek. These treatments, conducted under Valles Caldera National Preserve management with USDA Forest Service assistance, were implemented between 2002 and 2011 and used reconstruction and relocation of road drainage features (culverts and ditches) as tools for reconnecting surface and subsurface flows with the landforms that would have been served had earlier road systems not interfered.

In addition to the Valle Seco, plug and pond treatments (Figure 4) have been implemented elsewhere on the Preserve including Tres Arroyos, Nina's Spring, Six Tributaries of San Antonio Creek, Santa Rosa Creek, Jaramillo Creek, and Rito de los Indios watersheds. Many of these treatments were implemented in response to watershed impacts related to two large wildfire events, the Los Conchas Fire (2011) and the Thompson Ridge Fire (2013), which in total consumed approximately three-fourths of the surface area of the Preserve including the Valle Seco. Valle Seco was actively grazed by cattle through the summer of 2015, but not during 2016 or 2017. Decades of trailing by sheep and cattle to and from perennial water sources has severely impacted wet meadow landforms (Figure 5).

Figure 5. Site 42-44 complex, May 11, 2017. Incision due to cattle trailing in Tributary 3 wet meadow. View looking upvalley. (©W.D. Zeedyk)

Initial design of the Valle Seco project began in 2013. Designers examined satellite imagery to identify functional slope wetland and former wetland landforms no longer connected to a perennial or intermittent water source. Apparent headcuts were noted as were sites where: 1) the active channel appeared to have been captured or diverted by an abandoned road, and 2) former trailing or active trailing was evident. Sulphur Creek was defined as the dominant east-west channel; channels entering from the south were defined as

tributaries. There are no tributaries entering from the north. The main channel of Sulphur Creek is fed by six tributaries (Figure 6). The main channel of Sulphur Creek and five tributaries were selected for treatment. One was rejected because of its steepness and because the area of easily accessible former wetland surface was relatively small. Some reaches within the five tributaries were rejected because of the depth and width of the eroded gully formations.

The main channel of Sulphur Creek and the selected tributaries were next traversed on foot and potential treatments identified. The final selection of potential sites was eventually pared down to 53. Emphasis was placed on identifying significant headcuts for stabilization in order to protect and preserve wet meadow landforms upvalley from the headcut. Beyond that, priority was assigned to sites where active surface flows could be reconnected to former wetland landforms. Those wetlands were shaped by dispersed surface runoff occurring prior to formation of incised stream channels (gullies), whether perennial or intermittent. Tributary 1 and Sulphur Creek, for example, are entirely perennial. Conversely, Tributaries 2, 3, 4 and 5 are intermittent. Approximately 40 acres were identified for restoration using a variety of related treatments, but mainly the plug and pond treatment, the subject of this publication. Where plug and pond treatments were not appropriate, ancillary treatments were used to expand the total area restored.

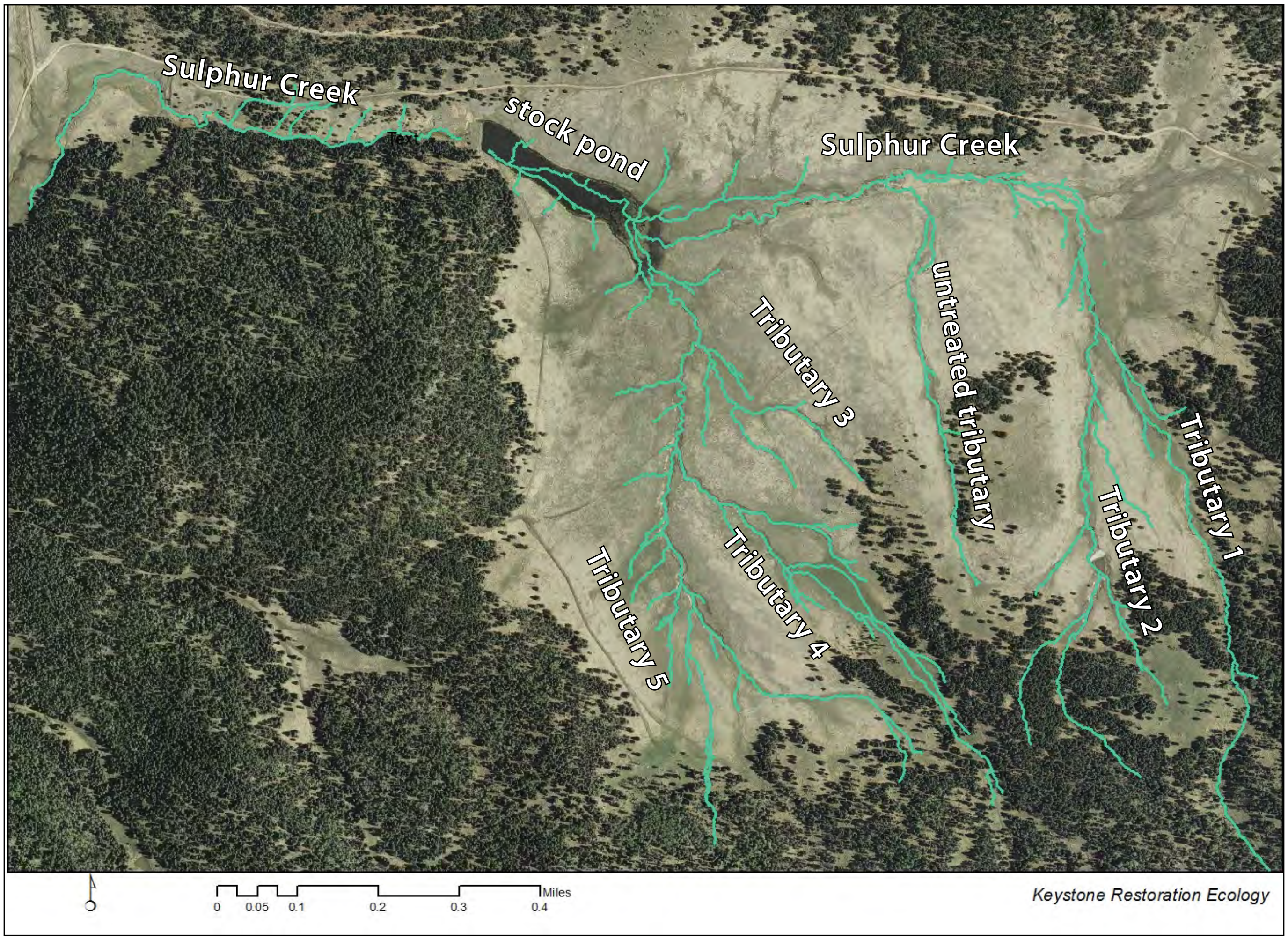

Figure 6. Valle Seco showing Sulphur Creek and tributaries. (©Google™ earth, Keystone Restoration Ecology, LLC)

For maximum benefit, in terms of wetlands restored, it is essential that planning and design remain open to the use of a broad assortment of evolving treatments in order to take full advantage of all potential restoration opportunities present on the landscape. Planning and design is a creative process requiring flexibility in choosing among a wide range of possible treatments in order to select the type of treatment, or combination of treatments, most appropriate to a given site. Possible treatments used separately, or as a complex of treatments can include: 1) the plug and pond, 2) plug and spread, 3) contour swales, and 4) distributary channels (Zeedyk and Clothier 2009, Zeedyk 2015). At each site, once an array of treatments has been considered, either separately or in combination, those deemed not suitable can be eliminated from consideration.

In the Valle Seco, at least 41.6 acres of former wetlands have been revitalized using the plug and pond and ancillary treatments (Figure 7). Most plug and pond structures were enhanced by adding hand-dug worm ditches at the outflow to spread flow more widely across the meadow surface than would be achieved by using just the plug and pond structure alone. Other ancillary treatments used to expand the wetted area include: contour swales, media lunas, and the plug and spread treatment. The plug and spread treatment was developed for application to ephemeral and intermittent stream systems incapable of providing sustained perennial flow to treated areas (Zeedyk 2015).

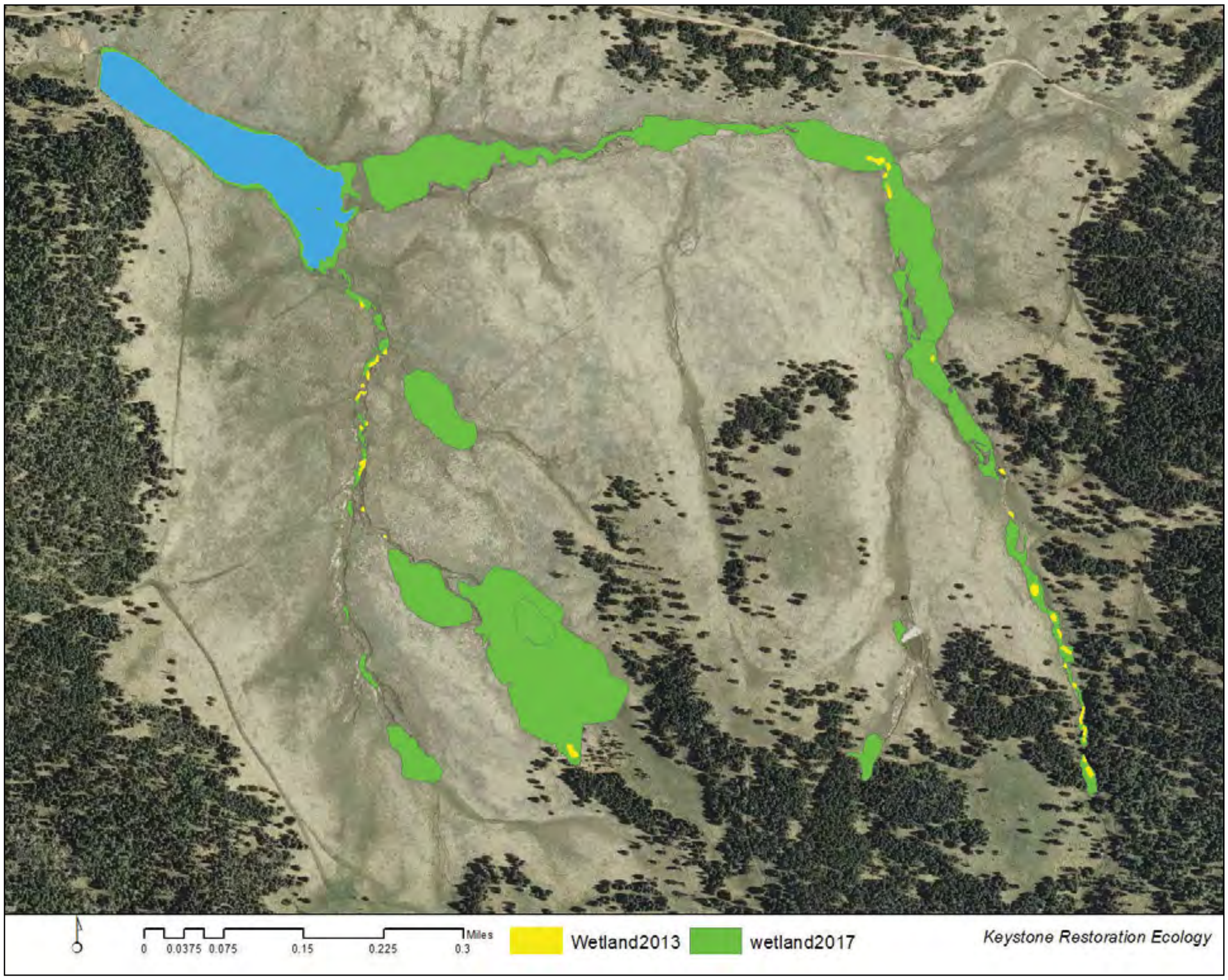

Figure 7. Valle Seco wetland delineation 2013-2017. Surface area of stock pond is noted in blue.
(©Google™ earth, Keystone Restoration Ecology, LLC)

CHAPTER 2 — PLANNING AND DESIGN

INTRODUCTION

Figure 8. July 6, 2017. Key wetland species, *Carex sp.,* surrounding a stock pond. (©T.E. Gadzia)

Reading the landscape is an art— the art of perceiving and understanding the origin of a landform and the processes sustaining, modifying or destroying it. In the case of wet meadow restoration, reading the landscape is the art of recognizing landforms that were shaped by slow-moving surface waters that both flattened the land surface and deposited successive layers of fine grained sediments, aided by the presence and distribution of wetland dependent species adapted to soil and water features. The ability to recognize representative landscape features and relate such features to the presence or absence of key wetland indicator plant species (Figure 8) is important, though not essential. For example, the presence of a typical species of sedge, e.g., Nebraska sedge, would indicate that the site in question is likely a wetland. A similar site, based on landform and soils, but seasonally lacking surface waters and dominated by such species as Kentucky bluegrass or dandelions, might indicate the presence of a former wetland no longer benefiting from seasonal surface flows due to channel incision. A closer examination might indicate the presence of an abandoned sinuous channel no longer subject to flooding. Similarly, a formerly active alluvial fan, as apparent from its typical triangular shape and gently sloping surface, might be longitudinally bisected by an eroding trail and no longer saturated by snow melt runoff. Rather than being dominated by sedges and Arctic rush, that same fan surface, deprived of dispersed surface flow, might currently be dominated by Arizona fescue or invading ponderosa pine trees. Scanning the landscape to internalize and interpret the subtle implications of various geologic, hydrologic and ecologic processes, as impacted by human activities, helps planners to read the landscape and to identify restoration opportunities. After reading the landscape, geomorphic features are used to guide the location of treatments and to quantify the number of treatments.

PRESERVATION OR RESTORATION

Each project and each site selected for treatment is confronted by the key question: What is the primary goal? Is the primary goal the preservation of residual wetlands or the restoration of former wetlands? A headcut is treated to stop the further advance of an incising gully. A headcut control structure is used to preserve functional wetlands upvalley from the point of incision. Various types of headcut control structures may be used to stabilize the headcut and prevent further incision thereby preserving functional wetlands further upvalley. Restoration requires planning for the design and installation of treatments which return surface flows to degraded wetlands in the quantity, patterns of distribution, and seasonality that created the original wetland. A plug and pond or plug and spread treatment is used primarily to reroute seasonal flood flows to a former floodplain or alluvial surface in order to restore a former wetland to functional status. Sometimes, both preservation and restoration can be achieved with a single treatment. Therefore, treatments can be either for 1) the purpose of preserving the functionality of wetland sites not yet damaged by channel incision, or 2) restoring the hydrology of previously damaged sites.

Preservation of wetlands should have priority over restoration because geomorphic and hydrologic processes, and dependent vegetation are still present and functional. Some treatments can often accomplish both objectives—preservation and restoration —if designed with both objectives in mind. For example, contour swales or plug and pond structures can be used to bypass a headcut (seasonally starving a headcut from concentrated flow) and at the same time rerouting flows across a former wetland surface dehydrated by the headcut.

The goals of the plug and pond treatment, as applied to perennial and intermittent stream systems, are to:

- reconnect runoff with a formerly hydric slope wetland or floodplain surface,
- rewet formerly saturated hydric soils,
- prevent further channel incision, and
- increase subsurface storage.

A successful plug and pond treatment will increase or extend baseflow to downstream areas, and restore or expand the distribution of wetland vegetation. The essential planning element, therefore, is to recognize and select suitable plug and pond sites where the above goals can be achieved with a high likelihood of success. In practice, this means selecting the least impacted sites while postponing treatment of more highly impaired sites. At Valle Seco, of the 53 sites selected for treatment, 22 sites received one or more plug and pond treatments.

PLANNING

In addition to reading the landscape, successful planning is a blend of art and science since the realm of possibilities is endless and viable choices must be made. In planning, the art is in the ability to: 1) choose appropriate restoration sites, 2) select between alternative treatments, or combinations of treatments, and 3) apply those treatments which will restore the maximum acreage for the least cost and with the highest chance for success. The science is in understanding the hydrology, geomorphology and ecology of the landscape (Figure 9). Planning is best accomplished by first studying available maps, aerial photography and satellite imagery. At Valle Seco, LiDAR (*https://en.wikipedia.org/wiki/Lidar*) was used experimentally to compare elevations and rank potential advantages and disadvantages of alternative sites. At Site 27 for example, on a trial basis, 50 different alternatives were compared by use of LiDAR in less than one hour.

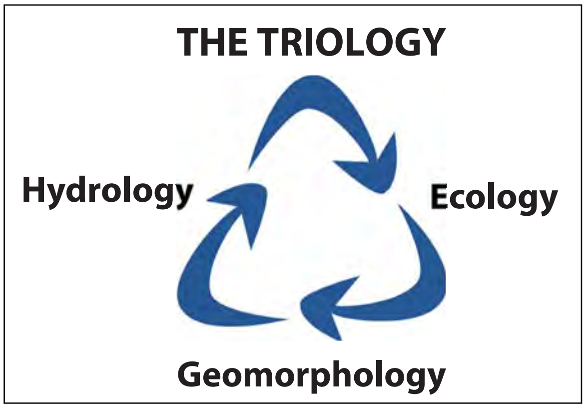

Figure 9. Sciences involved in planning and designing a restoration project include: hydrology, geomorphology and ecology.

Once an initial selection of sites has been conducted using satellite imagery, it is essential that all potential sites be examined on the ground to refine locations, dimensions, and surface elevations not apparent by imagery. When surveying the project site on the ground, it is best to start at the top of the watershed and proceed downvalley so as to easily assess cumulative benefits of restorative treatments and relate each treatment to the next one above it. Factors that influence the location, dimensions and orientation of potential structures can include: 1) width and depth of the channel, 2) the presence of remnant vegetation, 3) dimensions and configuration of remnant wetland soils which might be rewetted, and 4) how adjacent sites might relate to and interact with each other if treated. At Valle Seco, all candidate sites were judged accordingly with the goal of maximizing the total area benefitted by installing a complex of related treatments rather than isolated stand-alone treatment structures.

Another aspect of planning is the consideration of how the proposed treatments will be implemented—whether by machine or by hand. In the case of Valle Seco, volunteer labor was used for a large portion of the treatments so emphasis was placed on identifying treatments which could be installed utilizing hand labor. Many worm ditches, rock structures, sod plantings and even one plug and pond structure were planned for hand installation. In addition, other treatments were identified that could be installed economically by the use of mechanized equipment.

Perhaps the most difficult aspect of the initial planning effort at Valle Seco was the selection of those areas of desiccated, former wetlands which might be most effectively restored while rejecting those which were too small, too isolated, too irregular in shape or too deeply incised to restore at a reasonable cost. Planning also included the identification of access routes, conducting or referencing archeological surveys, and securing Clean Water Act permitting.

DESIGN

Figure 10. Site 23, May 11, 2016. Sulphur Creek headcut. (©W.D. Zeedyk)

Once the selected stream reaches have been evaluated and sites selected for treatment, each site is staked, measured and recorded for planning purposes. This information is used to estimate needed equipment, materials and labor.

Slope wetlands tend to occur on surfaces where steeper channels draining mountain slopes gradually flatten to merge with less steep valley slopes. Sediments accumulate at the point where stream velocities are slowed and incipient alluvial fans have formed. Slope wetlands often have a groundwater component occurring at or below the point where springs come to the surface and flow down slope as dispersed flow, moving at reduced velocities and more constant discharge. Slope wetlands tend to exhibit finer grained soils under these conditions, compared to hydrologic regimes dependent on snow melt, monsoonal runoff and dramatic changes in seasonal and annual precipitation.

Most slope wetlands have been damaged by roads or trails that have intercepted, consolidated and accelerated surface sheetflow into channelized flow resulting in channel incision or headcutting (Figures 10 and 11). Dispersed sheetflow has little erosional force but channelized flow is highly erosive and results in headcutting and further incision. Incision usually cuts down to the underlying boulder or cobble layer and then gradually widens, leaving the residual surface soils isolated from periodic flooding and subject to drying over time.

Where springs spread downslope to merge with the main channel, a wide variety of conditions ranging from desirable to highly undesirable may be evident depending on the stability and degree of incision of the receiving channel. Headcutting will be evident if the parent stream is incised at the point of confluence. The headcut may be apparent far upsteam in the affected tributary. Sites 19, 32 and 36 exhibited evidence of such origin (Figure 12, page 10).

Incised stream channels that collect dispersed flow proceed upvalley with a well-defined active headcut, or series of headcuts, at the point where the incised channel intercepts the dispersed flow (gently sloping, stable surface dominated by wetland obligate species) (Figure 11). It is essential that headcutting be halted by applying the appropriate treatment. A headcut control is a preventative, not a restorative treatment. The primary headcut control treatments used at Valle Seco include:

1) rock and sod structures that harden or revegetate the face of the pour-over;

2) bypass treatments, such as swales, plug and pond, plug and spread or worm ditch, that capture dispersed flow and reroute it around the headcut to prevent water from becoming concentrated at the lip of the falls; and,

3) stabilizing treatments such as the Zuni bowl, rock layback, and rock rundown for headcuts that would continue to receive concentrated flow.

Proper construction techniques for all the above are described in Chapter 4.

If dispersed flow is spilled onto a slope wetland surface, it is essential that a stable return site be selected to reconnect this flow with the receiving channel downvalley without creating a new headcut or eroding the streambank.

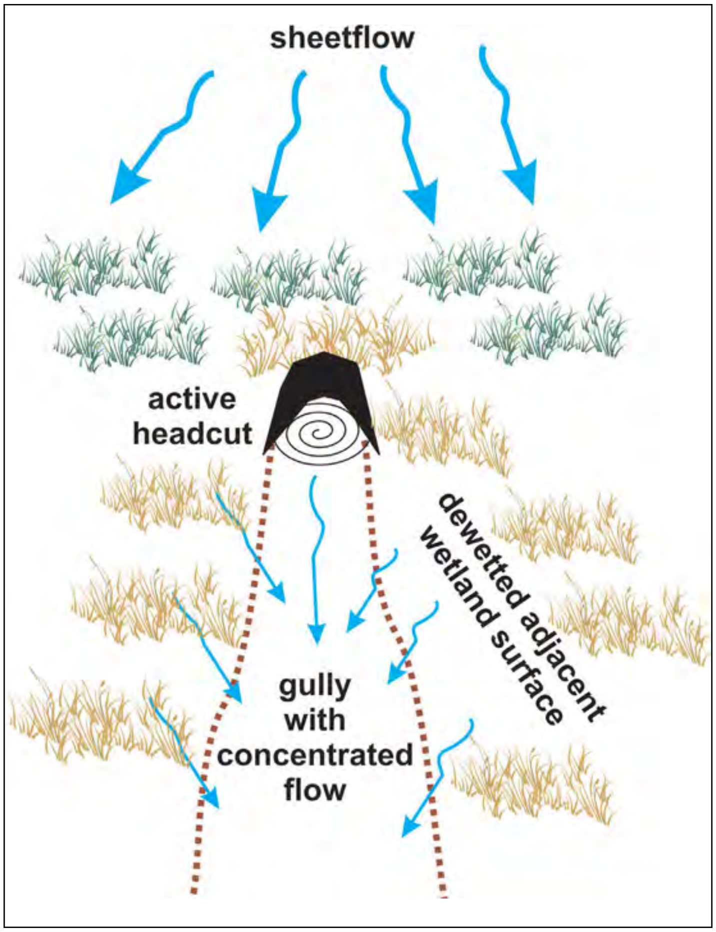

Figure 11. Incised channel or gully intercepting sheetflow.

The challenge of initial planning and design, then, is to find and select suitable locations where preventative or restorative treatments can be most economically and most effectively installed (Figures 12 and 13, pages 10-11). This also in turn requires an understanding of the capabilities and limitations of the various construction methods that might be used. Considerations in design should include: 1) types of equipment 2) how the selected sites will be accessed so as to not do further harm to the wetlands, and 3) the best season of the year for implementation.

SUMMARY

Initial planning should consider a broad range of possible treatments before selecting a favored alternative. What sorts of structures might be employed and where might they be placed? How should the proposed structures relate to and interact with adjacent structures installed as a complex in a given reach of channel? In what order should structures be installed? Some of the many factors to consider in choosing between alternatives include: maximizing the area restored and minimizing future maintenance needs. Ideally, once stabilized, all treatments should be self-sustaining.

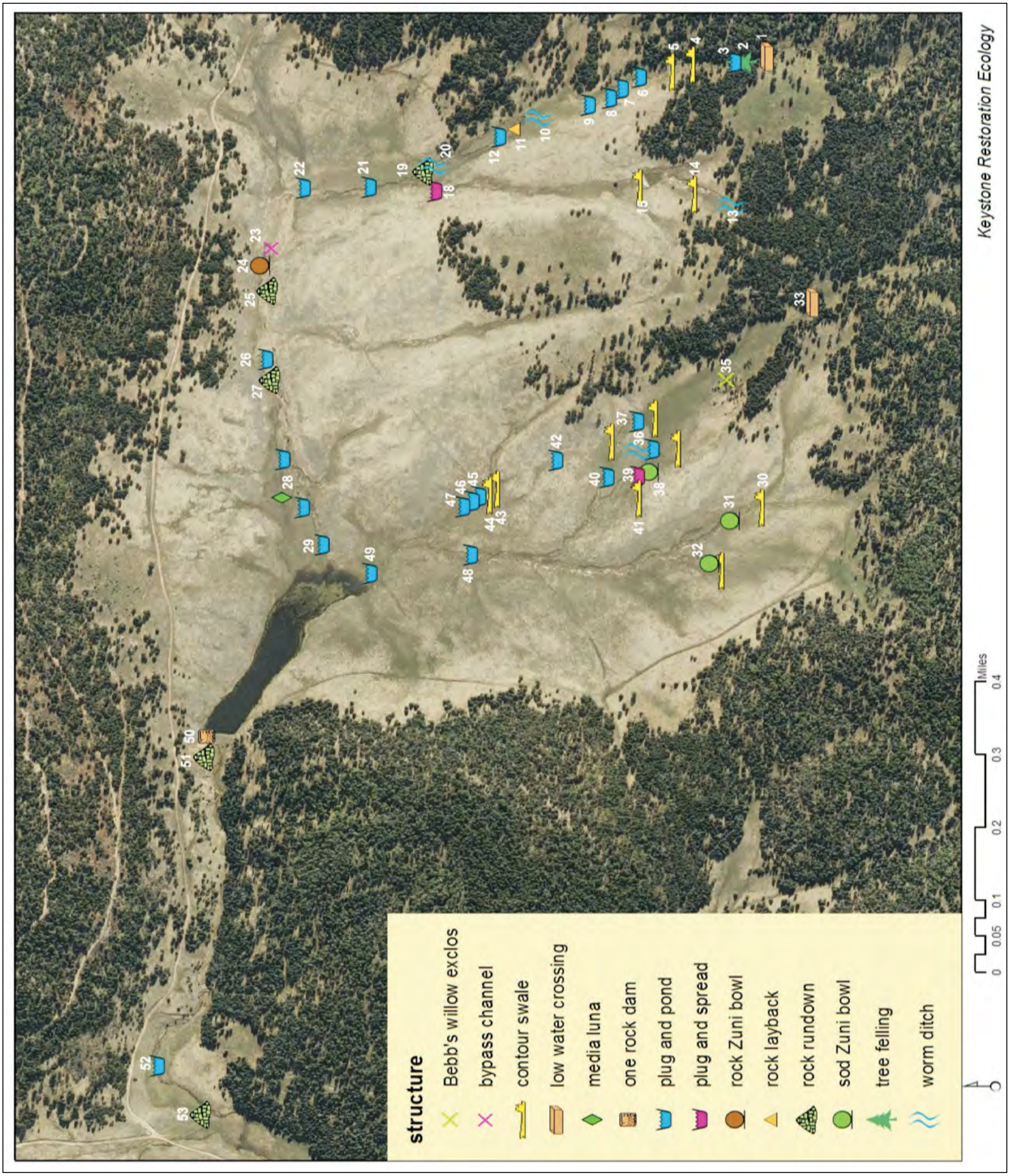

Figure 12. Valle Seco project site location map.

Site Number	Structure(s)	Structure Number	Tributary
1	low-water crossing	1	1
2	tree felling	2	1
3	plug and pond	3	1
4	contour swale	4	1
5	contour swale	5	1
6	plug and pond	6	1
7	plug and pond	7	1
8	plug and pond	8	1
9	plug and pond	9	1
10	worm ditch (2)	10	1
11	rock layback and one rock dam	11	1
12	plug and pond	12	1
13	worm ditch	13	2
14	contour swale	14	2
15	contour swale	15	2
16	Not Built		2
17	Not Built		2
18	plug and spread	16	2
19	plug and pond with rock rundown	17-18	1
20	worm ditch	19	1
21	plug and pond	20	1
22	plug and pond	21	1
23	bypass ditch	22	Sulphur Creek
24	rock Zuni bowl and one rock dam	23	Sulphur Creek
25	rock rundown	24	Sulphur Creek
26	plug and pond	25	Sulphur Creek
27	rock rundown with contour swale	26-27	Sulphur Creek
28	plug and pond	28	Sulphur Creek
28	plug and pond	29	Sulphur Creek
28	media lunas (2)	30-31	Sulphur Creek
29	plug and pond (2)	32-33	Sulphur Creek
30	contour swale (2)	34-35	5
31	sod Zuni bowl	36	5
32	contour swale	37	5
32	sod Zuni bowl	38	5
33	road crossing	39	4
34	drift fence not built		4
35	Bebb's willow exclosure	40	4
36	plug and pond	41	4
36	worm ditch	42	4
36	contour swale cascade	43	4
36	plug and pond	44	4
36	contour swale	45	4
37	contour swale cascade	46	4
38	sod Zuni bowl	47	4
39	plug and spread	48	4
40	plug and pond	49	4
41	contour swale (3)	50-52	4
42	plug and pond	53	3
43	contour swale	54	3
44	contour swale	55	3
45	plug and pond	56	3
46	plug and pond	57	3
47	plug and pond	58	3
48	plug and pond (4)	59	5
49	plug and pond (3) and worm ditches	60-62	5
50	one rock dam (multiple)	63	Sulphur Creek
51	rock rundown	64	Sulphur Creek
52	plug and pond	65	Sulphur Creek
53	rock rundown	66	Sulphur Creek

Figure 13. Valle Seco project restoration site numbers and structures by tributary. Example of a treatment inventory.

WILDFIRE—A ONE-TIME OPPORTUNITY TO RESTORE INCISED WETLANDS

However reprehensible in so many ways, a wildfire can present a one-time opportunity to restore incised channels and reconnect former wetlands downstream of the burned area. This phenomenon occurred at Valles Caldera outside the burned areas of both the Las Conchas Fire (2011) and the Thompson Ridge Fire (2013). The potential for gully restoration outside the burned area periphery is due to the large increase in stream discharge and accompanying sediment loading originating from within the burned area, especially from sites subject to severe burn intensities. Beneficial results, including a rise in streambed elevations, increased sinuosity and the reconnecting of floodplains, alluvial fans and slope wetland surfaces, have been observed at Santa Rosa (Figure 14), Jaramillo, and Rito de los Indios creeks downstream of the Los Conchas Fire and at Sulphur Creek below the Thompson Ridge burned area.

This result is not necessarily common but may occur where: 1) downstream channel gradients are less steep than within the burned area, 2) floodplains and alluvial fans are susceptible to fire-caused flood events, and 3) wetland vegetation is present to assist in recolonization at affected sites.

Channel treatments like grade control structures and plug and pond treatments can be highly effective if installed within the first few years following the burn (Figures 15-17). It is recommended that management respond accordingly and install treatments which might enhance wetland response outside the burned area and not limit erosion control efforts to sites within the burned area boundary. Opportunities to use sediment discharged from a burned area for positive benefit should be identified and inventoried in conjunction with the planning of treatments within the burned area. In addition, adjustments to livestock management practices, including use, timing and intensity of grazing, are critical to restoration success (Briggs 1996, Bellows 2003).

Figure 14. Santa Rosa Creek, Los Conchas Fire, Valles Caldera National Preserve, August 4, 2011. Sediment-laden flash flood waters spreading valley wide. (©S. Vrooman)

Figure 15. August 4, 2011. First monsoon season after the fire, sediments are already being deposited in Santa Rosa gullies. (©S. Vrooman)

Figure 16. Left, small rock grade control structures, September 22, 2012. Right, same site now occupied by wet meadow vegetation, October 2, 2017. (©S. Vrooman)

Figure 17. Left, rock headcut control structures, September 21, 2012. Right, same site now occupied by wet meadow vegetation October 2, 2017. (©S. Vrooman)

Figures 18-19 below display upstream and downstream, before and after views of adjacent wet meadow headcuts that were treated, prior to the Los Conchas Fire, by installing three large-rock headcut control structures (Zuni bowls). Fortunately, these structures not only successfully withstood the erosive force of subsequent fire-induced floods but also enabled sediment deposition within the gullied landform both upstream and downstream of the structures.

Figure 18. Looking upvalley. Left, June 24, 2012. Right, October 2, 2017. (©S. Vrooman)

Figure 19. Looking downvalley. Left, August 4, 2011. Right, October 2, 2017. (©S. Vrooman)

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CHAPTER 3 — THE PLUG AND POND STRUCTURE

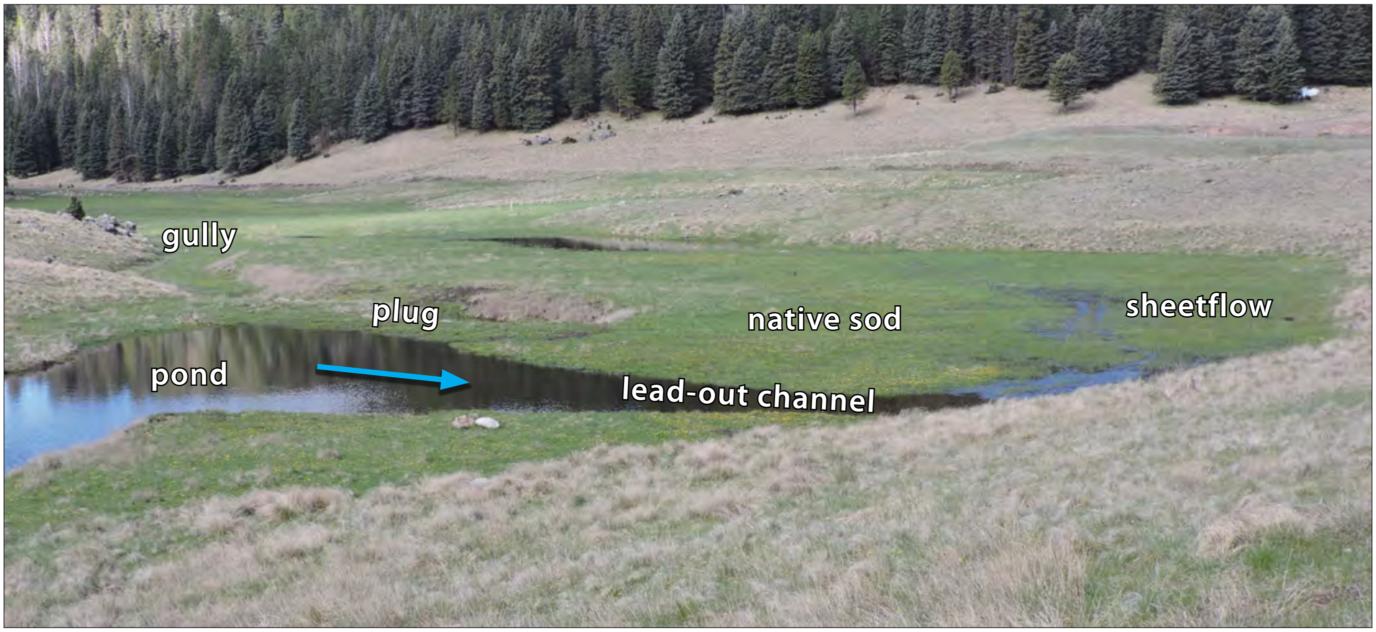

Figure 20. Key features of a typical plug and pond structure. (©W.D. Zeedyk)

A plug and pond structure used in a high elevation slope wetland ecosystem is designed to plug a gully or incised channel creating a pond that captures and holds upstream flows for a short period of time. The plug is normally created using on-site soil or sod that can be collected from the pond location. Once the pond is filled, outflow from the pond is directed to a desired location through a lead-out channel or over a brim. A plug and pond can be designed for: 1) rewetting abandoned floodplains or wet meadows (Figure 20), 2) controlling an active headcut, 3) reconnecting flows with their historic channels, and 4) moving flows back and forth between gullies.

STEPS FOR CONSTRUCTION

There are six primary steps involved in the construction of the typical plug and pond structure:

1. **Delineate approximate boundaries of the structure using stakes, pin flags or marking paint.** For larger structures, the use of a laser level is essential for identifying land contours that determine the point of spillover and direction of flow. The four corners of the plug should be marked with wooden stakes for future reference. Edges of the proposed pond and upper and lower ends of the lead-out channel(s) can be delineated by pin flags or lath stakes. The dimensions of the structure, length, width, and height of the plug, and tapers if appropriate, (Figure 21) are recorded and subsequently used to estimate cut and fill volumes required for a US Army Corp of Engineer (USACE) CWA Section 404 permit application (Zeedyk 2015).

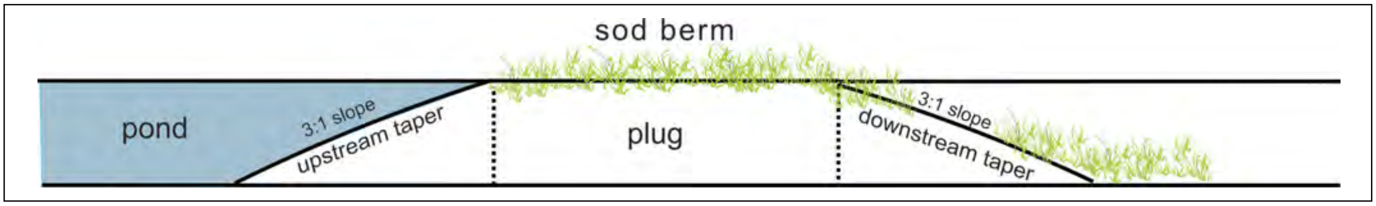

Figure 21. Logitudinal profile schematic of plug and tapers in a plug and pond structure.

2. **Use an excavator or a tracked skid loader to remove and stockpile wetland sod.** For larger structures it is best to remove wetland sod with a skid loader to a depth of at least eight inches. Harvest the sod mats the width of skid loader bucket. Stockpile the sod for use in stabilizing the plug at a suitable site convenient to the plug location (Figure 22A). For smaller sites, sod mats can be removed and placed within reach of the excavator for easy access. It may be desirable to enhance habitat diversity by varying the depth of the pond or ponds to suit the needs of frogs, water birds, insects and other species.

3. **Use the bucket of a tracked excavator to borrow material from the bed and banks of the gully to create the "pond." Use the borrow to build the plug** (Figure 22B)**.** Excavate a clean sod-free surface along the bank at the site of the plug before adding fill to create the plug. Place fill where needed to build the plug as staked. Compact the plug using either the bucket or tracks of the excavator or skid loader. Add fill until the height of the plug is equal to or slightly less than the bank height. As a general rule, the plug should be at least as long (channel length) as the channel width at that point. Taller plugs may require tapered slopes on the upstream and downstream sides. Once the plug is compacted, sod mats from the stock pile and lead-out channel are added to the surface of the plug, preferably using the skid loader to place the mats (Figure 22C). Sod mats should be placed neatly so that their edges interlock. The plug may be damaged by over-topping flows

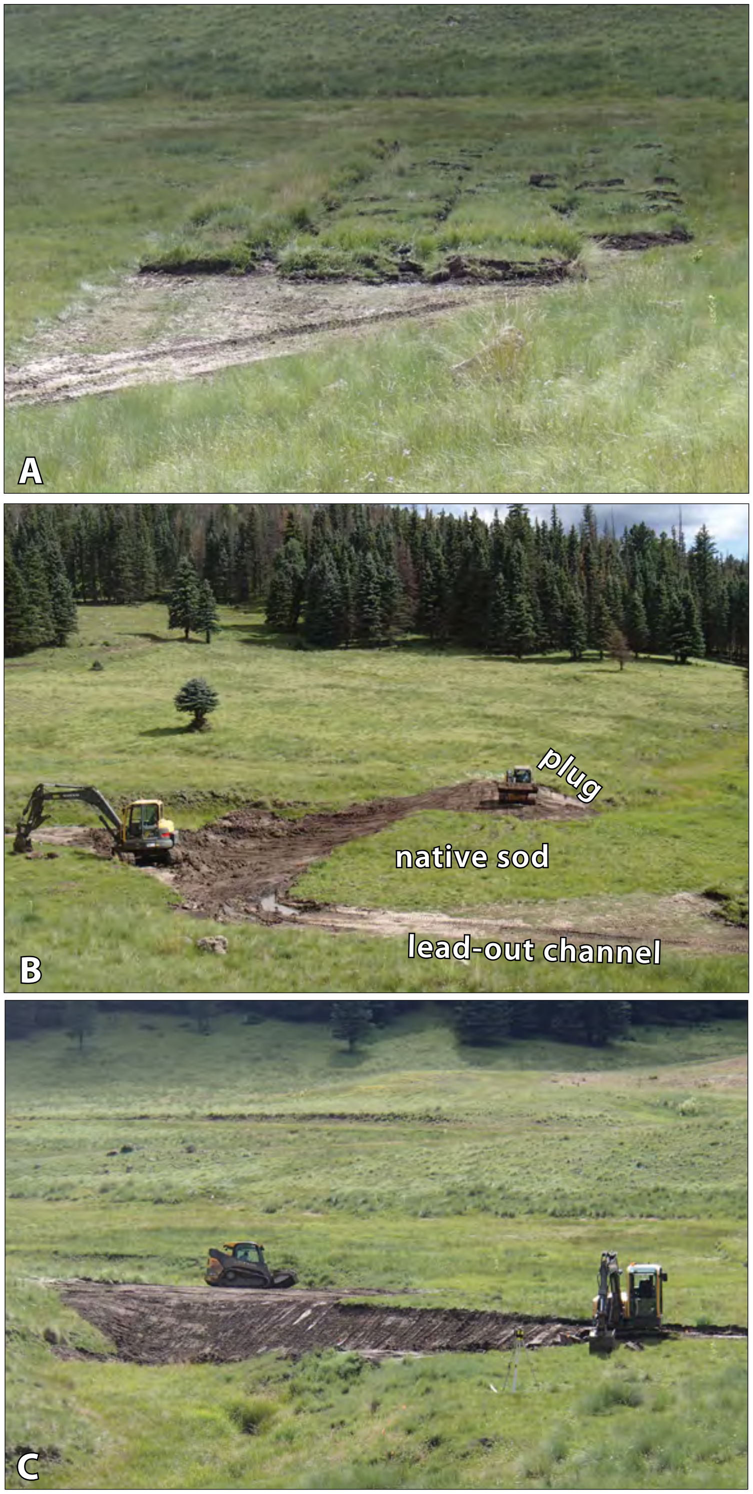

Figure 22. Site 52, August 3, 2016. **A**: Stockpiled sod. **B**: Excavator borrowing soil from pond. Skid loader is building and compacting the plug. Outlet in the foreground. **C**: Adding stockpiled sod to the surface of the plug. (©S. Vrooman)

especially early-on before the sod completely rejuvenates. Sedges on the surface of the plug provide the greatest resistance to erosion. At Valle Seco, the dominant sedges are Aquatic sedges (*Carex aquatilis*) and Northern Territories sedge (*Carex utriculata*). Where the flow is perennial, sedges can be expected to revegetate the surface of the plug within 2 years.

4. **Ensure that deflected flows are routed effectively toward the surface to be re-wetted by constructing a lead-out channel on either or both sides of the plug with sufficient capacity to accommodate the maximum expected flows and prevent erosion of the plug** (Figure 23). A lead-out channel or channels diverting water around the plug and onto the surface of the wetland to be rewetted is built last and should be so oriented as to maximize the area wetted. Water may be routed to either or both sides of the plug depending on the location of the area(s) to be wetted, presence of former wetland soils, and the presence of remnant wetland vegetation along either or both sides of the newly plugged channel. A plug capped by vigorous sod or "sod tiles," once well established, can resist erosion by over-topping flood flows, but it is best to minimize the depth of such flows by increasing the width of the lead-out channel. Health and vigor of the sod on the plug is sustained by capillary flow seeping through the plug more than by surface flow spilling over the plug. The lead-out channel should terminate where the bypassed flows will spill onto the reconnected meadow surface most effectively. Ideally, the downstream end, or brim, of the lead-out channel will be shaped so as to maximize the spread of water on the receiving surface. Once a flow event has occurred, the spread zone can

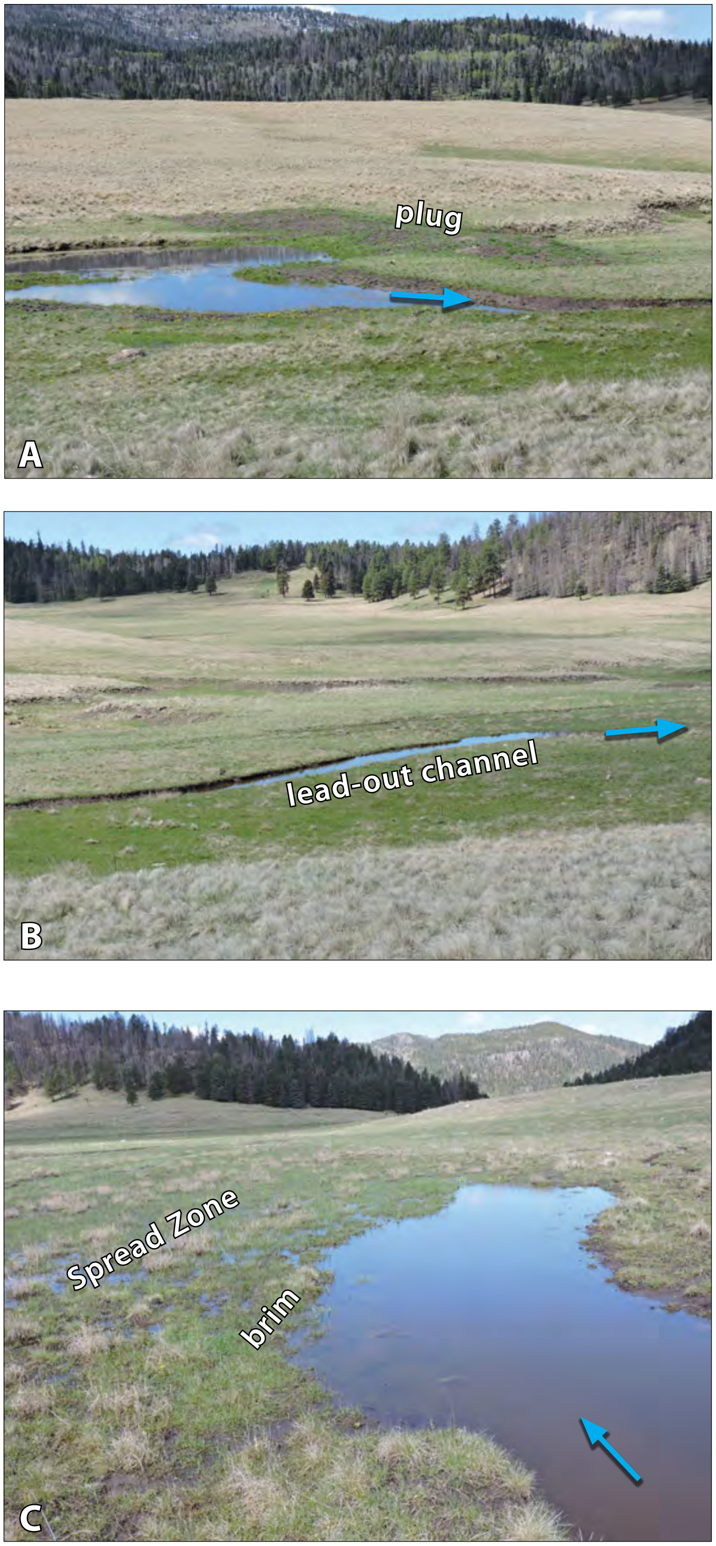

Figure 23. Site 28, May 11, 2017. **A**: the plug, **B**: the lead-out channel, and **C**: the brim and spread zone at the end of lead-out channel. (©W.D. Zeedyk)

be modified or enhanced by use of hand-dug ditches to widen the area wetted. Flows can be spread even more widely by the use of either spreader swales or rock structures such as media lunas (Chapter 4).

5. **Proceeding downvalley, construct a series of plugs in order to keep diverting flows onto the surface of the spread zone until a safe or stable site is located where sheetflow can be safely returned to the original channel without causing a new headcut to develop.** This feature is known as a stable return site. If a stable return site is not present, one must be constructed using rocks or logs as appropriate. Depending on the volume of flow diverted to the spread zone, a meandering Rosgen E channel (Rosgen 1994) may develop over time on the floodplain surface and reconnect with the main channel.
6. **Conduct follow-up measurements to confirm or revise fill volumes contained in the plug as required by USACE CWA Section 404 permit.**

PLUG AND POND AS HEADCUT CONTROL

If the plug is of the proper height and it ponds water to an elevation approximately equal to the lip of a headcut, ponding will stop any further upstream migration of the headcut (Figures 24 and 25). The reason for this is that the erosive force of the falling water is dissipated upon spilling into the still water of the pond. Also, the lip of the headcut will become revegetated as the result of the ponding and be more resistant to erosion.

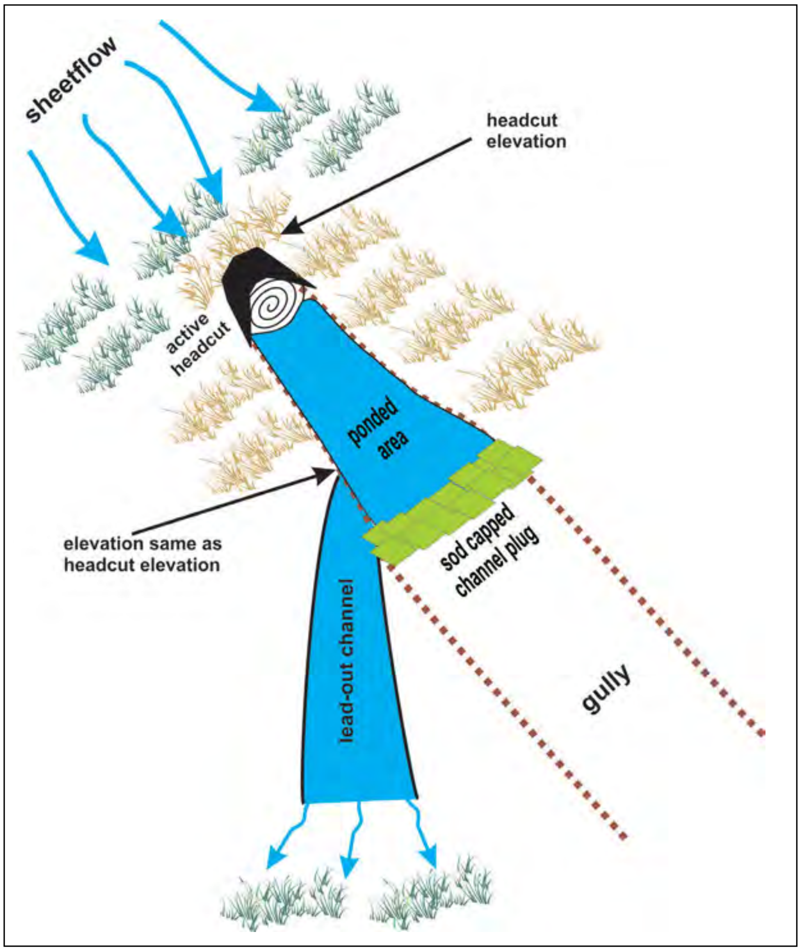

Figure 24. Plug and pond as headcut control schematic.

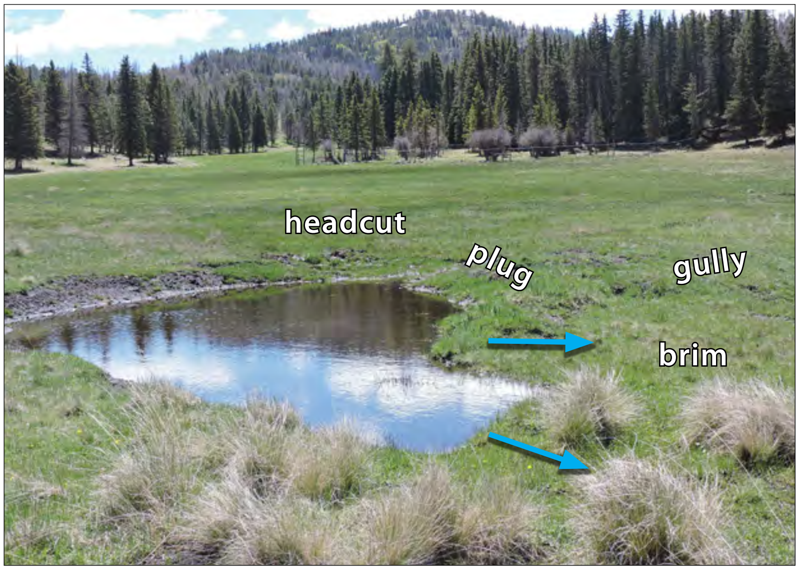

Figure 25. Site 36, May 11, 2017. Plug and pond as headcut control. (©W.D. Zeedyk)

PLUG AND POND CONSTRUCTION PHOTO SERIES AT SITE 21, OCTOBER 2016

Figure 26. Beginning construction of the pond by borrowing fill for the plug. (©S. Vrooman)

Figure 27. Excavator is removing sod from the surface of the area to be ponded and stockpiling it for surfacing the plug. (©S. Vrooman)

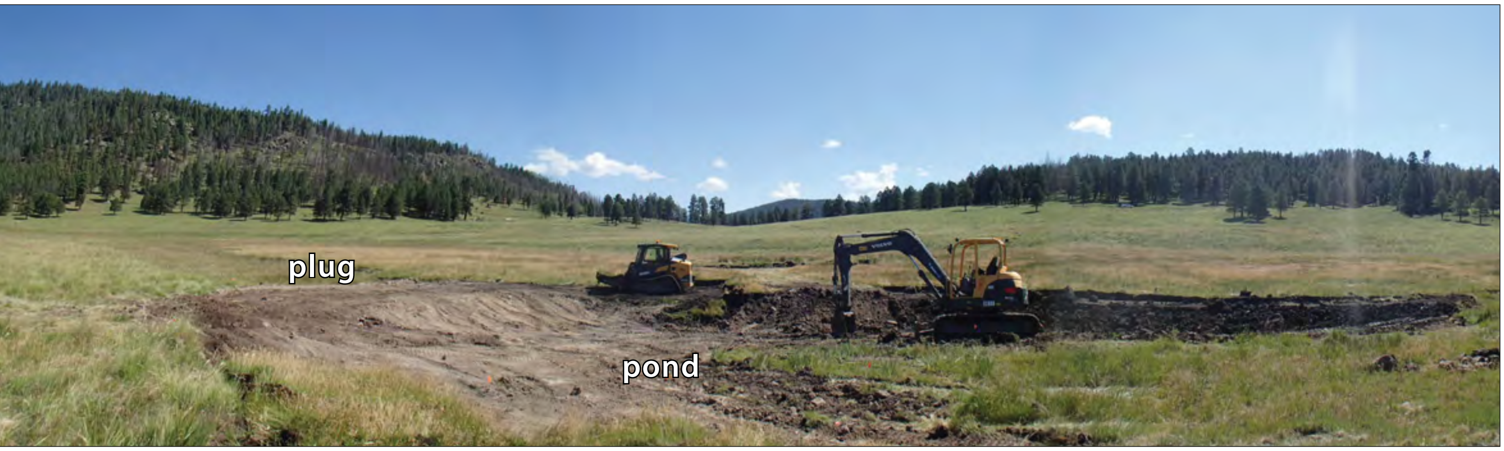

Figure 28. Constructing and compacting the plug. (©S. Vrooman)

Figure 29. Sod has been added to cap the plug. Skid loader is constructing lead-out channel. (©S. Vrooman)

Figure 30. Pond beginning to fill as construction continues. Area to be rewetted is beyond the end of the lead-out channel. (©S. Vrooman)

Figure 31. Construction completed and water from lead-out channel is spilling onto reconnected wetland surface. (©S. Vrooman)

OTHER PLUG AND POND PROJECTS IN THE VALLES CALDERA NATIONAL PRESERVE

The Valle Seco project (2013-2017) is the most recent and most complex of several plug and pond projects installed within the Valles Caldera National Preserve. Earlier projects included Nina's Spring (2011-2013), Tres Arroyos (2012), Six Tributaries of San Antonio Creek (2013-2016), Jaramillo Creek (2011-2015), and Rito de los Indios (2016-2017) (Figure 32). There are currently 129 plug and pond structures working to restore and expand wetlands on the Valles Caldera National Preserve: Nina's Spring (9), Tres Arroyos (5), Six Tributaries of San Antonio Creek (40), Jaramillo Creek (16), Rito de los Indios (35) and Valle Seco (24). The variety of treatments used has increased in number and broadened in complexity with each additional project. Nina's Spring and Tres Arroyos are described below.

Figure 32. Partial map of wetland restoration projects within the Valles Caldera National Preserve that used the plug and pond treatment. Jaramillo Creek and Rito de los Indios are not shown. (©Google™earth, imagery date 6/25/2014)

Nina's Spring

Nina's Spring was a severely eroded wetland valley that flows into San Antonio Creek off of the VC08 Road (Figures 33, 34A, and 34B). Three plug and pond structures were constructed in August 2011, followed by six additional plug and pond structures built further upstream in July 2012. The erosion through the wetland was the result of headcutting initiated by culverts draining the pipeline road built during World War II. Flows captured by the culvert were diverted directly into San Antonio Creek via an abandoned wagon road. The first project in 2011 re-diverted water from the old wagon road into the historic stream channel flowing westward along the floodplain of San Antonio Creek causing about four acres of wetland gain and an increase in channel length of 1200 feet. The second project in 2012 addressed upstream gullying. Wetlands were delineated by use of a sub-meter GPS. The area of wetland increased from 1.7 acres in 2012 to 12.7 acres in 2017.

This project included the following notable design features:

1. A number of structures were built as flow splitters, where two outlets drained a single pond. These worked very well, but after several years, were not splitting the flow due to erosion of the brim of the pond from trampling by elk. These structures were repaired by volunteers during 2014 with the addition of one rock dams built to stabilize the brims and have worked well ever since.
2. At the top of Nina's Spring gully, a worm ditch was constructed around the top of two large headcuts diverting about 75% of the flow away from the headcuts, which now flow only during large spring runoff events. This worm ditch eliminated the need for a more costly headcut control treatment structure such as a rock Zuni bowl.

Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Keystone Restoration Ecology

Figure 33. Nina's Spring. Symbols indicate construction sites.

3. A hand-built flow-splitter in the shape of a "V" was constructed with the use of a "Wolverine" sharp shooter shovel at the top of the wetland. This has remained effective for four years and has helped to divert water around two four-foot tall headcuts.
4. A series of large, three-foot tall headcuts was addressed by the construction of a pond upstream of the headcuts. This diverts the flow away from the headcuts and redirects it to the ungullied surface of the wetland. This pond runs perpendicular to the slope of the wetland and sub-irrigates the headcuts, which no longer have water flowing over them.

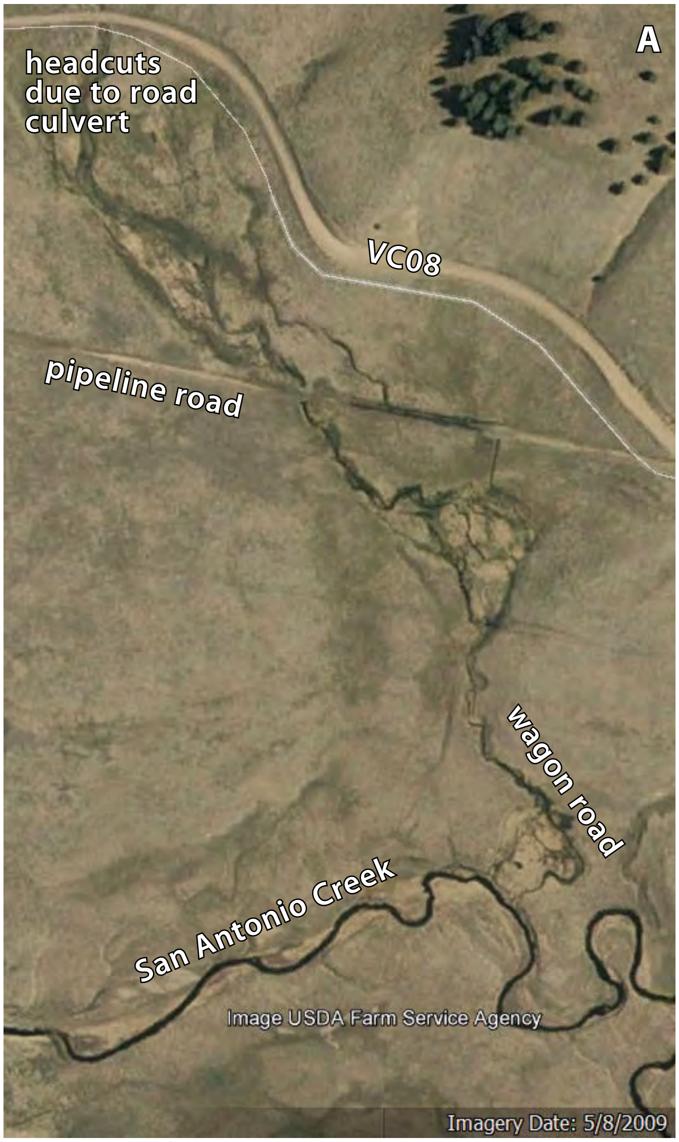

Figure 34A. Nina's Spring 2009 pre-treatment map. (©Google™ earth)

Figure 34B. 2014 Nina's Spring wetland response map. (©Google™ earth)

Principal gullies were formed by headcuts originating from: 1) the pipeline road, 2) an abandoned wagon road on the north side of San Antonio Creek, and 3) a more recent headcut related to the main road (VC08).

Treatments included: 1) adding a second culvert to VCO8 in 2009 to reconnect former wetlands in the northwest corner of the valley, and 2) the construction of numerous plug and ponds (Figure 33) to reconnect former wetlands on the east side of the valley to the delta on the north bank of San Antonio Creek.

Tres Arroyos

Tres Arroyos is a large, eroded slope wetland in the northwestern corner of the Valles Caldera National Preserve. This area was named for the three large arroyos that cut through and drained the wetland (Figure 35). The project was constructed in July of 2012, and took approximately one week to complete. Volunteers installed additional hand-built sod structures to augment machine-built features.

A unique feature of this project included the first use of "sod tiles" to cover the plug after construction. Sod tiles were obtained from the pond area by a tracked skid loader, stacked in rows, and then picked up and placed on top of the plug. After placement, the tiles were track-rolled by the loader for compaction. Later projects were trackrolled by the excavator to ensure contact between the sod tile and the soil beneath.

In addition, the "tres arroyos" were treated by the placement of a dam (1) at the head of the main gully in order to inundate the headcut and foster the growth of wetland vegetation at the headcut (Figure 35). This water, now deflected to Arroyo 2, flowed downhill at a higher elevation on the landscape, and was plugged downstream of the confluence of Arroyo 1 and 2. Lastly, the water spilled out of this pond into the smallest Arroyo 3, creating a sinuous flow to the ponded water (Figures 36 and 37).

This wetland complex retains some water in several ponds and is used by waterfowl all season long.

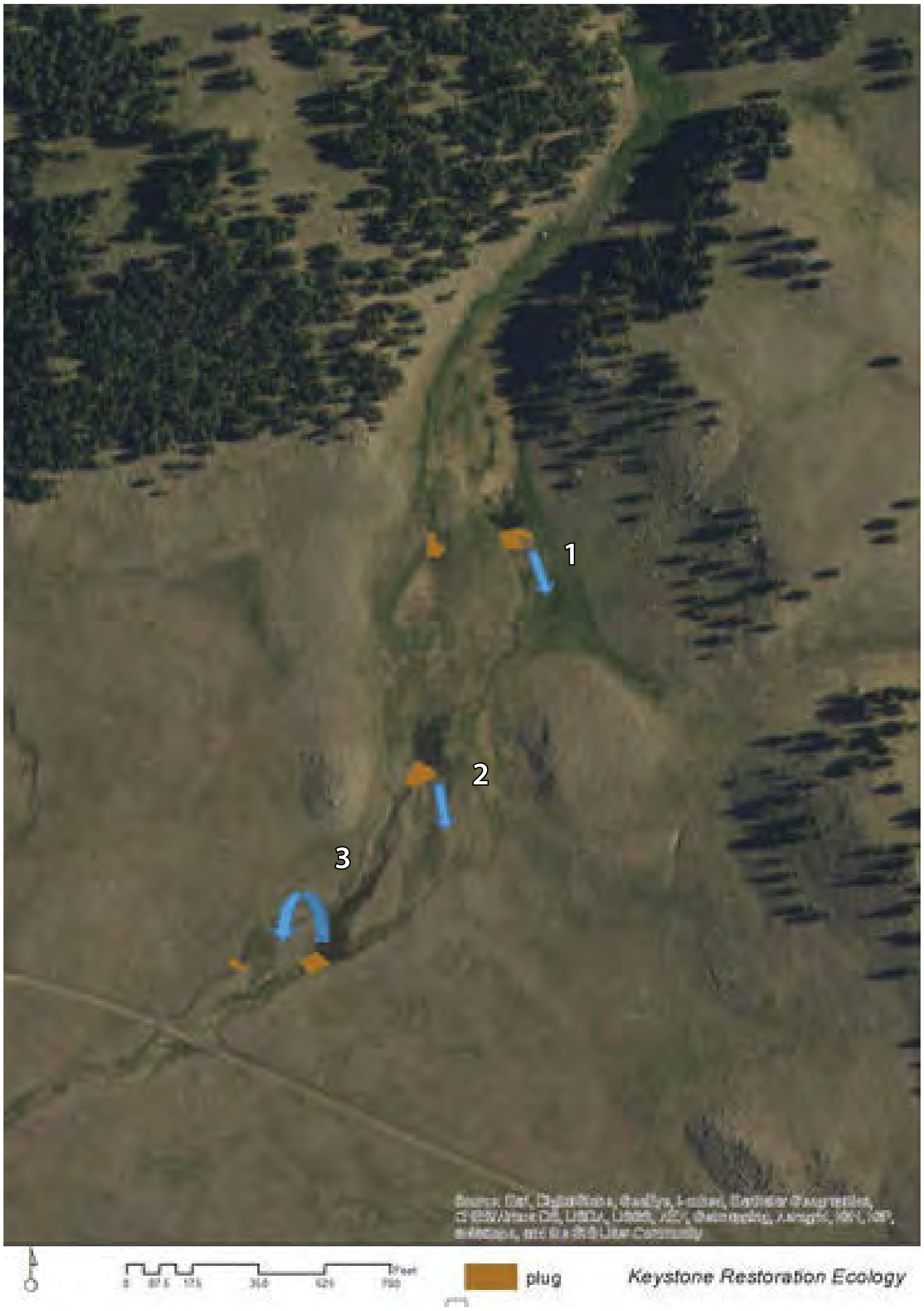

Figure 35. A satellite image of Tres Arroyos treatments.

Figure 36. Tres Arroyos, August 2012. Left, skid loader adds fill dirt excavated from the pond to the surface of the plug. Right, sod tiles stockpiled prior to constructing the plug are placed on the completed plug. (©S. Vrooman)

Figure 37. Tres Arroyos, April 2013. Two plugs created ponds impounding three adjacent erosion gullies and reconnecting multiple wet meadow surfaces. (©S. Vrooman)

CHAPTER 4 — ANCILLARY STRUCTURES

Eleven types of structures used to preserve or restore high elevation wetlands are described in Chapter 4. Water spreading structures include the plug and pond, plug and spread, contour swale, cascading swales, worm ditch and media luna. Structures used to prevent, stabilize or bypass active headcutting include the rock Zuni bowl, sod Zuni bowl, contour swale, worm ditch, rock rundown, rock mulch, and rock lay back. All structures described herein are best constructed during periods of minimal flow, usually late summer or early fall.

PLUG AND SPREAD

Plug and spread structures (Zeedyk 2015) are used to reconnect ephemeral and intermittent stream reaches with former wetland surfaces now dominated by mesic or upland plants including native and exotic grasses and forbs such as Kentucky bluegrass, oatgrass, clovers, timothy or smooth Brome (Figures 38 and 39). Key differences between a plug and pond structure and a plug and spread structure include:

1. The plug in the plug and spread structure is topped by an earthen berm that is one to two feet higher than the bank of the gully, whereas the plug in a plug and pond is approximately level with the top of the bank and remains wet.
2. In the plug and spread structure, the berm is 1) higher than the level of the pond, 2) not wet at the time of construction, and 3) not revegetated by use of wetland sod but by replanting mesic species such as Western wheatgrass.
3. In a plug and pond, a lead-out channel is used to guide the water from the pond to the area to be rewetted. In a plug and spread, water moves across the brim of the excavated pond as sheetflow.

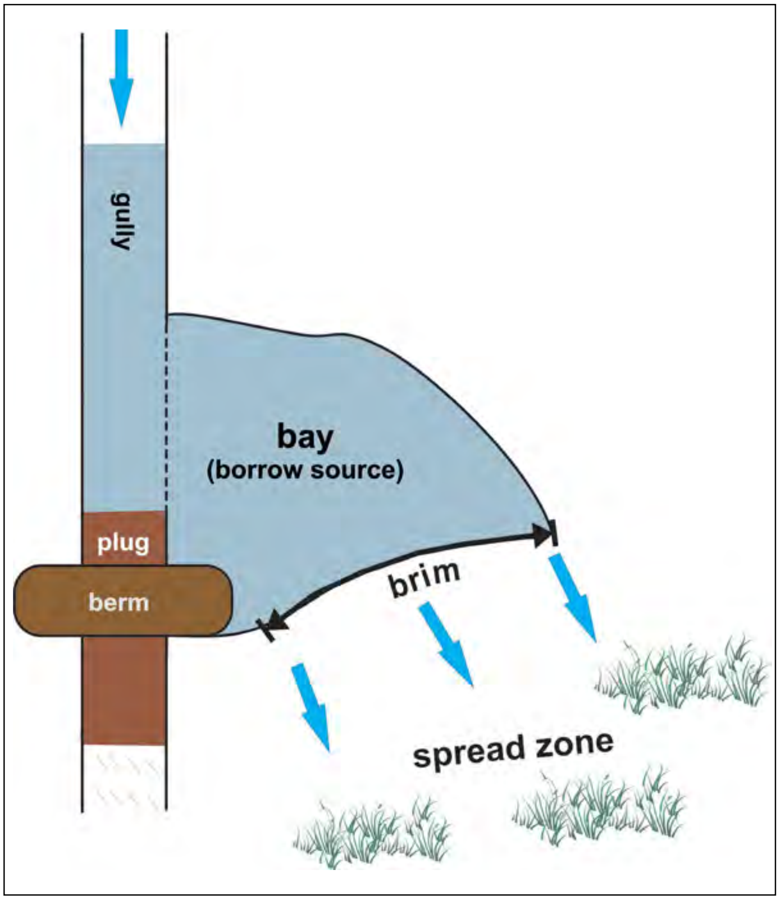

Figure 38. Plug and spread schematic (Zeedyk 2015).

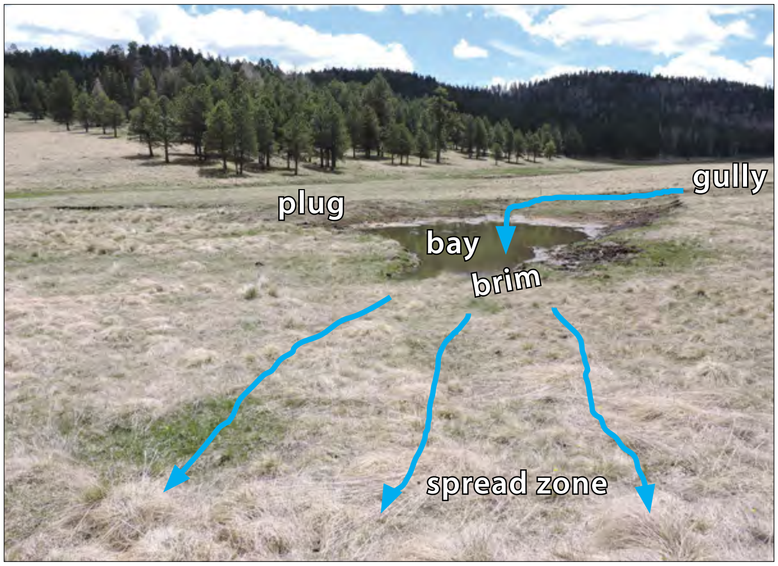

Figure 39. Site 18, May 11, 2016. Plug and spread treatment. (©W.D. Zeedyk)

At Valle Seco, a plug and spread structure was built on Tributary 2 at Site 18. Tributary 2 is an intermittent tributary of Tributary 1 flowing mainly during the spring snow melt season. Snowmelt runoff was routed to valley left in order to redistribute sheetflow across approximately two acres of formerly mesic vegetation which was dominated by upland (xeric) species at the time of construction. Sites 25 and 27 were built as a hybrid blend of a plug and pond and plug and spread structure in that a high berm was installed to deflect all flows onto formerly wetland surfaces but the berms were revegetated using wetland sod. This treatment was only partially successful because the sod became dehydrated and died. An alternative, to insure proper revegetation, would have been to reseed the berm using appropriate upland species. Site 39 was also built as a modified plug and spread treatment with a berm and has proven highly successful because the berm was revegetated with appropriate upland species harvested on site.

CONTOUR SWALES

Contour swales, including diversion swales and spreader swales, are shallow ponds excavated on flat to gently sloping meadow surfaces and used to collect sheetflow and reroute such flows onto a more desirable receiving surface (Figure 40). Swales are best constructed using a tracked skid loader to create a shallow ditch equal to the width of the skid loader bucket. The sod removed from the swale can be harvested and used to construct a sod-lined rundown (sod Zuni bowl) on the face of the headcut or for other purposes. The swale should be dug as shallow as feasible (only 6-12 inches deep) and still function properly. Constructing a shallow swale will promote seeding, growth and establishment of obligate wetland vegetation. More deeply dug swales are apt to remain unvegetated because impounded flows suppress growth. Before excavating the swale, the downstream contour should be flagged by using a laser level to identify the contour. Swales can also be easily built by use of an excavator bucket, but salvaging the resulting sod plugs is more problematic. The advantage is that the swale can be less wide than that produced by a skid loader. On dry sites, wheeled rather than track-mounted equipment can be used.

A **diversion swale** is built with a slight downhill slope or grade in order to route flowing water around the lip of a headcut or to reconnect a former wetland surface (Figure 41).

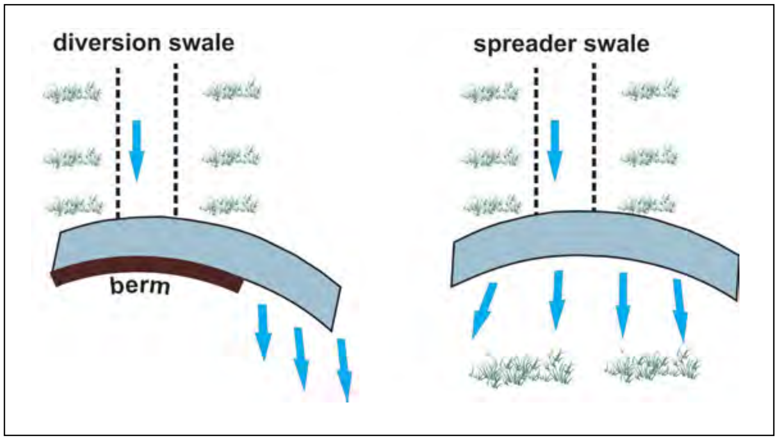

Figure 40. Diversion swale and spreader swale schematic.

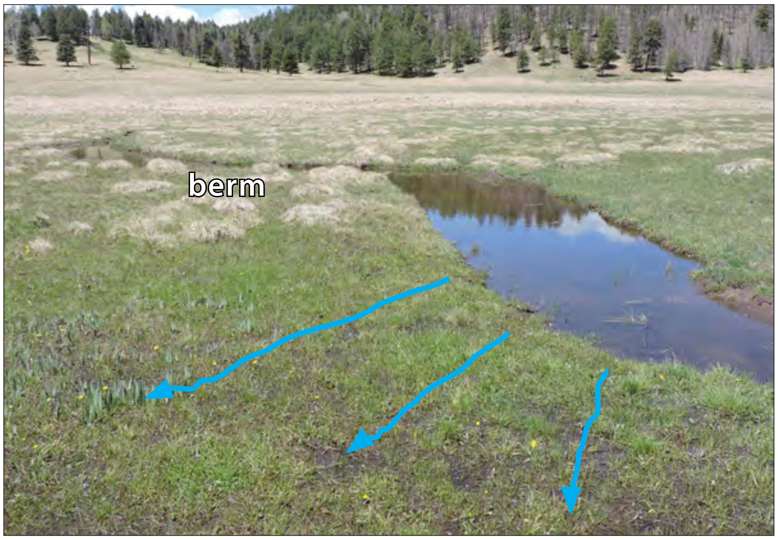

Figure 41. Site 36, May 11, 2017. Diversion swale. (©W.D. Zeedyk)

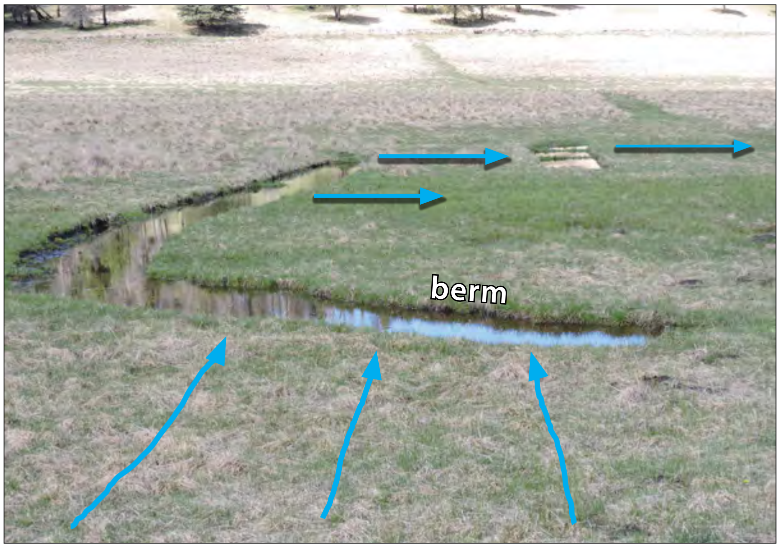

Figure 42. Site 32, May 11, 2017. Diversion swale and spreader swale. (©W.D. Zeedyk)

A slope of 0.2 to 0.5 percent was used at Valle Seco. Additionally, sod excavated from the swale was used to build a low dike, or berm, on the downhill side of the swale for approximately half the length of the swale. The remaining length of the swale was built on the contour so as to spill water evenly from the downslope brim to reconnect flow with the former wetland surface. The diversion swales were most effective when used in succession as cascading swales that served to spread flows progressively across a wider surface. Diversion swales were built by excavator to an average width of two feet, a depth of six to twelve inches and to variable lengths appropriate to the situation. Diversion swales have proven highly successful, adaptable and easily constructed. This concept was developed by Steve Vrooman, Keystone Restoration Ecology, LLC.

A **spreader swale** is used to reconnect flows to the surface of a dewatered, former wetland landform that was drained by the advancing incision. Spreader swales may be built in combination with diversion swales. A spreader swale is built downvalley from a diversion swale in order to intercept all surface runoff and redirect such flows evenly across the meadow surface as sheetflow (Figure 42). The lower lip of the swale must be excavated level with the receiving meadow surface. A low berm may be constructed along a portion of the down slope side of the swale to act as a levee deflecting flows further to the left or right as appropriate in case a depression on the meadow surface threatens to capture and redirect such flows. The swale is extended as far as necessary to safely deflect away from the gully. Finally, a level brim, or a worm ditch, may be excavated around one end of the swale to spill more widely across the receiving meadow surface. Use of a laser level is important in flagging the downvalley edge of the spreader swale.

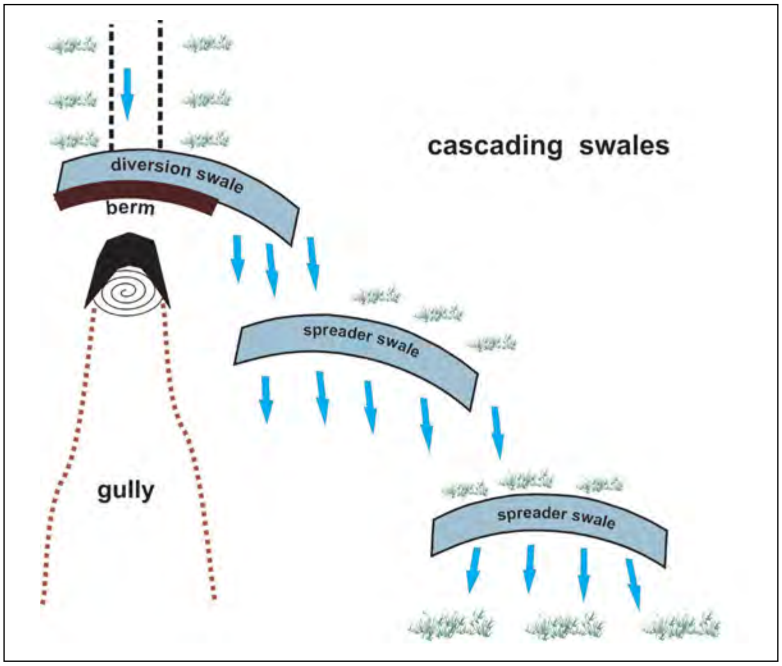

Figure 43. Schematic depicts cascading swales that bypass a headcut and related gully.

The use of **cascading swales** is an evolving method for routing sheetflow around the lip of an incising headcut and reconnecting rerouted flows to the former wetland surface that was dehydrated by the gully (Figure 43). Cascading swales may consist of two or more parallel swales which collectively capture and lead surface runoff further to the left or right of the

incising headcut, thereby re-saturating a broader swath of meadow surface than would be possible with a single swale alone. Cascading swales resemble a chevron of swales on the landscape (Figures 43 and 44). The length, width and pattern of adjacent swales comprising the cascade can be arranged to take optimum advantage of the topography and spread restored sheetflow as widely as possible. Another advantage of using several swales in succession is that depressions on the meadow surface that might otherwise capture and return diverted flows to the gully can be bypassed and avoided. A set of cascading swales installed at Site 39 has successfully rehydrated approximately four acres of formerly mesic wetlands. As with a single swale, the cascading swales should be built as narrow (2-4 feet) and as shallow (6-12 inches) as feasible. Sod clumps salvaged from the swales can be used to construct sod Zuni bowls or to revegetate barren reaches of the bypassed gully. The swales can be further enhanced by the use of simple worm ditches leading further outward to reconnect as much former wetland surface as possible.

Figure 44. Site 31, April 20, 2017. Upper swale, left, diverts flow around a headcut and directs it to two spreader swales, valley left. (©S. Vrooman)

WORM DITCH

A worm ditch is used to direct water around a headcut or for other purposes such as leading flows away from a plug and pond structure or further extending the area wetted by a swale (Figure 45). Worm ditches can be constructed by hand or machine. The goal of the worm ditch is to build a conveyance channel having a slope less steep than the slope of the land surface to be wetted by the ditch. The ditch should have the capacity (width and depth) to convey the expected flows. Use of a sinuous channel (worm ditch) reduces the velocity of water flowing in the ditch to less than would occur in a straight (steeper) ditch with the same beginning and ending points. Because the water moves more slowly, it fills the channel and spills gently along the length of the ditch, thus wetting the soil and vegetation on either side of the ditch. Because a worm ditch is longer and less steep than a straight ditch would be, the flow has less erosional power which might scour the bed of the ditch thus making it deeper (Zeedyk and Clothier 2009).

Figure 45. Site 20, July 2015. Worm ditch hand-dug by volunteers. Here water spills as sheetflow to the left. (©K. Menetrey, NMED)

To build a worm ditch channel, a starting point is selected above the headcut or at the edge of a plug and pond structure that will collect the designed flow. Select the end point downvalley. Measure the straight line distance (the “valley length”) between those two points. The constructed worm ditch should have a channel length about two times the valley length,

yielding a channel having a slope half the valley slope. For example, valley slope might be two percent whereas the slope of the worm ditch would be only one percent.

A length of rope twice the valley length can be used to align the ditch. On a trial and error basis, the rope is laid out in a series of evenly spaced meander bends connecting starting and ending points. This will be the course of the new channel. By hand or by machine, dig a meandering channel next to the rope. A machine-built worm ditch was installed at plug and pond Site 36. The ditch at Site 36 was 12 to 18 inches wide and 6 to 12 inches deep. Soil from the ditch was scattered. A levee was not built along the downstream edge of the ditch but low spots were plugged to spread flows more widely. Flood flows follow the channel and some water spills to irrigate wetland plants the full length of the ditch. Site 20 is a worm ditch that was hand dug by volunteers. It is 240 feet long, 6 inches deep and about 30 inches wide. It restores sheetflow to about seven acres of former wetland.

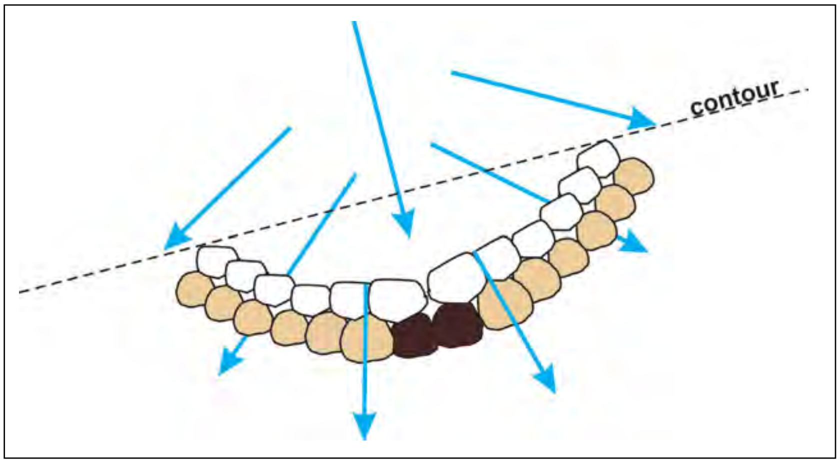

Figure 46. Media luna schematic. (NMED-SWQB, 2014)

Figure 47. Complex Site 28, May 11, 2017. Media luna spreading water downvalley from plug and pond. (©W. D. Zeedyk)

MEDIA LUNA (HALF MOON SHAPED)

“There are two types of Media Luna structures – both used to manage sheetflow and prevent erosion. Sheetflow collectors (tips DOWN) prevent erosion (small headcuts) at the head of rills and gullies by creating a stable transition from sheetflow to channel flow at the collection point. Sheetflow spreaders (tips UP) are used to create a depositional area on relatively flat ground by dispersing erosive channelized flow and reestablishing sheetflow where it once occurred. Original concept developed by Van Clothier.“ (Sponholtz and Anderson 2010) (Figures 46 and 47)

ZUNI BOWLS

“The Zuni bowl is a frequently used headcut control structure. It is a rock basin built by machine or hand, using properly sized rock at headcuts ranging between 1.5 to 6 feet in height (Figure 48). The Zuni bowl is built on the step-falls or step-pool principle and designed to create two or more drops replacing the single drop of the original headcut. The bowl is lined with rock to harden the bed against the erosive, scour effect of falling water. Water pooled within the bowl blunts the shear stress of the falling water, further reducing erosion of the bed and walls of the headcut.”

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

Figure 48. Site 24, May 11, 2016. Rock Zuni bowl. (©W.D. Zeedyk)

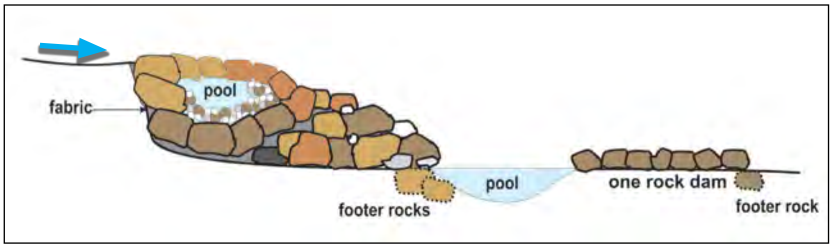

Figure 49. Zuni bowl and one rock dam schematic (Zeedyk and Clothier, 2009)

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

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

"A Zuni bowl, 6 feet wide by 10 feet long by 4 feet high and creating a single step fall, will require about 3 cubic yards of rock to build. A second pool is created by installing a simple one rock dam downstream from the

Figure 50. Site 38, left, sod Zuni bowl after construction, May 13, 2016 and right, one year later, May 11, 2017. (©W.D. Zeedyk)

Zuni bowl (Figure 49). The upstream edge of the one rock dam should be approximately 6 to 8 times the height of the falls downstream from the footer rocks in the bowl." (Zeedyk et al. 2014) Original concept developed by the people of Zuni Pueblo.

SOD. Sod Zuni bowls can be used to stabilize headcuts bypassed by a worm ditch or diversion swale. Several sod Zuni bowls were constructed at Valle Seco (Figure 50, page 32). Sod harvested from swales was used to build the bowls. Sod Zuni bowls were first used at Tres Arroyos at the Valles Caldera National Preserve by Stream Dynamics, Inc. in 2012.

The bowl is constructed using successive layers of sod placed on a 3:1 slope either by hand or by use of an excavator bucket. Unlike when building a rock-lined Zuni bowl, the back shape of the sod bowl is not reshaped to create a tapered slope. Every effort is made to retain all existing well-rooted sod clumps in order to strengthen the structure against erosion and retain moisture. Shaping the bowl would make the soil more erodible.

Once the bowl is built, the sod is moistened by groundwater seeping from the banks or by very shallow, well-dispersed sheetflow spilling over the lip of the headcut. Because the surface flow has been deflected by the bypass structure, the volume, velocity and force of water falling onto the sod bowl is much reduced. This keeps the bowl from being damaged or washed away. With time, the sod grows stronger and becomes more resistant to erosion (Figure 50).

ROCK RUNDOWN

"Low energy headcuts in small watercourses and arroyos can be repaired by laying back the channel at a shallow gradient and building a rock rundown to stabilize the slope, allowing grasses and sedges to colonize the slope (Figure 51). Several structures of different types applied in sequence are often required to stabilize a headcut. For instance, since headcuts often advance in waves of three drops of different heights, a rock rundown might be used to control the upper, more shallow drop, a Zuni bowl to control the middle or taller drop and a one rock dam to control the third drop. Adding a one rock dam or weir beneath the central structure is always an effective way to reduce the depth of scour, while also creating a more permanent scour pool as a water source for livestock or wildlife." (Zeedyk and Clothier 2009) A hand-built rock rundown was installed at Site 53 to stabilize the plug and pond outlet for Site 52.

Figure 51. Site 19. Left, rock rundown after construction, August 25, 2015. (©W.D. Zeedyk) Right, two years later, July 6, 2017. (©T.E. Gadzia)

ROCK LAYBACK

A rock layback is used to armor a long, low vertical headcut subject to erosion by shallow, well-dispersed, slow moving sheetflow events. This is in contrast with narrow, taller "V" shaped headcuts caused by higher velocity concentrated flows having greater erosive force normally treated by use of a Zuni bowl or rock rundown. A rock layback, rather than a Zuni bowl, is used to minimize the volume of rock needed to treat a headcut (Figures 52 and 53).

A rock layback serves three purposes: 1) prevents erosion (deepening) of the scour hole, 2) prevents erosion of the vertical face of the headcut and, 3) preserves moisture and prevents drying of the vertical face so that the roots of vegetation are not desiccated by exposure to air during no-flow periods. At Site 11, a rock layback was built by volunteers. The layback was feasible because primary flows had been routed around the headcut by use of a plug and pond structure (Site 12).

Figure 52. Site 11, August 25, 2015. Rock layback after construction. (©W.D. Zeedyk)

Figure 53. Site 11, July 6, 2017. Paired rock layback and one rock dam as revegetated two years later. (©T.E. Gadzia)

Steps to construct a rock layback include:

1. Use a shovel or spade to remove dry soil and dead roots to create a smooth vertical face and a squared, flat surface at the base of the headcut. Any exposed roots should be live roots.
2. Place a row of larger footer rocks in the scour pool at the base of the falls. For best results, the long dimension of the "footer" rocks should be parallel with direction of flow and have a relatively flat surface. A row of footer rocks should span the full width of the headcut.
3. Stand rocks upright on the footer rocks and lean them into the vertical bank at a slight angle. The top edge of each vertical rock should be level with the lip of the pour-over at the top of the headcut. This step is critical. If the tops of the standing rocks are less than the height of the lip of the headcut, plant roots will dry when exposed to air and the headcut will continue to advance. If the height of the rocks is higher than the lip, flowing water will be diverted and concentrated thus increasing the erosive force of the flow and the chance of failure at the spill-over points.
4. Chink any exposed bare soil with a secondary layer of smaller rock to prevent erosion and drying so as to favor prompt revegetation of the lip.

ONE ROCK DAM

A one rock dam (ORD) "is a low grade control structure built with a single layer of rock on the bed of the channel (Figure 54). ORDs stabilize the bed of the channel by slowing the flow of water, increasing roughness, recruiting vegetation, capturing sediment, and gradually raising the bed level over time. ORDs are also passive water harvesting structures. The single layer of rock is an effective rock mulch that increases soil moisture, infiltration and plant growth. Original concept developed by Bill Zeedyk." (Sponholtz and Anderson 2010).

STABLE RETURN SITES

At Valle Seco, four structures were built to perform as stable return sites that is, at locations where dispersed flow can be safely returned to the main channel without forming new headcuts (Figure 55). Those sites included: Site 22, downstream from Site 20 and 21; Site 19 below Site 20; Site 11 below Site 10; and Site 53 below 52. Site 11 was constructed as a long rock layback, Site 19 and 53 as rock rundowns and Sites 22 and 24 as Zuni bowls. All rock structures were built by hand using volunteers from Albuquerque Wildlife Federation and Los Amigos de Valles Caldera (Figure 56). At all other sites, sheetflow was widely dispersed and does not re-enter the main channel in concentrated amounts, hence poses no threat for newly developing headcuts.

Figure 54. Site 50, August 11, 2015. One rock dam at stock pond outlet. (©W.D. Zeedyk)

Figure 55. Site 53, May 11, 2017. Rock rundown constructed by volunteers as a stable return site for plug and pond at Site 52. (©W.D. Zeedyk)

Figure 56. Site 50 and 51, July 18, 2015. Volunteers build grade control rock structures at stock pond outlet. (©W.D. Zeedyk)

A TREATMENT COMPLEX

As noted under Planning, page 7, several structures can often be installed in a complex of related treatments in order to take full advantage of a restoration opportunity. In this regard, various types of structures were used as a treatment complex at Sites 18, 19, 20, 21 and 22 to optimize the spread of sheetflow across the affected wetland (Figures 57 and 58). At Site 21, the original structure did not function as planned and a new plug and pond was built in October 2016 to direct flow toward the unwetted area as noted in Figure 57.

SUMMARY

Plug and pond structures can be highly effective in diverting and returning channelized flow as sheetflow back across the surfaces of gullied and desiccated formerly wetland landforms. Installing appropriately sized, spaced and situated ancillary structures placed in combination with plug and spread treatments in patterns unique to the landscape being treated, can render such treatments more effective to use, more economical to build and more resistant to erosion than when used separately and apart from other plug and pond treatments.

Each type of ancillary treatment, as described above, has specific applications, limitations and requirements for proper design and construction. Such treatments can be used to disperse flow more widely across the receiving landform, remove or avoid minor erosional features on the landscape, stabilize headcuts above or below the plug and pond site itself, and safely return dispersed flows to the main channel.

Proper construction techniques must be followed as outlined for each treatment. Perhaps most importantly, hand-built ancillary structures, such as worm ditches and one rock dams, provide an opportunity to attract eager volunteers to help in the restoration and recovery of damaged wetland environments scattered across their publicly owned lands. These structures, built and paid for in the form of good feelings in the moment, give personal satisfaction in the long term.

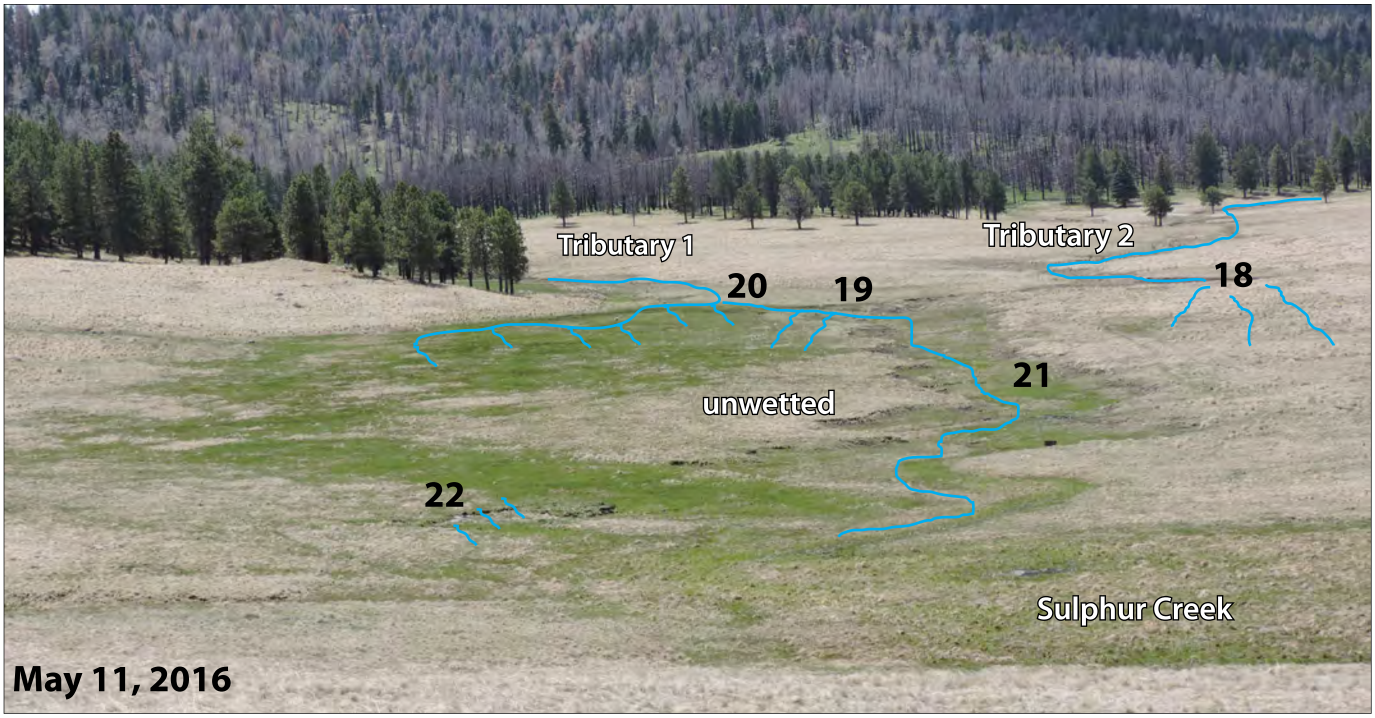

Figure 57. Sites 19 and 22 plug and ponds, Site 18 plug and spread, and Site 20 worm ditch. Treatments constructed in 2015. This pattern of varied treatments was used to disperse surface flows more widely. The structure initially installed at Site 21 was not effective, leaving the central area unwetted. (©W.D. Zeedyk)

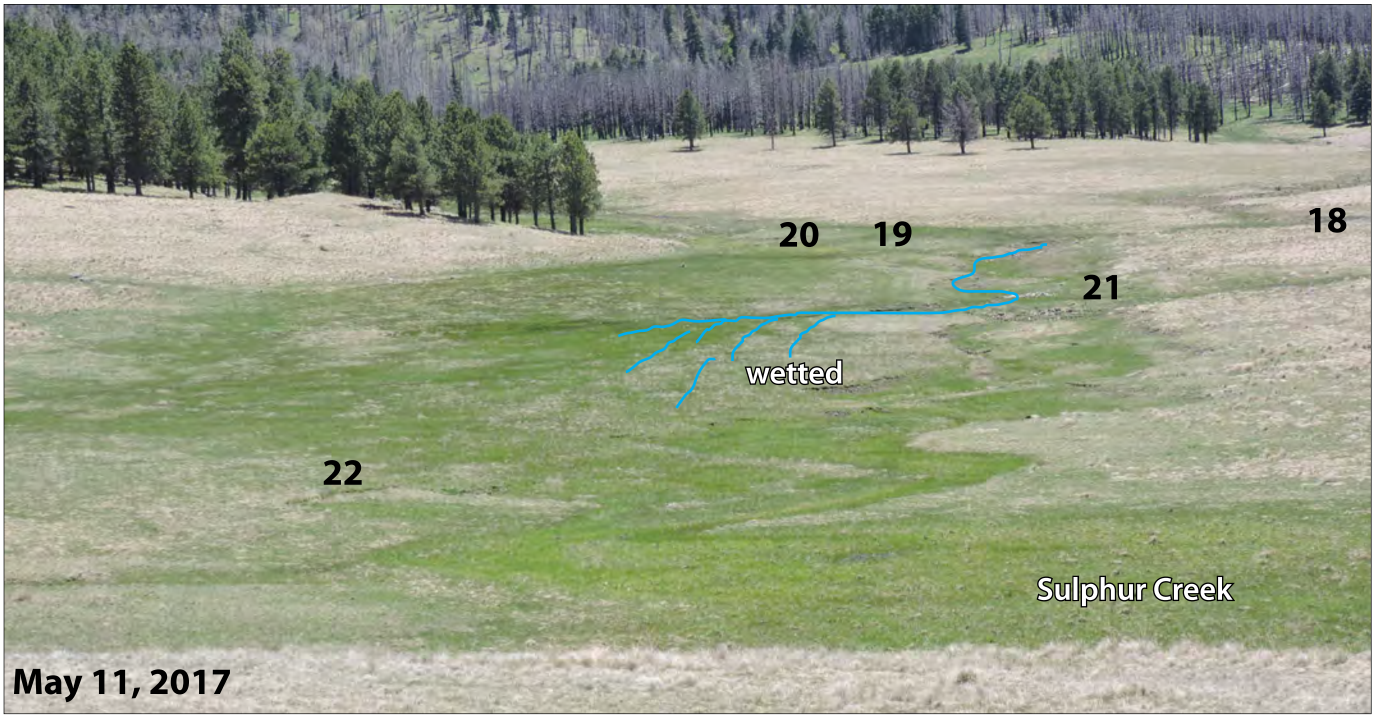

Figure 58. A new plug and pond was installed at Site 21 during October 2016 and successfully rewetted the central portion of the meadow. The area below Site 18 is also beginning to respond to treatment. (©W.D. Zeedyk)

CHAPTER 5—MONITOR, MAINTAIN, MODIFY

INTRODUCTION

Monitoring can include the periodic and systematic review of all installed treatments to determine if structures are functioning as planned and what maintenance or modification may be needed. Monitoring is a requirement of USACE CWA Section 404 permits. Monitoring also provides a systematic learning opportunity upon which to revise and amend future planning, design and construction techniques. In the case of slope wetlands, monitoring is best conducted during spring snowmelt and during mid-summer monsoon season when it is easy to observe runoff distribution patterns and to identify where maintenance or modification may be needed. Monitoring during periods of minimal flow can be less certain and more subject to error due to possible misinterpretation of apparent distribution patterns, flow depth and duration of flow. Deposited organic materials and eroded soils provide clues as to distribution patterns and depth of flows, but can be misinterpreted.

At Valle Seco, monitoring was performed annually in May after snowmelt and August or September after monsoon events. Maintenance performed in response to monitoring included making minor modifications to rock structures, digging additional worm ditches, increasing ditch sinuosity, and modifying the brims of dug structures in order to spill flows more widely. Vegetation was transplanted to key locations in order to accelerate stabilization of structures and to reintroduce adapted native species more quickly and more widely to restored surfaces. Vegetation included sedges and rushes that were replanted from local sources found near the structures.

Several structures were modified by lengthening worm ditches, or adding lead-out ditches to the brims of completed structures. Examples include Sites 12, 18, 20, 27, 32, 36, 39 and 49. Most importantly at Site 52, the lead-out ditch, or brim, was undersized and did not have sufficient capacity to handle snowmelt runoff. The outlet was subsequently widened by one third to increase discharge capacity and reduce potential for floods to over-top the plug. The outlet was not deepened, only widened. This was done in order to maintain maximum water depth and continue to saturate sod on the surface of the plug.

OBSERVATIONS FROM MONITORING OF TREATMENTS

Four small plug and pond structures built in succession at Site 48 on Tributary 5, August 2015, failed during 2016 spring runoff. These structures were built as small earthen plugs spanning a portion of the channel width in this overly wide gully. The selected spread zones were within the confines of the gully itself and did not reconnect the structures with the former alluvial fan surface in keeping with standard plug and pond methodology. The lead-out channel(s) draining each structure had too little capacity to contain snowmelt discharge. Flows over-topped the plug at each structure damaging or destroying all four structures due to their earthen consistency and the fact that sod on the surface of the plugs could not withstand erosive force of concentrated flows. Rock structures designed as one rock dams would probably have withstood the erosive force of the peak discharge. This site demonstrated inappropriate use of the plug and pond technique.

At Site 23, two overlapping ditches (Figure 59) were installed upvalley from a very active headcut in order to route sheetflow around the

Figure 59. Site 23, July 6, 2017. Ditch. (©T.E. Gadzia)

headcut (Page 8, Figure 10). These two ditches overlapped so that the upper ditch captured and routed sheetflow from valley left and toward valley right and in the direction of the lower ditch. The lower ditch captured and routed these flows further toward valley right, the relict channel of Sulphur Creek itself. The downvalley edges of the two ditches were lined with berms built of sod wads dug from the ditches by an excavator. The sod wads were loosely stacked and compacted on the surface of the natural sod. This treatment was not fully successful because some waters trapped by the ditch leaked through cracks between the loosely placed sod wads. While most of the flow was successfully rerouted around the headcut and into the historic channel, sufficient sheetflow remains on the surface to maintain active headcutting in part. The error was in not compacting the sod berm sufficiently to prevent leakage. In retrospect, diversion swales, as described on pages 28-29, might have proven more effective. In August of 2017, the sod berms were repaired by volunteers but have yet to be subjected to spring runoff events and remain untested.

VEGETATION

Vegetation monitoring can be very enlightening when tracking response to various treatments. Vegetation transects were installed in treated locations at Valle Seco. The change from upland to mesic and mesic to hydric species is usually evident as a gradual transition beginning in as early as one or two years, but the transition may not reach potential for at least four years or longer (Neely and Rondeau 2017).

At one wet meadow restoration project in Gunnison Basin, Colorado, average cover in wetland species increased successionally between two to four years post treatment at ten of eleven restoration sites. At the ten sites showing change, the increase ranged from 6% after two years to up to 245% after five years. Five years of data showed that the rate of increase declined, at two of the four sites, after the fourth year. The author noted that there was no one pattern to explain variation in the rate of increase (The Nature Conservancy 2017). These findings are similar to studies from elsewhere in the West.

Monitoring allows practitioners and funders to understand if their restoration efforts are producing positive results. By collecting vegetation data and before- and-after photographs, we determined that wetland species cover has increased at treated sites compared to untreated sites. It is critical to have untreated areas that are similar to treated areas to ensure that our comparisons are scientifically sound.

– Renée Rondeau, Colorado Natural Heritage Program

Vegetation Succession from Wetland Restoration Treatments

A few indicator species have been observed to respond rapidly to the rewetting of wetlands by use of plug and pond and other treatments at Valles Caldera National Preserve.

Year 1: *Poa pratensis* (Kentucky bluegrass) and *Juncus articus* (Artic rush) respond with increased and vigorous growth (Figure 60). Almost all *Poa pratensis* goes to seed across the re-wetted area in year 1. In late summer, the small grass *Agrostis scabra* (rough bentgrass) also goes to seed (Figure 61). This normally three-inch tall bunch grass has tall pink stalks in mid-August under re-wetted conditions.

Year 2: *Juncus articus* is a clonal species with rhizomes. During year 2, it puts out more above-ground growth and becomes more abundant. *Poa pratensis* either continues to bloom, or becomes less vigorous in the wetter sites. During Year 2, clonal sedge species such as *Carex praegracilis* (Clustered Field sedge), *Carex aquatilis* (Aquatic sedge) and *Carex utriculata* (Northwest Territory sedge), become much more vigorous and more abundant, due to the rewetting, and spread into new areas.

Year 3. Facultative wetland species begin to appear such as *Epilobium ciliatus* (Fringed willow-herb), and *Juncus ensifolius* (Rocky Mountain rush), and *Carex microptera* (Smallwing sedge). These species are most likely being brought to the site by water flowing from upstream sites and are germinating under the newly wetted conditions. A smelly, sticky herb, *Matricaria discoidea* (disc mayweed), a facultative upland species, begins to invade the wetland area and become more abundant as does the grass, *Alopecurus aequalis* (Shortawn foxtail) (Figure 62), which is not classified as a wetland or facultative species, but is strongly associated with wetlands on the Valles Caldera National Preserve. This plant appears to be strongly wetland adapted on the Preserve and can be found growing in several inches of water in most ponds and cattle tanks. It is not normally considered an aquatic species such as buttercup (*Ranunculus* sp.) (Figure 63).

Figure 60. July 14, 2017, *Poa pratensis* and *Juncus balticus*. (©S. Vrooman)

Figure 61. August 23, 2017, *Agrostis scabra* (rough bentgrass) (©S. Vrooman)

Figure 62. September 16, 2017, *Alopecurus sp.* (©S. Vrooman)

Figure 63. May 11, 2017. *Ranunculus* sp. (Buttercup) responding to water sheeting across a mesic site. (©W.D. Zeedyk)

CHAPTER 6— CONCLUSION

THE PLUG AND POND TREATMENT

Twenty-nine plug and pond structures were installed at 53 sites at Valle Seco, with 24 structures functioning as designed. Ancillary treatments done separately or in combination were installed at the remaining sites. Preference was given to installing various structures as a complex of treatments to maximize potential rewetting based upon prevailing characteristics of the landscape in that portion of the Valle Seco. Sulphur Creek and five of six primary tributaries were treated. As a result, at least 41.6 acres of wetlands were restored. Tributary 1 and Sulphur Creek are perennial; the remaining tributaries are intermittent. It is anticipated that the duration of flows related to intermittent tributaries will lengthen with time as a direct result of base flow originating from the treated wetlands.

Increases in wetland vegetation at the rewetted former wetland sites is apparent from vegetation transects and from repeat photography. Vegetative response has also been accelerated by removing livestock from Valle Seco by the National Park Service. Snowmelt runoff was at or above normal during Spring 2016 and 2017 which may have accelerated wetland recovery at Valle Seco sites. Recovery is proceeding rapidly at other project sites where the plug and pond method has been implemented. There are currently 129 plug and pond structures working to restore and expand wetlands on the Valles Caldera National Preserve: Nina's Spring (9), Tres Arroyos (5), Six Tributaries of San Antonio Creek (40), Jaramillo Creek (16), Rito de los Indios (35), and Valle Seco (24).

All the above projects have utilized contracted firms specializing in wetland restoration and/or volunteer groups such as Los Amigos de Valles Caldera and Albuquerque Wildlife Federation, eager to assist in restoration. Project areas have been visited by individuals and tour groups interested in applying these methods to other areas within New Mexico and adjacent states (Arizona and Colorado).

WETLAND RESTORATION SERVES MANY PURPOSES

On the Valles Caldera Preserve, restored wetlands are providing habitat for waterfowl, northern leopard frogs, Wilson's snipe and Phalarope (Figures 64 and 65). At Valle Seco, northern leopard frogs have occupied all plug and pond sites. Early spring greening of sedges provide essential nutrients for elk. Sedges are high in protein and vitamins, essential to pregnant females at critical times. Spring greens are also sought after by wild turkeys, especially nesting hens. Wet meadows store shallow ground water for release later in the season thereby sustaining base flow in downstream reaches. Ongoing depositional processes detain and retain fine grained soil particles, building new soils and improving water quality (reducing sediment loading). Perhaps most importantly, the vibrant green expanses of wetlands nestled among the bowl shaped valleys of the Valles Caldera National Preserve are highly attractive and are the most memorable, scenic attractions of the Preserve.

Opportunities to restore former wetlands on the Preserve are limited. Many gullies have eroded too deeply and are too wide to be economically treatable. Often, the relict meadow surfaces are too narrow, too disjointed or too irregular in shape for efficient dispersal of surface flows. Wetland restoration

Figure 64. Site 52, May 11, 2017. A pair of mallards utilizing the wetlands. (©W.D. Zeedyk)

must be coupled with on-going management activities at every opportunity such as: 1) the proper construction of road drainage features in order to reconnect captured flows with nearby meadow surfaces, 2) changes in livestock management, 3) changes in recreational uses, and 4) changes in burned area recovery efforts.


Figure 65. Northern leopard frog. (©S. Vrooman)

Throughout the VCNP, as elsewhere, wetlands have been almost universally threatened, damaged or destroyed by improperly located, or improperly drained, roads. This includes active roads, recently inactivated roads or long-abandoned roads reminiscent of a bygone era of widespread logging and ranching. A continuing program is needed to properly drain such roads to reconnect wetland surfaces with the water sources that would sustain them, if the roads were not interfering. Often such treatments can be routinely installed as an on-going aspect of road construction or maintenance activities if the opportunity is recognized before the treatment is designed and installed. Wetlands adjacent to primary access roads within the VCNP, including VC01, VC02, and VC08, have benefited from construction and maintenance treatments installed for that purpose and subsequently augmented by plug and pond installations.

Finally, wetland restoration, once initiated, can reverse a degrading trend and gain restorative momentum with positive interactions between hydrology, geomorphology, and ecology. As vegetation responds to the added moisture, more sediments are detained and retained to build new wetland soils and spread water even more widely across the landform and thereby sustain a more diverse community of wetland plants—just as all wetlands were initially formed across the expanse of the VCNP. Hopefully this publication will help guide similar projects into the future.

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