TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE STATE OF COLORADO NATURAL RESOURCES CONSERVATION SERVICE

Range Technical Note No. 40 May 2018

Hand-Built Structures for Restoring Degraded Meadows in Sagebrush Rangelands

Examples and lessons learned from the Upper Gunnison River Basin, Colorado

Zeedyk rock structures installed to restore incised channel. Photo by: Nathan Seward

Purpose: Gully erosion and channel incision are widespread problems reducing the function and resilience of wet meadows and riparian areas. The loss of natural water storage capacity in these systems is of concern in low-precipitation areas where wet-mesic areas represent a small fraction of the landscape but are disproportionately important to wildlife and livestock. This technical note provides conservation practitioners with information on simple yet effective "Zeedyk" restoration techniques. The emphasis here is on structures that can be built by hand to address shallow headcuts or small incised channels (< 4 ft deep) impacting meadows and low-to-moderate gradient (< 3% slope) intermittent/ephemeral drainages in sagebrush rangelands. The note provides examples and lessons learned from partners in the Gunnison Climate Working Group who have been implementing a landscape-scale project using these techniques in the Upper Gunnison River Basin, Colorado. The note provides information and references to help practitioners identify opportunities, prioritize treatments, and design projects in similar watersheds across the West.

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I. Introduction

Background

Riparian areas and wet meadows occupy a small fraction of rangeland ecosystems, yet these **mesic areas** provide critical resources for many species and are especially crucial during periods of drought. Functioning meadows and floodplains capture and hold water in the soil, slowly releasing it after runoff events, sustaining continued base flows, and maintaining higher water tables throughout the growing season. Holding water in the soil later into the summer season results in plant communities that are more productive than surrounding landscape, making them attractive for wildlife and livestock.

However, the hydrological and ecological function of many riparian and meadow areas have been degraded by gully erosion, channel incision, and lowered water tables. Causes are varied but often include current and past land uses, such as, improper grazing, soil compaction by livestock and wildlife trailing, roads, historic flooding events, and invasive plant species. Given the scale of the problem, restoration techniques that are relatively simple, cost-efficient, and effective are needed in the toolbox to allow more conservationists and landowners to engage in implementation.

This publication provides information on a suite of techniques for erosion control and restoration in semi-arid systems pioneered by Bill Zeedyk (Zeedyk Ecological Consulting, LLC), with support from the Quivira Coalition (Zeedyk and Jansens 2009; Zeedyk and Clothier 2014; Zeedyk et al. 2014; Zeedyk 2015). Restoration techniques include installation of simple structures that kickstart regenerative hydrologic and ecological processes to reduce or reverse degradation over time. In general, structures are designed to slow and disperse water, dissipate energy, capture sediment, and increase soil moisture, thereby promoting mesic and wetland plant species expansion and channel recovery. Benefits of structures are varied but include improved wildlife habitat, water quality and quantity, soil health and carbon sequestration, forage for livestock, drought resilience, and overall watershed function.

While a variety of Zeedyk techniques have been developed for various situations, the focus of this note is on a subset of hand-built rock or wood structures that can be used to treat wet meadows and intermittent/ephemeral streams impacted by gully erosion in sagebrush rangelands. The emphasis is on addressing relatively shallow headcuts or small incised channels (< 4 ft deep) where recovery to desired floodplain or meadow surfaces can be achieved in a reasonable timeframe without heavy machinery and earth work.

Anytime conservationists are working in riparian and wet meadow systems, it is highly recommended that an interdisciplinary approach be taken (e.g., including hydrologists, ecologists, geomorphologists). Given the landscape position of these systems, many watershed-level geomorphic and hydrologic factors influence their sensitivity to disturbance and inform restoration (Chambers et al. 2004). It is not within the scope of this publication to be a comprehensive planning guide or encompass watershed-scale considerations. Instead, the focus here is to help natural resource managers identify relatively low-risk opportunities for restoration and introduce a suite of potential treatment techniques.

Gunnison Basin Wet Meadow and Riparian Restoration and Resilience-Building Project

This note draws upon examples and lessons learned from the Gunnison Basin Wet Meadow and Riparian Restoration and Resilience-Building Project, which is a watershed-scale effort that has installed and monitored over 1,000 Zeedyk structures across the Upper Gunnison River Basin, Colorado (Fig. 1; TNC 2017; TNC and GCWG 2017). The project is led by the Gunnison Climate Working Group Project Team (GCWG)[1] – a public-private partnership that has been working collaboratively since 2012 to restore wet meadows and enhance resilience to help wildlife and ranchers in the face of drought and a changing climate.

The Upper Gunnison River Basin is home to the federally threatened Gunnison sage-grouse (*Centrocercus minimus*) where the loss of wet meadows for brood-rearing habitat has been a concern. Sage-grouse rely on mesic habitats, especially during the summer, to provide abundant food resources to feed growing chicks. These areas also provide important habitat for a host of other wildlife species, such as, deer, elk, migratory birds, and amphibians. Many wet meadows in the Gunnison Basin have already been impacted by erosion and lowered water tables and are likely be further impacted (or stressed) by increasing drought and intense precipitation events associated with warming temperatures. To address

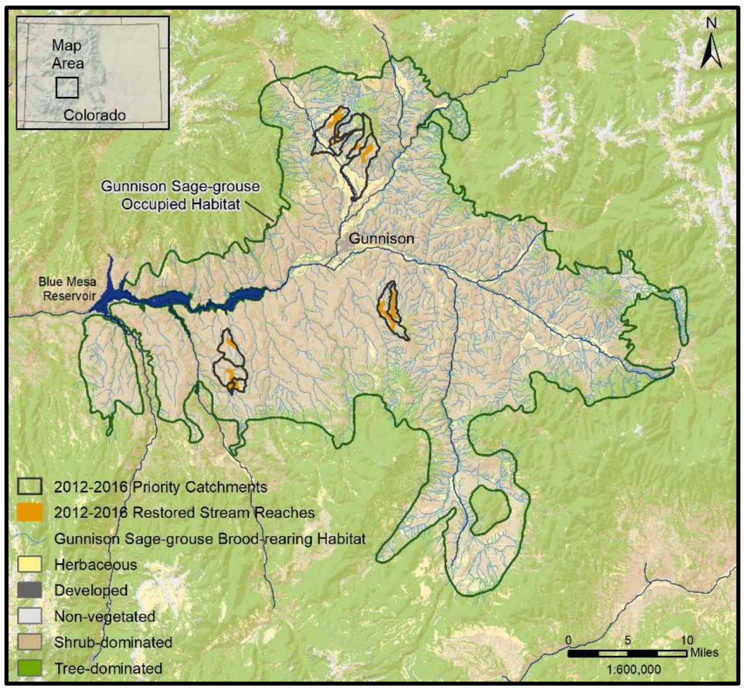

Figure 1. Wet meadow and riparian restoration project area in the Upper Gunnison River Basin, CO. Figure by: Teresa Chapman

[1]GCWG Project Team Members: Gay Austin and Andrew Breibart (Bureau of Land Management-Gunnison Field Office), Teresa Chapman and Betsy Neely (TNC), Jim Cochran (Gunnison County), Shawn Conner (BIO-Logic, Inc.), Jonathan Coop and Pat Magee (Western State Colorado University), Tom Grant and Frank Kugel (Upper Gunnison River Water Conservancy District), Imtiaz Rangwala (Western Water Assessment), Renée Rondeau (Colorado Natural Heritage Program), Nathan Seward (Colorado Parks and Wildlife), Theresa Childers (National Park Service), Brooke Vasquez (Gunnison Conservation District), Matt Vasquez (US Forest Service), Liz With (Natural Resources Conservation Service), and Bill Zeedyk (Zeedyk Ecological Consulting).

these concerns, partners in the Basin have been working to improve hydrologic and ecological function of wet meadows and riparian areas to prepare for a changing future.

The Gunnison Basin Wet Meadow and Riparian Restoration and Resilience-Building Project serves as an important demonstration of simple and effective tools for increasing resilience of wet meadow and riparian habitats. Approaches applied in this project are transferable to other areas with similar goals and landscape conditions across the sagebrush steppe. For more information on this project, visit www.conservationgateway.org and search for Gunnison Basin.

II. Reading the landscape to recognize problems and opportunities

Landform, morphology, soils, and vegetation all provide important clues about the current function and potential of a site. Learning to read the landscape to recognize resource problems and restoration opportunities is both an art and science. Below are a few key features to pay attention to when walking a watershed that may help you identify situations where Zeedyk restoration techniques could be useful.

Basic geomorphic landforms

Figure 2. Basic geomorphic and fluvial landforms in a valley (from Wheaton et al. 2015).

Identifying the basic landforms within a valley is helpful when planning in riparian and meadow systems (Fig. 2; Wheaton et al. 2015). The margins of a **valley** can be described as the area between the bases of adjacent hillslopes, or uplands. The **valley bottom** is the area within a valley that includes the channel (if present) and active **floodplain**. The valley bottom margin may abut hillslopes or other features like **terraces** (former floodplains) and **alluvial fans** (fan-like sediment deposits usually at the mouth of an adjoining canyon). Larger wet meadow complexes are often located just upstream of alluvial fans or rock outcrops. Identifying the valley bottom is especially useful as it defines the maximum extent of riparian vegetation under current conditions.

From a cross-sectional view of the channel, the **bankfull** elevation is the point at which water flows onto the floodplain (aka, ordinary high water or channel-forming flow). The relationship of bankfull elevation to channel depth is important as it affects water availability to support riparian vegetation.

Channel incision, gully erosion, and headcuts

Channel incision is the process of downcutting in a stream channel leading to a lowering of the channel bed elevation. An **incised channel** is one in which a stream has lost access to its floodplain. Meadow systems typically lack a discernable channel but can be impacted by incision through the process of **gully erosion** when surface flows become concentrated and downcut into meadow soils. The term "**gully**" is often used broadly to describe various types of incision.

Figure 3. Top: Headcut advancing in meadow. Bottom: Plant roots on the headcut lip become exposed resulting in mortality. Photos by: Kyle Tackett

Most visible channel incision and gullies occur and advance by way of **headcuts** (aka, nickpoints or gully-heads). Headcuts are identifiable points of active incision where there is an abrupt change in channel gradient, creating a waterfall and plunge-pool (Fig. 3). Water accelerates as it plunges off the headcut ledge, generating turbulence, scouring bed material to form a pool, and undercutting the drop-off by eroding soils. Vegetation that once held soils together is left dry, resulting in plant mortality that allows the headcut to advance upstream. Once gullies are formed, groundwater sapping (seepage erosion) can further accelerate incision in meadows as well.

There are few things in nature that can stop a headcut from advancing once started. The rate at which headcuts migrate upstream depends heavily upon the soil textures and structure, vegetation, and water flow. Headcuts typically move upvalley in stages as bed erosion continues until an impermeable substrate, such as bedrock or tree roots, is reached and a new grade established.

Being able to recognize headcuts in the field provides an opportunity to intervene to protect upstream riparian areas and meadows that have not yet been incised.

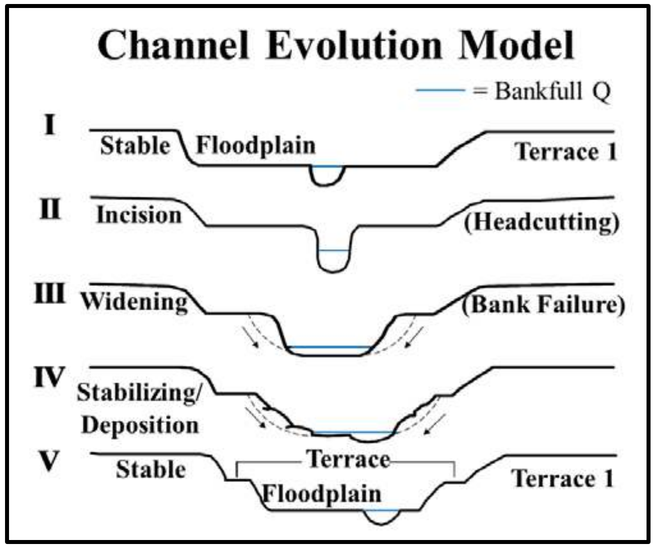

Figure 4. Channel evolution model from Schumm et al. (1984). Courtesy of W.B. Southerland.

Once incision begins, most channels tend to undergo a sequence of changes that are fairly predictable (Fig. 4; Schumm et al. 1984). When degraded, previously stable channels or meadows first downcut (stages I and II), then widen (stage III), then aggrade (stage IV), and ultimately stabilize at a new, lower elevation within the gully trench (stage V). While overly-simplistic, it is a helpful conceptual model for considering what stage of the evolution process your site might be in as it can inform the type of restoration approach used. Early intervention using the techniques described in this publication can help reverse incision by accelerating natural processes that more quickly restore floodplains, water table connectivity, and stable riparian and meadow systems.

Human nature is to tackle the most severe gullies on the landscape first. However, the cost of doing so can be very high in terms of the amount of effort needed to recover those sites, the potential risk of failure, and the foregone opportunity to prevent further degradation in less impacted areas. If given the choice, *it is highly recommended that conservationists prioritize sites that are still in the early stages of channel evolution (stages II and III) where headcuts and gully trenches are relatively low*. The degree of incision can also be estimated by the **bank height ratio**, or the ratio of the floodplain bank height to the bankfull channel height (Rosgen 1996). Areas with low bank height ratios offer a higher potential reward versus cost/risk.

Vegetation indicators

Vegetation can be indicative of hydrologic function of a site. Incision results in a lowering of the water table and capacity to store water in soils, which induces changes in riparian and meadow vegetation (Fig. 5). Prior to incision, functioning channels and meadows maintain high water tables across the valley bottom which create conditions that support wetland, mesic, and riparian plants (wetland indicator status: obligate (OBL), facultative wet (FACW), facultative (FAC); see Lichvar et al. 2012). After incision, these species give way to dryland species, such as, sagebrush (wetland indicator labels: facultative upland (FACU), upland (UPL). Most sagebrush species cannot tolerate saturated soils; sagebrush presence on a floodplain or meadow is an indicator of an altered hydrology. Even subtle shifts in vegetation, from mostly wetland obligate species (OBL) to mesic species (FACW) to riparian species (FAC), can indicate a shift from wet to drier conditions resulting from a lower water table and potentially reduced hydrologic function.

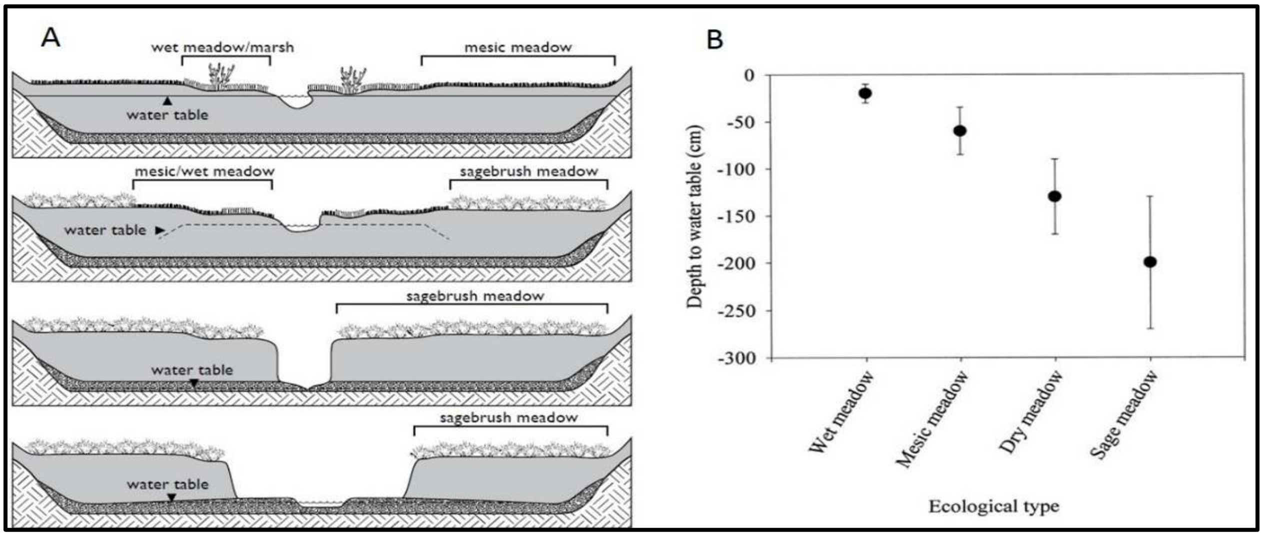

Figure 5. Panel A: Typical change in vegetation types with incision and lower water tables (adapted from Dickard et al. 2015). Panel B: Actual water table depths (means + S.E.) for typical meadow ecological types in the central Great Basin (from Chambers et al. 2004).

Soils and sediment

Erosion is a natural process that results in relocation of soils when transported by water through sedimentation. It is neither good nor bad, but a process in watersheds. However, site degradation can occur when accelerated erosion results in sediment transport that exceeds replenishment rates. Considering the sediment supply to your project site is helpful as sediment is also a resource that can assist in restoring incised channels. Detailed assessments of sediment supply can be done but simple indicators on degraded sites, such as bare sediment deposition on vegetated surfaces and point bars in channels, can be clues to the current amount and type of sediment. Sites with more sediment may allow faster recovery of incised channels.

Examining the channel bed and cutbanks within the incision trench also provides useful information. Sediment in a valley floor (alluvium) is typically sorted by natural processes resulting in layering, or strata, in the soil profile. Larger, heavier soil particles like cobble and gravel mostly end up on the lower layers and finer particles like sand, silt, and clay are typically deposited in the upper layers. In terrace cutbanks, look for darker soils, rich in organic matter, and hydric soil indicators in the upper strata as evidence of a recently disconnected floodplain. Channel beds comprised of thick fine-grained particle layers may still be actively downcutting until the less mobile cobble/gravel layers are reached, or stabilization measures are implemented.

Where the cobble/gravel layers intercept the channel, the stream is connected to the valley's near-surface groundwater. Groundwater moves down valley through this cobble/gravel layer. When flows in this layer are in direct contact with fine-grained layers, it serves as a mechanism to sub-irrigate the valley through **capillary action** in the soil that wicks water up to plant roots. Conversely, channel incision can drain riparian areas and meadows by lowering the base flow and reducing capillary action. *This presents an opportunity to enhance riparian and meadow vegetation by restoring sub-irrigation of the first terrace in an incised channel by raising the elevation of the riffles in order to put the water surface at base flow back in contact with the cobble/gravel layer and restore capillary flow to root zones* (Zeedyk and Clothier 2014).

III. Zeedyk approach for treating headcuts and gullies

After reading the landscape to identify challenges and opportunities, the Zeedyk restoration approach requires practitioners to think about how water flows through the system and interacts with vegetation so it can be managed to support restoration goals.

Thinking like water

Four basic sources of streamflow include: 1) groundwater flow that provides base flow of the stream, 2) **interflow** from the soil moisture zone that augments base flow, 3) surface runoff from overland flow that contributes to streamflow during storms or snow melt, and 4) precipitation falling directly into channel (Zeedyk and Clothier 2014).

Gullies are often initiated when dispersed overland flow converges to channelized concentrated flow, increasing the velocity of water and erosive potential. Once incision begins, seepage from groundwater and interflow can further exacerbate gullies. Incised channels have higher **stream power** (a function of water velocity, channel width and depth) as flow is forced to move through a smaller area with steeper gradient.

Zeedyk techniques work with water and natural processes that dissipate energy to reverse degradation and accelerate recovery of incised channels.

The energy of flowing water is dissipated primarily through roughness, erosion, and sediment transport. **Roughness** refers to the obstacles water encounters along its path and includes things that interrupt flow, like vegetation and rocks, and features that create drag, like pools, riffles, and meanders. Streambank erosion serves to widen channels and create floodplains and is another mechanism by which flowing water is slowed and energy dissipated. Flow containing sediment carries less energy than clear running water which tends to be more erosive. With this in mind, bank erosion and sediment become resources that can be harnessed and put to work building floodplains for enhanced roughness and channel recovery.

Critical role of vegetation

Promoting healthy riparian, meadow, and upland vegetation is essential to stabilizing incised channels and facilitating recovery. The critical role of plants is often underestimated, but is a key component of the Zeedyk restoration approach. Above ground, plant stems provide roughness to redistribute flow patterns and facilitate deposition and soil building. Below ground, living plant roots feed the biological processes that help bind soil particles and provide stability. Healthy roots enhance the ‘sponge’ capacity of the soil by creating pore space that allows for better infiltration of overland flow and precipitation which affects how fast water moves through the system and into the channel.

Zeedyk structures are designed to work in concert with vegetation to stabilize and recover degraded sites (Fig. 6). For structures to be successful, land management practices in meadows and surrounding uplands must be compatible with the maintenance of healthy vegetation. Many practices can affect vegetation but a primary consideration

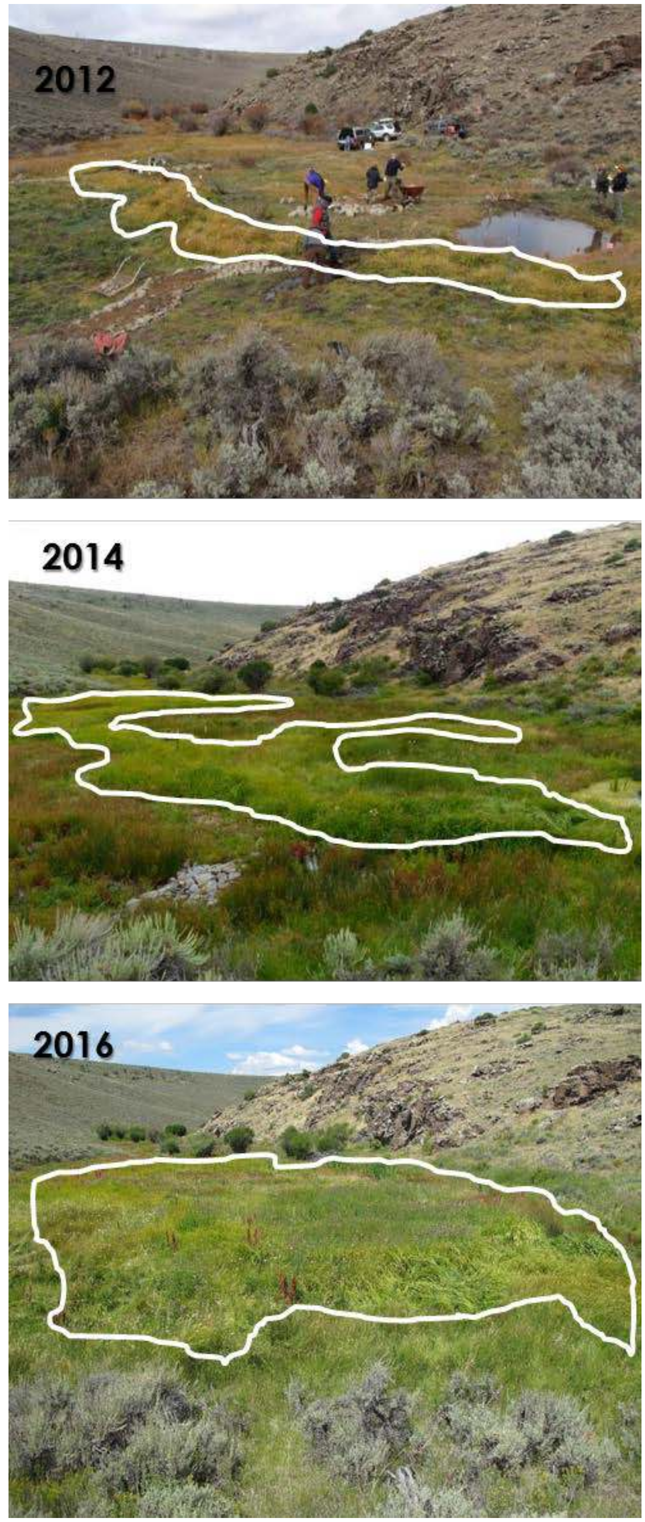

Figure 6. Extent of wetland vegetation before Zeedyk structures (2012) and 2-4 years post-treatment (2014 and 2016). White polygons represents the area supporting predominantly wetland vegetation. Photos by: Claudia Strijek (2012) and Renee Rondeau (2014, 2016)

in rangeland settings is grazing. Improper grazing and trailing by livestock and wildlife can reduce plant health and vigor. There are many strategies for managing grazing to be compatible with vegetation goals (Swanson et al. 2015), including adjustments in timing of use or installation of drift fences to reduce trailing in valley bottoms. Practitioners should consider proper grazing management, and potentially other upland treatments (e.g., pinion-juniper removal), as integral components of the restoration plan.

Healing principles

Zeedyk techniques generally seek to slow and disperse water, dissipate energy, capture sediment, and increase soil moisture retention thereby promoting vegetation and channel recovery. The following are some principles to follow when treating headcuts and gullies from Zeedyk and Jansens (2009):

*Principles for Treating **Headcuts**:*	*Principles for Treating **Gullies**:*
• Lower the height of the falls in order to reduce the force of falling water. • Widen the lip of the falls to disperse concentrated flow. • Harden the base of the falls to protect substrates from erosion. • Conserve soil moisture to enhance plant growth and root densities.	• Disperse surface flow, prevent concentration, increase infiltration and percolation. • Reduce channel slope to reduce runoff velocities to reduce available energy. • Widen channel bottom to lessen erosion force. • Increase channel roughness. • Retain soil moisture to improve environment for colonization and growth of plants.

IV. Zeedyk structure types and key features

Here, we describe several types of hand-built Zeedyk structures that have been successfully applied at a large scale through the Gunnison Basin Wet Meadow and Riparian Restoration and Resilience-Building Project (TNC and GCWG 2017). The project setting is a semi-arid sagebrush landscape within in the Upper Gunnison River Basin, Colorado. The area receives 8-16 in of annual precipitation that falls predominantly as winter snow and summer monsoonal rain events that can create localized floods. Hand-built structures were constructed primarily on shallow headcuts and small incised channels of ephemeral/intermittent streams and meadows where the incision was not too deep (< 4 ft).

Zeedyk structures can be characterized by what they are primarily designed to achieve: 1) headcut control, 2) grade control, and 3) flow dispersal. Headcut control structures result in *preservation* of riparian and meadow areas upstream that will be degraded without intervention. Grade control and flow dispersal structures are intended for *restoration* of riparian and meadow areas with low-to-moderate gradients (< ~3% slope) that have already been degraded. This is an important distinction when articulating and monitoring intended project outcomes. Multiple types of structures are often installed together in a treatment complex and are designed to work in concert to achieve desired objectives within a reach. Treatment should begin at the top of the watershed and work down, which frequently requires coordination across land ownerships.

While Zeedyk structures may appear similar to traditional techniques, such as check dams and gully plugs, there are some subtle but important differences. Zeedyk structures are low-profile in the channel and meant to work *with the system* slowly over time to foster processes that lead to recovery (like floodplain development). They are not intended to impound water, capture as much sediment as possible, and walk away. To build Zeedyk structures properly, individual pieces of rock or wood must be carefully placed to ensure water flows over them in a specific manner that promotes stability and vegetation growth rather than serving as barriers to flow that often results in structures being end-cut or undermined. Zeedyk structures are relatively low-risk and cost-effective compared to traditional approaches, allowing more to be implemented in series which reduces the importance of any one structure. However, installation of these structures can be more labor intensive and often requires multiple interventions through time.

Highlighted below are various structure types with a brief description of what they are designed to do, where to locate them, and some key design features to pay attention to during construction. *For additional details on these structures, refer to the following publications: Sponholtz and Anderson (2013) and Zeedyk and Clothier (2014).*

Headcut control techniques

Headcuts are critical erosional features to treat, as they migrate upstream and can lead to further channel incision, gully formation, dewatering and the potential loss of areas of wet and mesic meadows. Of the headcut control structure types listed below, deciding which to use is usually a function of the headcut size and type (Table 1). All have the purpose of stopping the advancement of a headcut, and stepping the water down into the channel to minimize the erosive power.

Headcut Type	Potential Structures
Low energy headcuts (< 1.5 ft tall) in small catchments and off-channel return sites	Rock Rundown, Rock Mulch
Long, low headcuts (< 1.5 ft tall) in areas with primarily shallow, well-dispersed, slow-moving sheet flow	Rock Layback
In-channel headcuts (1.5 to ~4 ft tall)	Zuni Bowl, Log and Fabric
In-channel headcuts (> 4 ft tall)	Machine-built Zuni Bowl with additional engineering design

Table 1. Potential Zeedyk structures to treat various types of headcuts.

Zuni Bowl

The Zuni bowl is a rock-lined, step falls with plunge pools used to dissipate the energy of falling water and stabilize a headcut (Fig. 7, 8, 9). These structures stabilize the progression of a headcut by both stepping down the water in a way that minimizes the erosive and scour potential of falling water, and by protecting and maintaining moisture and vegetation at the pour-over. Hand-built Zuni bowls are typically applied to treat in-channel headcuts (1.5-3 ft tall). See Appendix A for construction specifications.

Figure 7. It is critical to ensure the top rocks of the Zuni bowl wall match the existing elevation of the headcut pour-over (denoted by yellow arrow). This helps irrigate vegetation at the lip, allowing it to become the most vigorous instead of the weakest point subject to erosion. If rocks are too high, they divert water around structure, concentrate flow, and potentially cause new gullies. If rocks are too low, soils and roots are exposed and vegetation dies. Photo by: Nathan Seward

Some key features:

- The headcut pour-over is a critical location and the top rocks of the wall must match the existing elevation of this pour-over so that water freely flows over the structure (Fig. 7). Trim the headcut back to expose live roots as the maintenance of healthy vegetation at this spot is key to stopping the progression of the headcut.
- When building the back wall up the face of the headcut, offset the layers of rock for stability and lean them back to form a sloping wall around the headcut instead of trying to build a vertical wall.
- Armor the plunge pool with tightly-placed rock of sufficient size to avoid scouring.
- Construct a one rock dam (ORD, described below) downstream of the Zuni bowl to create another pool (Fig. 8, 9). Place the upstream edge of the ORD 4-6 times the height of the headcut away from the bottom of the Zuni bowl.

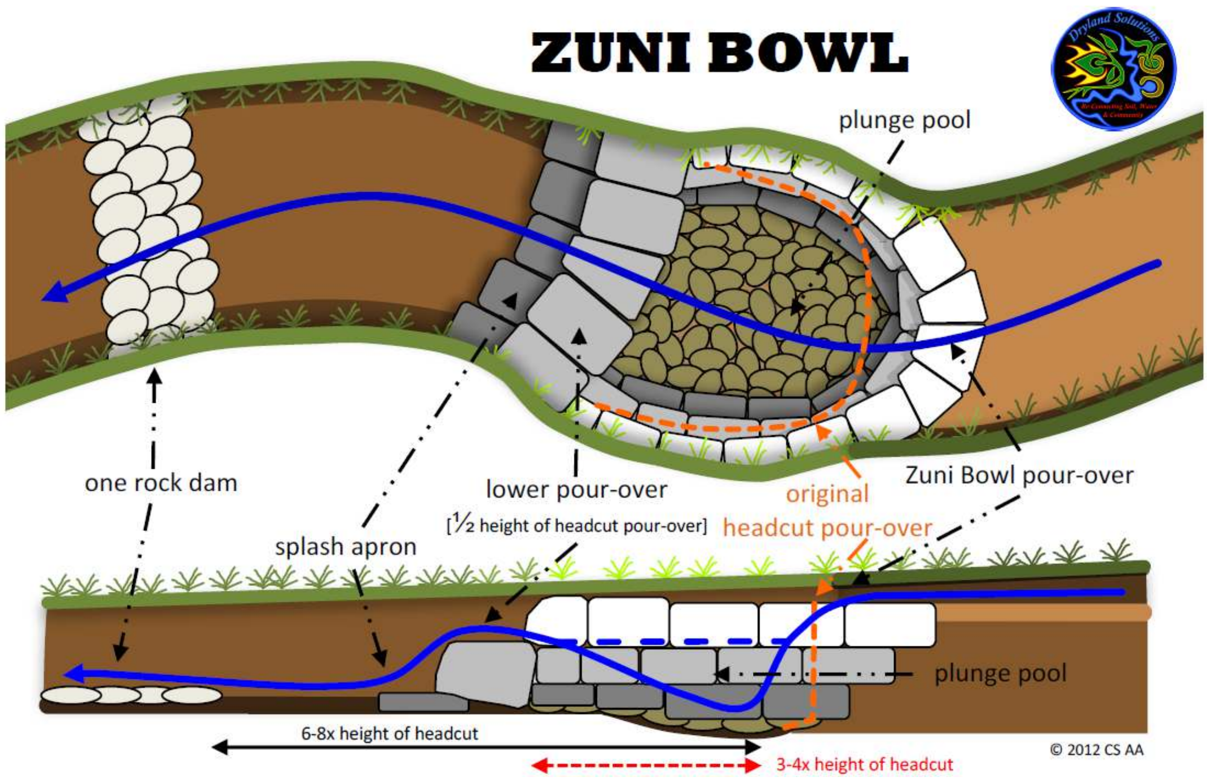

Figure 8. Zuni Bowl plan and cross-sectional views (Sponholtz and Anderson 2013; figure courtesy of C. Sponholtz).

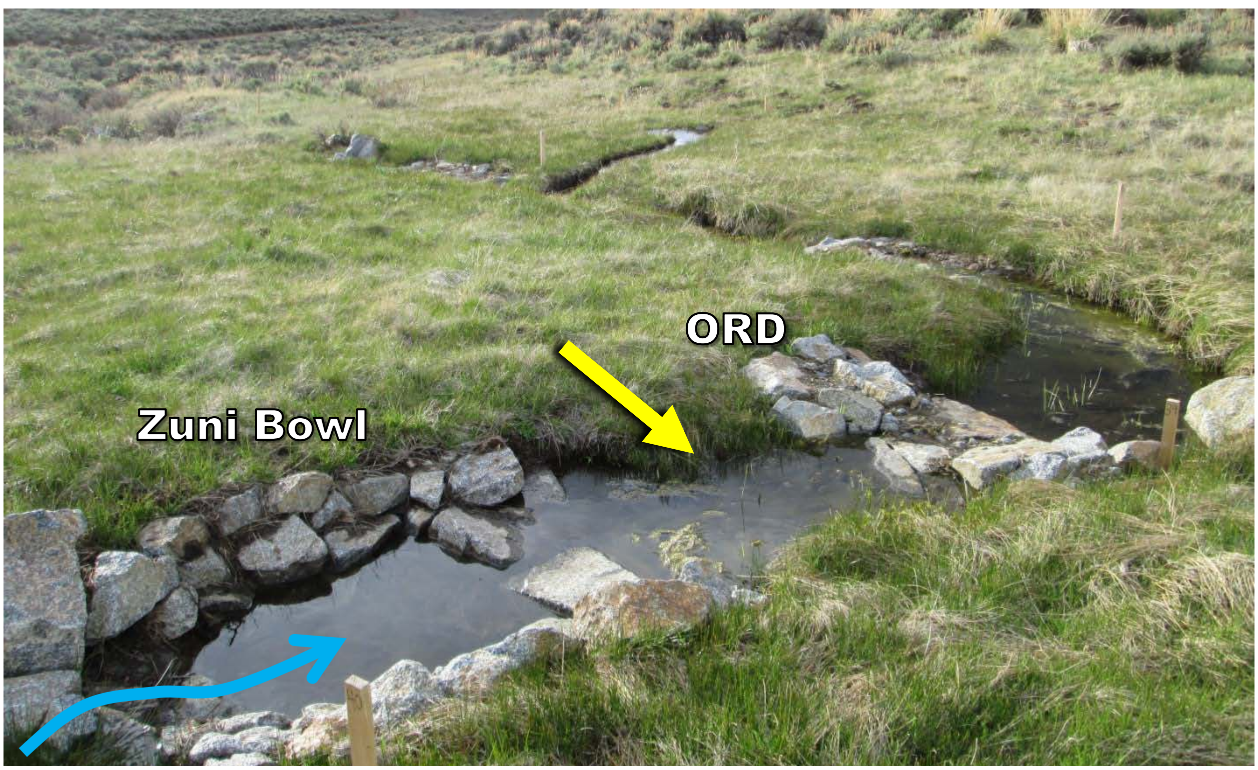

Figure 9. Placing a one rock dam (ORD) just downstream of the Zuni bowl creates another pool (denoted by yellow arrow). Where there used to be one drop with the headcut, there are now three to dissipate energy. Pooled water also irrigates the banks which strengthens vegetation and reduces erosion potential. Photo by: Shawn Conner

Rock Rundown

The rock rundown structure is used in low energy headcuts (< 1.5 ft tall) in small catchments and off-channel return sites to stabilize them and prevent upstream erosion (Fig. 10). Typically, the headcut is first laid back by shaping it to a stable angle (3:1 slope), and then the slope is armored with rock. In some small headcuts, shaping is not required. See Appendix B for construction specifications.

Figure 10. The center of a rock rundown should be the lowest so water runs down the middle and not around the structure. Photo by: Nathan Seward

Some key features:

- Make sure the rocks at the pour-over lip are at the same elevation of the headcut so that water flows freely over it and trim the headcut back until live plant material and roots are exposed.
- The center of the rundown should be the lowest, so water runs down the middle and not around the structure.
- The tighter the rocks fit together the better to eliminate gaps between rocks as much as possible.
- Another version of the rock rundown is the "rock mulch" which can be utilized in areas outside or adjacent the main channel to armor or prevent trampling alongside in-channel structures (Fig. 11).

Figure 11. Rock mulch can be used in off-channel areas to address minor headcuts and return flow sites. Photo by: Nathan Seward

Rock Layback

The rock layback is used to treat long headcuts that are often in areas subject to shallow and well-dispersed, low velocity sheet flow events (Fig. 12). Laybacks are built by shaping the shallow headcut back to a slope which will accept a stacked rock wall for armor, and exposing live vegetation roots at the pour-over lip. See Appendix C for construction specifications.

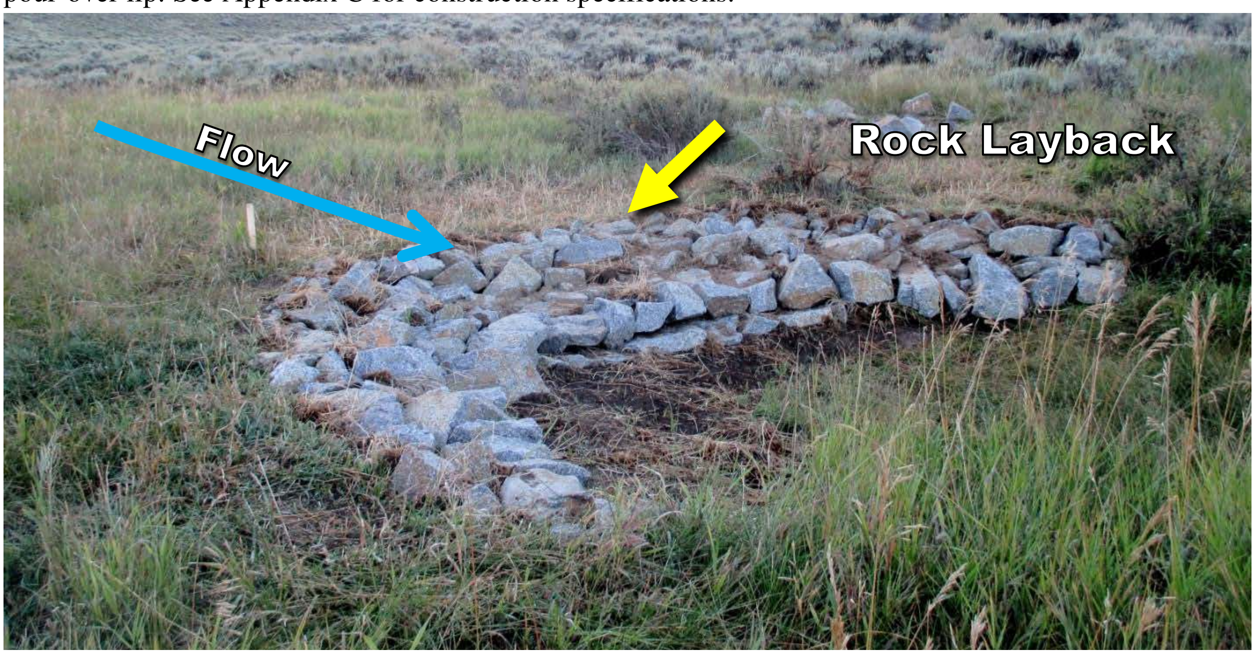

Figure 12. Rock laybacks can be used to treat long, shallow headcuts. Start with a row of large rocks as the footer, then build the stacked wall of rocks by leaning rocks into the slope for stability. Ensure the top rocks of the layback wall match the existing elevation of the headcut pour-over (denoted by yellow arrow). Photo by: Shawn Conner

Some key features:

- Create a **footer** for a splash apron to eliminate the scour pool. Begin with a row of large rocks as the base to build the stacked wall of rocks.
- Batter, or lean, rocks back into the slope for stability.
- The rock wall should be even with the lip of the headcut pour-over.

Log and Fabric

The log and fabric step falls is used in larger (up to 4 feet tall) in-channel headcuts and in areas where access to logs is more practical than rock (Fig. 13). Log timbers can also be easier to use in large headcuts where the size of the rocks needed may be too heavy for hand-build structures. See Appendix D for construction specifications.

Some key features:

- Make sure the logs are secured properly together and in place so they do not move or float in large flow events.
- Utilize filter fabric or woven geotextile material under and between the log layers. The fabric should also run vertical up the headcut wall to conserve soil moisture.
- Ensure that the critical pour-over location is the same elevation and has good contact with the top of the log structure to maintain moist and healthy vegetation. This is key to stopping the advancing headcut.

Figure 13. Log and fabric structure for treating headcuts before (top) and after (bottom) installation. Photos by: Renee Rondeau

Grade control techniques

The following structure types can be utilized to counteract channel incision and actually raise the bed of an incised channel over time by promoting sediment deposition. In addition, these structures have the effect of slowing down the water to allow water to soak into the banks of the channel, supporting plant growth.

One Rock Dam

The one rock dam (ORD) is one of the most commonly used Zeedyk structures for channel recovery (Fig. 14). It effectively slows the flow of water, increases bank infiltration, captures sediment and helps recruit vegetation which can raise the channel bed elevation in gradual increments over time. An ORD is made of many rocks fit tightly together, but gets its name from being only one rock high (generally no more than a third the height of the bankfull channel).

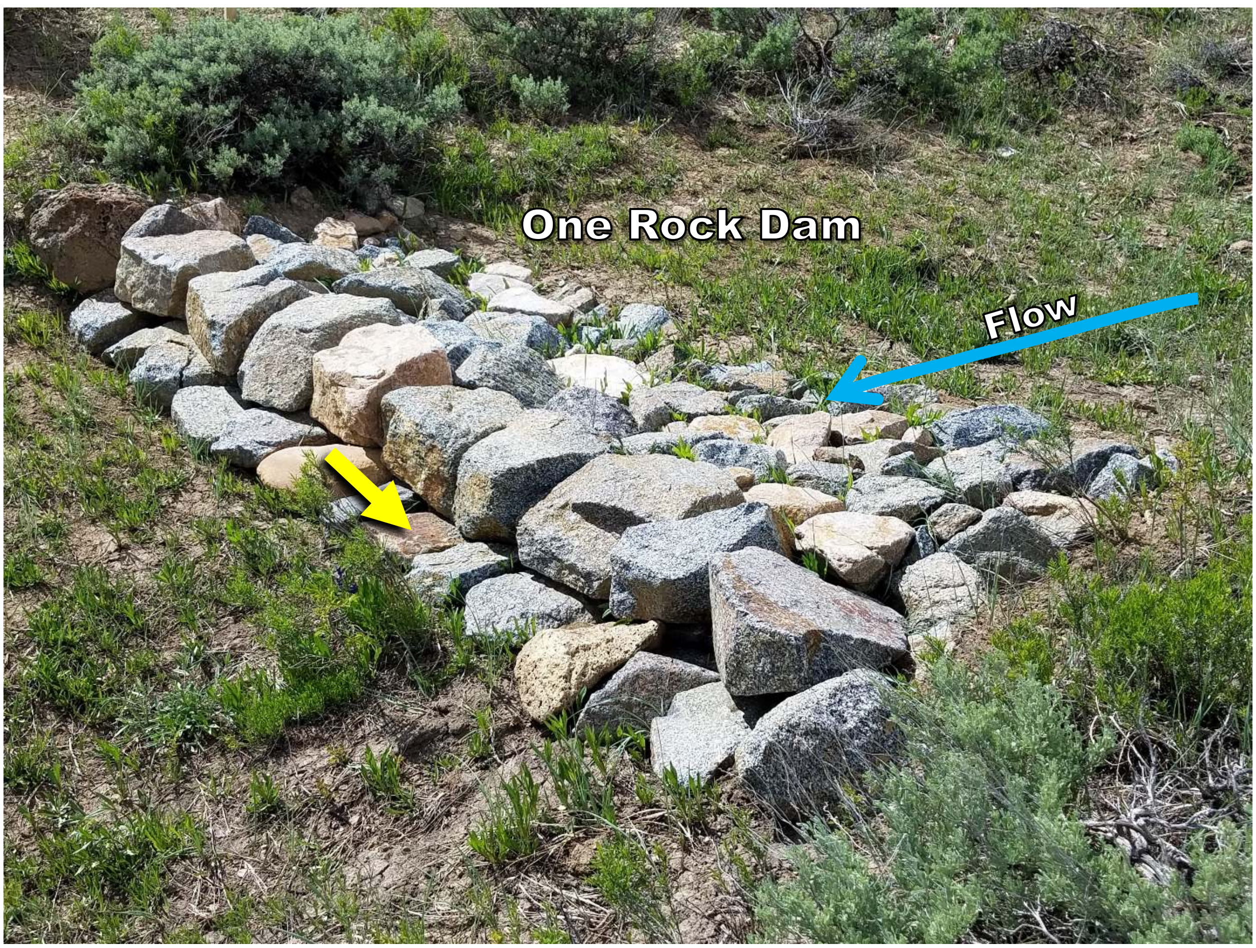

Figure 14. One rock dams should have a footer for splash apron on the downstream end that extends far enough to intercept water pouring over the structure in a high flow event (denoted by yellow arrow). Photo by: Nathan Seward

Placement of ORDs varies with channel type and morphology. In a channel with natural meanders, place ORDs at the natural area of deposition – the crossover or "riffle" in a riffle-pool stream sequence (Fig. 15). Look for sites where the structure can facilitate water slowing and soaking into adjacent banks, or for places where raising the bed elevation over time might assist in reconnecting the channel with its floodplain or subsurface hydrology. See Appendix E for construction specifications.

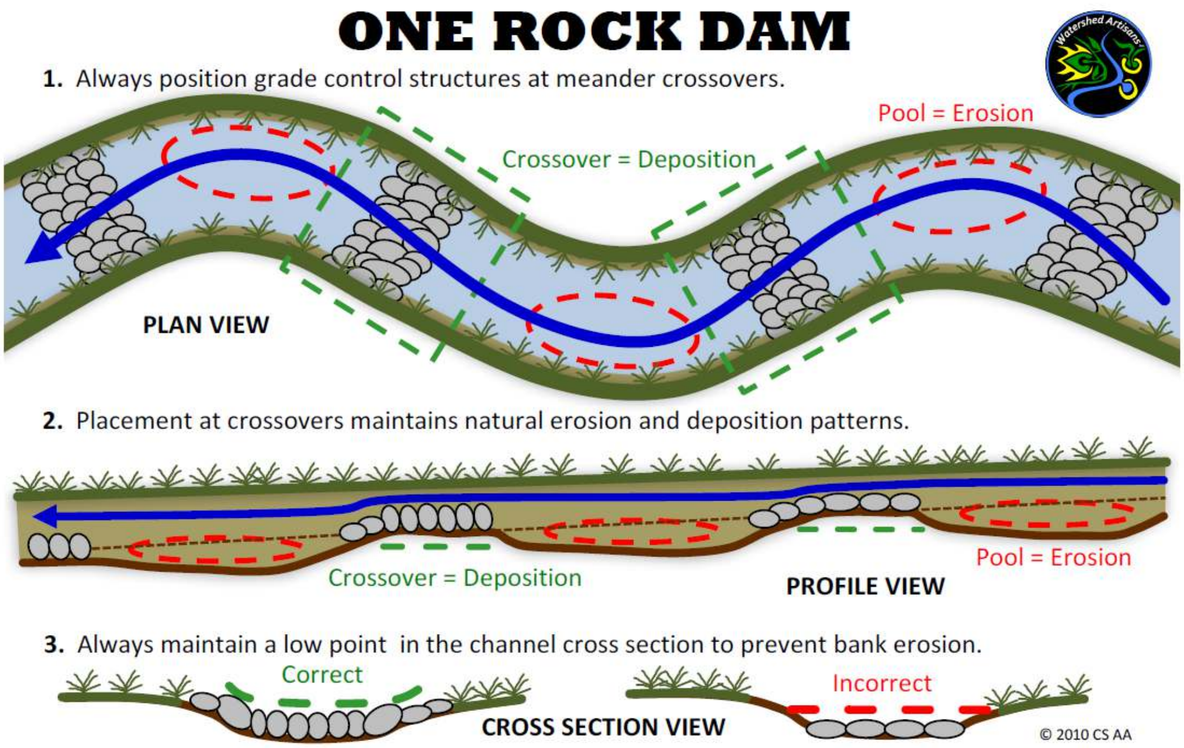

Figure 15. One rock dam plan, profile, and cross-sectional views (Sponholtz and Anderson 2013; figure courtesy of C. Sponholtz). Note how ORDs are placed at the meander crossover or riffle.

Some key features:

- Build a footer for splash apron on the downstream end that extends far enough (2x the height of the ORD) to intercept water running quickly over the structure in a high flow event.
- Fit rocks together tightly, all at the same height, to create a relatively uniform surface on top.
- Extend the bankside edges of the structure up the bank a bit to facilitate water going over the structure and not around it.

Filter Dam

The filter dam is a structure that is used to raise the bed of a gully by temporarily impounding shallow water, allowing it seep through the rock slowly, thereby trapping sediment (Fig. 16). Filter dams consist of three zones of carefully placed rock ranging from large boulders on the downstream edge, smaller boulders in the middle, to cobble on the upper end. Filter dams pond water longer than ORDs and were used only in limited situations in the Gunnison Basin where a ponding effect was desired to raise the channel bed and reconnect floodplains. For more information on potential filter dam applications and construction specifications, see Zeedyk and Clothier (2014).

Figure 16. Filter dams temporarily impound shallow water but allow water to seep through the porous structure, thereby capturing sediment. Photo by: Betsy Neely DSC-0886

Flow dispersal techniques

The following structure type is used to spread flow across the landscape or used to reconnect stream channels with their floodplains.

Media Luna

The Media Luna (half-moon in Spanish), originally designed by Van Clothier, is a curving rock structure primarily used to manage overland sheet flow. While this type of structure can be created to collect and concentrate sheet flow (tips down; Sponholtz and Anderson 2013) they are most commonly used to spread sheet flow across a wider surface (tips up; Sponholtz and Anderson 2013) (Fig. 17, 18). See Appendix F for construction specifications.

Some key features:

- This structure type requires establishing accurate level grades with either a string level or a laser level because the tops of the rocks must be perfectly level for the structure to function properly.
- First layout and stake the contour where the structure is to be built, and then build the downstream row of rocks to match this level.

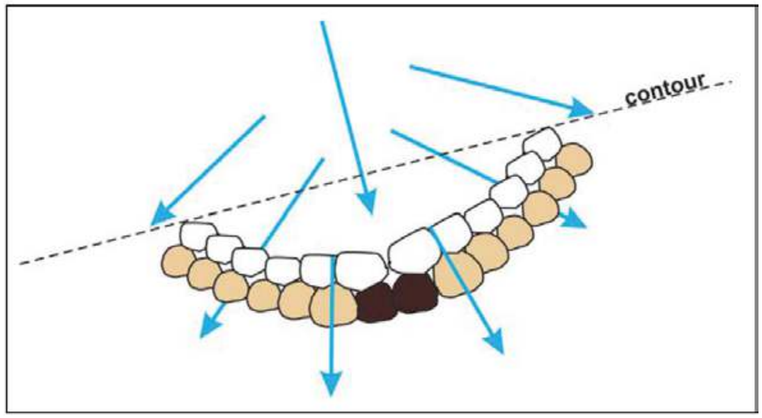

Figure 17. The media luna with the structure tips pointed upvalley helps evenly spread out overland flow. Figure from Zeedyk et al. (2014)

- Fit the rocks together as tightly as possible and utilize small gravel (or plants, sod) to fill gaps if possible.

Figure 18. Media luna (looking upvalley) being used to spread sheet flow; note structure is placed on contour with uniform surface. Photo by: Shawn Conner

Related techniques

Although not the focus of this publication, there are a few other Zeedyk techniques and associated practices that may be helpful to consider when restoring a stream or meadow reach. *Refer to referenced publications for detailed technical information on how to design and implement these techniques.*

Drift fences**:** Trailing up and down the valley bottom by domestic livestock and wild ungulates can compact soils, form trails over time that trap runoff and start gullies that de-water meadows. The drift fence is a linear fence segment, built perpendicular to the valley bottom or stream channel, to discourage excessive trailing. The fence segment spans the valley bottom with the ends either at the meadow/upland interface or wholly in the upland. This obstruction in the valley bottom serves to interrupt the trailing animals, and forces them up and out of the meadow. The drift fence does not exclude livestock or wildlife from utilizing the meadow areas; it just interrupts the damaging trailing of the valley bottom. Refer to agency standards and guidelines for fence specifications and consider the need for wildlife-friendly design features (e.g., high-visibility markers).

Low water crossing**:** Roadway crossings of wet meadow areas can have dramatic detrimental results in the form of excessive rutting and erosion. In areas where roadways or recreational vehicle trails must cross meadows, an effective treatment is the low water hardened crossing. These treatments can take a variety of forms, depending on type of travel, frequency of use and other considerations. The low water crossing can be used as an opportunity to spread and distribute flows across a wider area, rather than the traditional method of installing a culvert which can concentrate flows and dewater adjacent areas. For details, see Zeedyk (2006).

Road re-grading**:** Another potential practice to consider is how runoff can be used to benefit meadows when re-grading roads. Often roadways were established in the path of least resistance, which meant they went right up the valley bottom and through the meadows. While it is preferable to relocate roads out of wet areas and into the uplands, roads that cannot be moved can still be maintained in a way that provides some benefit to the wet meadow system. For more information, see Zeedyk (2006).

Worm Ditch**:** The worm ditch is a treatment technique that is often used to enhance other structures by diverting flow and bypassing a headcut to starve it of water, or spreading concentrated flow into sheet flow onto a meadow surface. It is done by digging a very shallow, sinuous conveyance channel with a slope less than that of the land surface to reduce erosive power. It can be installed by hand or machine. For details, see Zeedyk and Jansens (2009), Zeedyk and Clothier (2014), or Zeedyk and Vrooman (2017).

Plug and Spread: Plug and spread structures are used to reconnect ephemeral and intermittent streams with former meadow surfaces. The technique involves dirt work with a bulldozer and a skid steer. This technique can be used in areas where transporting rock is not practical or where channel incision is too deep to feasibly recover with hand-built rock structures. These structures are most effective in low gradient systems with wide floodplains and broad valleys, as they can restore more acres of former wetland with a small number of structures. For details, see Zeedyk (2015) and Zeedyk and Vrooman (2017).

Tree Length Log Mat: Tree length log mats are grade control structures used in small watersheds to promote sediment deposition, widen the incised channel, and raise the channel bed. This structure type has not been utilized to date in the Gunnison Basin, but it may be something to consider in other sagebrush rangelands where wood is more readily available than rock (e.g., pinion-juniper removal areas or burned areas). Installing log mats quickly after wildfire, and before first the storm, helps maximize sediment capture and reduce gully erosion. As opposed to traditional log-drop structures, tree length log mats have logs placed parallel to the channel, not perpendicular, with tree bases pointing upstream which helps filter flow and capture sediment without serving as just an impediment to flow. For details, see Zeedyk and Clothier (2014).

V. Project planning

Whether at the scale of an individual ranch or a watershed, projects require thorough planning before structures are installed to maximize the likelihood of success and make efficient use of limited resources. While Zeedyk techniques are relatively cost-effective and low-risk when compared to other approaches to treating headcuts and gullies, they still require considerable investment of time and effort to install and maintain. Careful planning is needed to ensure structures are well-placed, functional, and minimize unintended impacts. Good planning also helps make sure regulatory permits and consultations are secured well in advance, and materials, contractors, and volunteers are in place and ready to go during desired work windows. Taking an interdisciplinary, community-based approach is recommended and beneficial for successful implementation. Listed below are a few key aspects related using Zeedyk structures for meadow restoration based on experiences in the Upper Gunnison River Basin (for a summary of lessons learned, see Appendix G).

Goals and objectives

Developing a shared vision among project partners and articulating long-term goals and objectives should be done early in project planning. This not only helps keep partners on the same page, but it informs prioritization and site selection and provides a way to gauge project success. Goal/objective descriptions should go beyond just ‘stopping erosion’ or ‘installing structures,’ and instead focus on the desired hydrologic or ecological outcomes of the treatments. Emphasizing anticipated vegetation responses provides one meaningful way to determine if structures are achieving desired objectives within a reach.

Goals/Objectives Example: Gunnison Wet Meadow Restoration and Resilience-Building Project

Vision: *Natural wet meadows and riparian habitats within the sagebrush landscape of the Gunnison Basin are resilient and support a sustaining population of Gunnison sage-grouse and other species, biological communities, ecosystem services and livelihoods in the face of a changing climate. Sustained and long-term community commitment to stewardship of wet meadows and riparian areas helps nature and people adapt to a changing climate.*

Overall Goals:

1. Increase ecosystem resilience to climate change by restoring hydrologic function of priority wet meadow and riparian habitats within the sagebrush landscape at a scale large enough to help the Gunnison sage-grouse, neo-tropical migratory birds, big game species and people who depend on these habitats for their livelihoods cope with projected impacts of a changing climate.
2. Build a sustainable and enduring program to increase restoration across the Basin.
3. Ensure scientific rigor of this project through a long-term monitoring program.
4. Develop and evaluate cost-effective tools, methods, and planning to help scale up the project.
5. Share best practices and lessons learned to encourage application of methods within and outside of the Basin.

Site-Specific Objectives:

Kezar Basin: Restore stream flows in wet and mesic meadow habitats, reverse incision and active gully expansion, and create barriers to reduce trailing by livestock and wildlife in riparian zones.

- *Management objective 1*: Increase the average cover and density of native sedges, rushes, willows, and wetland forbs (obligate and facultative wetland species) in the restored portion of the treated properties by at least 20% within 5 years after treatment.
- *Management objective 2*: Decrease the average cover of rabbitbrush, sagebrush, and other upland species in the restored portion of treated properties within 5 years after treatment.

Prioritization

While many project conversations start by visiting a particular sore spot on the landscape, it is always a good idea to zoom out for a moment to consider how that site compares to other restoration opportunities in the area. Many drainages impacted by headcutting and gully erosion across sagebrush rangelands would benefit from Zeedyk restoration techniques. However, resources, funding, and capacity are often limited, so it is important to be strategic about where you work and prioritize sites with the greatest potential for achieving desired outcomes using these techniques. Whether working with multiple partners to restore meadows at the watershed scale, or working with an individual landowner, conducting a site-selection analysis based on project goals can be a helpful exercise to evaluate potential restoration reaches. Using widely-available GIS spatial layers, combined with locally-defined priorities, can help project partners identify and narrow sites for on-the-ground evaluation.

This type of approach was applied successfully in the Gunnison Basin to assist land managers and landowners identify areas in need of restoration and most likely to respond favorably to treatment. The Nature Conservancy and the Gunnison Basin Project Team developed a climate-informed GIS process to identify stream reaches within critically important Gunnison sage-grouse habitat that offer the greatest potential to respond favorably to the restoration (for description of methodology, see: TNC and GCWG 2017). The team created a simple restoration index for riparian areas along small streams using publicly available satellite imagery. This restoration index calculated the area of very green vegetation (a proxy for vegetation health and productivity) between wet and dry years.

Riparian areas were prioritized based on how much this green vegetation area remained stable or decreased during dry years. For example, riparian areas with very green vegetation in both wet and dry years indicate sites that are more likely to be well-connected to their floodplains, functioning, and more resilient to drought. Riparian areas that only produced very green vegetation in wet years, but not in dry years, indicate that hydrologic connectivity may be impaired but recoverable. In these cases, incision was not too severe, which allowed for sites to still function during wet years. This information highlighted potential opportunities to increase drought resiliency through restoration. To further narrow sites that were most relevant to the Gunnison project goals, the team also used additional data, such as, distance to sage-grouse leks (< 2 mi) and brood-rearing habitat. This helped the team reduce the scope of potential treatment reaches for field investigation (Fig. 19).

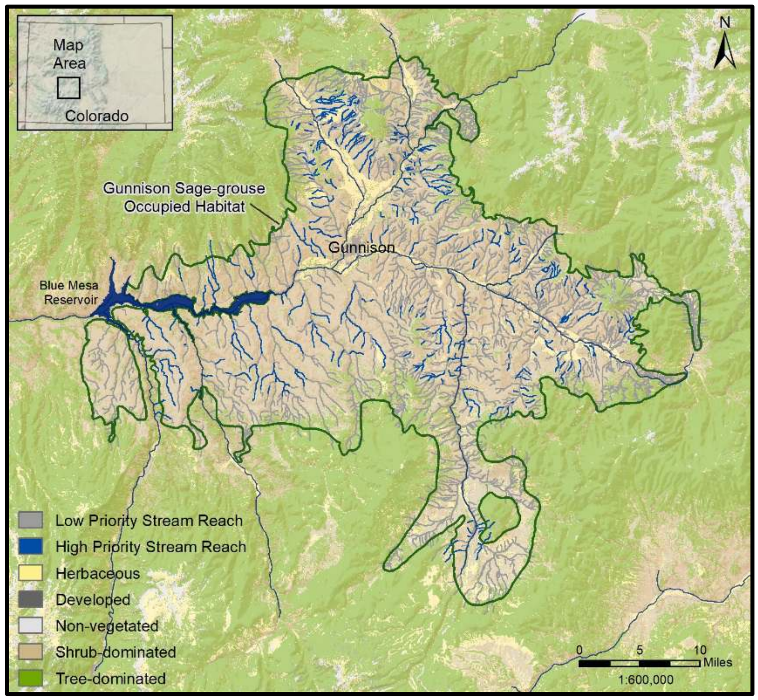

Figure 19. Results of the GIS prioritization analysis in Gunnison Basin. Figure by: Teresa Chapman

Site evaluation and inventory

Once high potential areas are identified through a GIS analysis, interdisciplinary partners (e.g., biologists, hydrologists, restoration experts, land managers) should be engaged to narrow down the list of potential stream reaches to visit based on local knowledge. Criteria to consider during this phase may include things like: land ownership and willingness of landowners/managers, accessibility, opportunities for efficiently scaling-up beyond a single reach, sources of water, geographic representation, habitat condition and values, and status of permitting and planning documents. The results provide a starting point for field evaluation to further prioritize stream reaches for on-the-ground treatment.

Next, the restoration team should conduct field visits to evaluate the condition of the site, identify problems, and determine specific restoration opportunities and needs. The team should walk stream reaches from the top to bottom. Some factors to consider during the initial field assessments include:

- Stream reach impairments (e.g., headcuts, gullies, compaction, roads)
- Restoration potential versus effort required (e.g., level of incision)
- Valley setting and valley bottom width (i.e., how large of an area could restoration impact)
- Ease of access for delivery of materials and field crews
- Importance of site for achieving project goals (e.g., wildlife habitat)
- Sediment supply and source
- Water supply and source
- Potential for success in achieving goals and objectives
- Opportunity to increase efficiency in scaling up (e.g., treat multiple sites in same area)
- Feasibility and estimated costs
- Compatibility of current or planned land management with treatments (e.g., grazing)

Treatment design and placement

Treatment design begins after a thorough site analysis and inventory of problems and opportunities in a given reach. Stream reaches should be walked several times as it is easy to miss things on the first pass. Reading the landscape and thinking like water are key aspects of the Zeedyk process. Pay careful attention to landform, grades and changing elevations, vegetation types that may inform site conditions, areas where water moves faster and becomes concentrated, or where it slows down and spreads out. All of these site details inform effective treatment design. Learn to identify resource problems, such as, headcuts, channel incision, and areas that are drying out due to de-watering. Also, look for opportunities to reconnect the channel with its floodplain, areas of deep soils that can hold water in the system for longer periods when saturated, and landforms where water could be spread out further on the land surface. Multiple structures are often installed together to achieve desired objectives within a reach (Fig. 20).

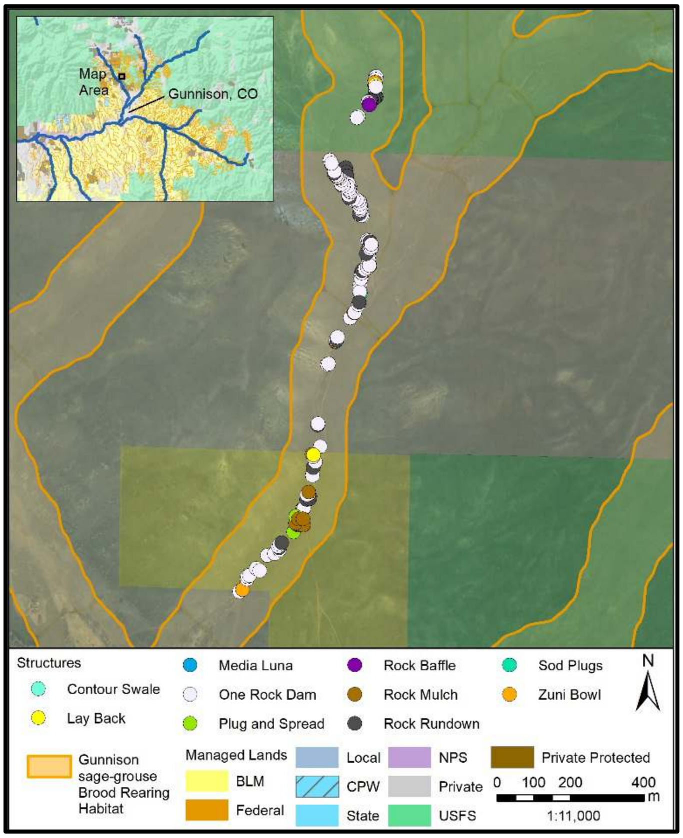

Figure 20. Treatment design for typical reach showing multiple types of structures working in concert across land ownerships. Figure by: Teresa Chapman

Identifying opportunities to treat headcuts that *preserve* intact meadows within a reach is just as important as restoring sites that are already degraded. It is often the size and type of headcut that determines which structure type should be utilized. For larger in-channel headcuts, the Zuni bowl or log and fabric step falls are good choices depending on your material availability. Long horizontal headcuts in sheet flow areas without concentrated flow patterns are often best treated with a rock layback, whereas smaller headcuts can be treated with rock rundowns. Stopping the ever-advancing headcut is a critical first step in wet and mesic meadow preservation.

Second, look for *restoration* opportunities where raising the grade of an incised channel could reconnect the floodplain and cobble/gravel layer for subirrigation of the meadow, or for areas where treatment efforts could spread concentrated flow wider on the landscape. To be most effective, grade control structures like one rock dams should be located at the crossovers (riffles) of the meander pattern. Also, look for areas of deep soils along a channel that can soak up the water being slowed down by the structure can boost success. Tree length log mats can be used in similar situations where tree materials are more readily available. Identifying areas of potential infiltration and water storage often informs suitable structure placement.

Finally, it is helpful to identify flow dispersal opportunities where channelized flow can be easily spread out onto the meadow surface, allowing it to sheet flow, slow down, and infiltrate into the soil. On relatively flat surfaces with shallow concentrated flow paths, media lunas can be used effectively to spread out flow and reduce erosive power. In more incised situations, other techniques such as plug and spread may be more appropriate. Often the height of the gully wall will inform if a hand built structure is feasible, or if machine work is needed to get the water out of the gully. It is important to think like water, and identify where the water will go once it is re-applied to the meadow surface. *You must identify the site where the water will re-enter the channel.* This is a site of potential erosion, and should be treated as well for a stable return site. Often a rock rundown can be used to step the water back down into the gully and prevent formation of a new headcut.

Regardless of the structure type, remember to keep in mind the sources and timing of flow and sediment supply in treatment design to manage expectations and determine if additional steps may be needed to generate desired responses. For example, in the Gunnison Basin, some treated reaches were located in spring-fed systems with primarily fine-particle size (clay) sediment. To accelerate effectiveness of relatively porous rock structures in these sediment-poor systems, the team took a few additional measures to encourage vegetation establishment and sediment capture. These included: 1) utilizing any excavated materials to fill gaps in rocks after the structure was built, 2) using a collar of gravel or coarse material on the upstream edge of the structure so that the material was washed down into pore space over time, and 3) using on-site vegetation plugs, such as sedge or rush root plugs, to seal off rock structures and make them more water tight.

Often it is not possible to treat every condition or opportunity that is identified in the site analysis. This could be due to many different issues – site access is too challenging for material delivery, supply of native materials for building is limited, or the workforce capacity will only allow construction of a limited number of structures. In these situations, it is important to identify and install the most critical or most impactful structures first.

Consultation and permitting

Projects in waterways and wet areas typically require consultation with a variety of regulatory agencies to obtain necessary clearances and permits. Consultation should begin early in the planning process. Specific regulatory laws and policies vary depending upon the state and local conditions and source of project funding, but often include the Clean Water Act, Rivers and Harbors Act, Endangered Species Act, National Historic Preservation Act, and related state laws.

The U.S. Army Corps of Engineers is the primary federal regulatory authority for water bodies and wetlands. Section 404 of the Clean Water Act requires a permit for discharge of dredged or fill material in Waters of the United States, while Section 10 of the Rivers and Harbors requires a permit for work or structures in, over, or under navigable waters. Rock, wood, or soil for Zeedyk structures may be considered ‘fill’ material. A first step is to contact your local Corps representative to determine if your site is within their regulatory jurisdiction. Not all sites are considered ‘jurisdictional,’ especially erosional features like gullies with low volume, infrequent, or short duration flow.

If the site is jurisdictional, then a 404 permit will be required prior to project implementation. Two types of permits are available: General and Individual Permits. First, check to see if a General Permit is available that fits your specific situation. Nationwide Permits (NWP) 18 and 27 are two General Permits that often apply to Zeedyk restoration scenarios. If these NWPs do not fit your situation, then an Individual Permit may be required. Permits often involve a wetland delineation be conducted in order to determine potential impacts. If a permit is granted, be sure to abide by all terms and conditions, including timing restrictions, monitoring, reporting, etc. Establishing a good working relationship with your local Corps representative early in the project is highly recommended.

Other laws commonly requiring consultation on Zeedyk project, especially when there is a federal nexus, include the Endangered Species Act (ESA), administered primarily by the U.S. Fish and Wildlife Service, and the National Historic Preservation Act (NHPA), administered by State Historic Preservation Offices (SHPO). ESA consultation will be needed if there are federally-listed species that may be affected by the project. NHPA consultation is needed if there are cultural resources in the project area. Where federal partners are involved in projects, consultations should be a normal part of complying with the National Environmental Policy Act (NEPA).

Several other federal, tribal, state, and local laws and regulations and agency policies may be applicable, so be sure to gain a thorough understanding of the rules in your watershed.

VI. Pre-construction and installation

Once the treatment design has been developed and approved, there are some pre-construction activities needed to help ensure successful implementation.

Laying out and staking structures

Typically, structure locations are marked with wooden stakes that denote the structure type and size. It is helpful to have a standard protocol to aid with material estimates and provide consistent guidance to construction crews during implementation.

Structures are typically sized by listing 3 dimensions: length (up and down channel), width (distance from side to side), and height (height of structure). For example, a stake might say “ORD, 4 x 6 x 0.5,” which would indicate the staked location of a one rock dam that is 4 ft long, by 6 ft wide, by 0.5 ft tall. A standard method is to place the stake at the valley-right (looking downstream) corner of the intended structure. An additional option is to spray paint the corners of the intended structure location immediately prior to the construction event to help field crews quickly identify boundaries of the structure.

It is helpful to GPS structure locations and record structure dimensions for a given reach. This allows pre-construction mapping, and helps facilitate calculating the amount of materials needed for a given project.

Estimating structure materials

Once all the structures have been staked and dimensions recorded, the total amount of material needed for the project can be calculated. To calculate materials needed for a particular structure, multiply the length, by width, by height, to obtain volume in cubic feet. Then, divide the cubic feet by 27 to get cubic yards of material for the structure which is generally an accepted unit to order material with. For example, a one rock dam that is 4 ft x 6 ft x 0.5 ft = 12 cu ft, divided by 27 cu ft/cu yd = 0.444 cu yds. Rounding up to increments of 0.5 cu yd is recommended since it can be difficult to deliver smaller quantities accurately. Once the amount of material is calculated for each structure, sum them up to yield the total amount of material needed for the project. Maintaining a treatment database/spreadsheet facilitates the recording and calculation of total material needed for a given project. In most cases, adding a little to the overall quantity (~3%) is a good idea, as having enough material is critical. Leftover material can be utilized in the future for maintenance or for structure additions.

Sourcing and delivering materials

This can be one of the most challenging portions of the project planning process. Each site is unique, and opportunities for appropriate building materials will vary. Spending time exploring local possibilities is important. Here we offer some tips and lessons learned from the Gunnison Basin, specifically related to rock. These ideas should be viewed as possibilities, and not necessarily the only course of action.

Using native local rock: If local rock suitable for building structures is available, this can be an inexpensive method for securing materials for a given project. However, some considerations with this method include: 1) collecting and transporting rock to the treatment locations can be very time consuming and labor intensive, and 2) over-harvesting rock from areas adjacent to the project reach could have unwanted detrimental effects including increased disturbance, introduction or expansion of weeds, soil erosion, and impacts to wildlife habitats. In remote areas where mechanical delivery of rock is not possible, utilizing on-site native materials may be necessary so project planners should consider treating the critical areas first if building materials are limited.

Using imported rock: Generally, in sagebrush rangelands, local rock in the quantity or size needed for a large project is not available. Importing rock materials for a project involves a number of steps and can be accomplished in different ways depending on site conditions and local resources. In the Gunnison Basin, the project team utilized granitic angular rock produced from a local quarry (see Appendix H). Be mindful of potential ancillary impacts from restoration activities. Products from gravel pits can often harbor unwanted weed seeds that could get transported with building materials. Using clean blasted rock was an attractive option available in the Gunnison Basin, and operators were required to maintain a clean pit and sorting area, as well as, ensure delivery equipment was washed and weed-free prior to entering the project area.

Material delivery techniques can be accomplished in a variety of ways. In the Gunnison Basin, different methods were utilized depending on site conditions and ease of access, land manager preference, and availability of different equipment. Some options and considerations are listed below:

- One method used was to import the rock with dump trucks or end dumps to a centralized staging area, and then use wheeled loaders to further sub-stage material to building locations (Fig. 21). This method has the advantage of being able to transport large amounts of rock quickly with minimal labor involved. Some potential disadvantages could be impacts from loaders crushing vegetation as piles are sub-staged, or transporting excess soil with the rock that was scooped up during staging. This also can be an expensive route, depending on equipment costs.

Figure 21. Staging rock for wheeled loaders to transport to restoration sites. Photo by: Shawn Conner

- Another method used for sub-staging from a central staging area was by UTV. Rock was hand-loaded from the staging area pile into the beds of UTVs and driven to individual structure locations and dumped or unloaded again by hand. This method is time consuming and labor intensive, but with multiple vehicles and many hands helping, it is actually surprising how much rock can be mobilized using this method. Some advantages of using this technique include the ability to have clean delivery to the project site and not have excess soil with the rock to clean up after, as well as, the ability to sort rock for a particular structure and deliver the exact size and quantity needed for each structure.
- Other methods of transporting rock included steel, hand-held rock haulers for short distances (Fig. 22), transporting rock in the back of pick-up beds, and also buckets for smaller sized materials and gravel.
- Keep in mind that the time and effort needed to get material to the building sites is considerable and must be planned for. Building the actual structure is often much quicker than the effort needed to get the materials to the site.
- Depending on the work force available, consider the possibility of using one crew to deliver materials to the individual site locations, and then another crew to build structures. In Gunnison, an effective

technique was to utilize youth groups to transport and stage materials, and then have older more experienced volunteers build the structures.

Plan to have staging areas cleaned up and reclaimed after construction. This may involve cleaning up excess materials and soil off the meadow surface, or re-seeding disturbed staging areas with native plants. Leftover materials can be piled in the smallest footprint possible for eventual use in structure maintenance or for structure additions.

Figure 22. Steel rock carriers can be helpful tools for moving rock short distances by hand.

Training field crews and contractors

Project orientation and training for field crews is essential to proper structure installation with minimal corrections. Because these structures are labor intensive, it helps to have many hands available to complete the project. In the Gunnison Basin, a variety of volunteers were engaged including youth groups like the Western Colorado Conservation Corps and Youth Conservation Corps, Wildlands Restoration Volunteers, High School and University classes, and also conservation organizations like The Wildlife Society, Rocky Mountain Elk Foundation, and others. Private contractors have also been engaged and trained which can be an attractive option especially on private lands.

Training and orientation includes why structures are being built and how to effectively build them. Volunteers and field crews that understand the ecological importance of mesic areas, as well as the function and desired outcomes for individual structures, have a much more rewarding experience and can become repeat volunteers/contractors and effective advocates for this type of work. Working with rock can be dangerous, so safety and proper handling techniques are always critical to emphasize during training. Some safety aspects to keep in mind are instructing field crews on proper lifting position to avoid injury, being aware of your surroundings and other people, wearing protective clothing such as pants, gloves and boots, and being aware of unstable footing while working on the rock pile or transporting material.

Construction

Following pre-construction activities, project implementation can begin when the appropriate work window is available. Often it is best to split field crews into groups of 4-5 people, as this is generally the most people that can work effectively together on any given structure at a time unless it is a large or complex structure. The group should discuss the structure prior to initiating construction, not only to learn about the objectives and desired outcomes for the planned structure, but also to determine the size and shapes of rock material needed to build it. Effective groups often discover that some individuals have natural ability to fit rocks together tightly by visualizing shapes and angles, while others prefer to haul or supply rock to the structure location. Many structures begin with the installation of the footer or splash apron. This requires digging with either a shovel or a tool like a spade-billed pick. Safety when using tools in close quarters should be covered in the training and practiced in the field. Do not take for granted that field crews automatically know how to properly use tools.

The amount of field crew oversight needed depends on the type and experience level. Often it is best to have a restoration expert or project leader travel up and down the reach visiting each group while offering instruction, critiquing progress and answering questions that may arise. *It is a good idea to emphasize quality construction over speedy construction.* Carefully fitting rock together and crafting a quality built structure takes time, but quality construction results in fewer maintenance costs and longer-term benefits.

One of the most powerful effects of utilizing hand-made restoration structures is that it can generate a sense of pride and ownership in the structures by those who build them and a keen interest in restoration outcomes. In the Gunnison Basin, some volunteers return year after year and are excited to see how the structures work over time, and are eager to keep the work going. These types of hands-on restoration projects can take on a life of their own and become legacy projects, where volunteers return annually to witness the results of their own restoration efforts.

VII. Monitoring and maintenance

Landowners and managers should understand Zeedyk techniques are designed to make gradual improvements through time, not necessarily be a one-time fix and walk away. A long-term commitment is key to success. Various types of monitoring and maintenance will be required to ensure projects are meeting desired goals and objectives including regular evaluation of structure condition and performance, outcome-based monitoring, and potentially compliance monitoring associated with regulatory permitting.

Structure condition and performance monitoring

At a minimum, structures should be inspected for their condition and performance annually soon after runoff events until stability is reached and project goals and objectives are met. Remember that treatment effects are contingent upon precipitation and sediment supply, so patience may be needed when evaluating performance. Practitioners should consider how the structures responded to the flow event relative to the dominant channel forming flows at the site when judging performance. Typically, structure maintenance and repair is most important following the first runoff event before the structure has the opportunity to fill with sediment and be colonized by vegetation. Rocks or logs that have become dislodged or washed out should be replaced to ensure proper function. Minor adjustments to the original structure may be needed if it appears water is not flowing as desired or is causing unintended erosion. By the third year on most sites, maintenance needs are often minimal. For more information on specific success/problem indicators and repairs for each type of structure, refer to Zeedyk and Clothier (2014).

Because multiple structures often operate as a complex within a reach, the ‘failure’ of an individual structure may not be problematic if undesired impacts are not occurring and management objectives are still being achieved in the planned reach. Performance should be judged relative to project goals and objectives. The structures are designed to initiate restoration of natural processes but additional interventions are often necessary to slowly build incised channels back up to desired levels. As structures fill with sediment and vegetation, it may be desirable to build additional layers on top of existing structures or increase the number or types of structures to further raise the water table and expand riparian and wet meadow areas.

Outcome-based monitoring

Measuring success is an important attribute of any restoration and adaptive management plan. The monitoring results can determine if your objectives are being met, and adjustments are needed. In addition, they can provide valuable information to your funders. Developing time-sensitive and measurable management objectives is the first step for any type of monitoring program. These can be stated as desired future condition or expected change. Desired outcomes vary by project but typically include ecological and hydrological changes. For the Gunnison project, the primary management objective was to increase the obligate and facultative wetland species by 20% over 5 years. This simple statement was meaningful and relatively easy to measure. Another important guideline for monitoring is to incorporate controls; that is, don’t treat the entire site. This allows you to determine if changes are due to restoration and not just due to changes in the annual weather.

Vegetation monitoring is one common, and readily implemented, approach to quantifying a variety of outcomes. Changes in vegetation composition, cover, and productivity can provide meaningful evidence of improvement in hydrologic conditions, wildlife habitat, and livestock forage. For example, the Colorado Natural Heritage Program led ground-based vegetation monitoring efforts to successfully evaluate restoration outcomes and management objectives for the Gunnison project (for details, see TNC and GCWG 2017). Using the simple and repeatable line-point intercept method, they were able to document that the Zeedyk structures resulted in an average wetland plant cover increase of 240% (ranging from 60-470%) at four treated sites, compared to an average increase of 44% at untreated sites, five years post construction (Fig. 23; Rondeau et al. 2018). They suggest at least five years of post-treatment are needed to detect vegetation response. Repeat photo monitoring provided visual confirmation of project outcomes and is highly recommended on every project.

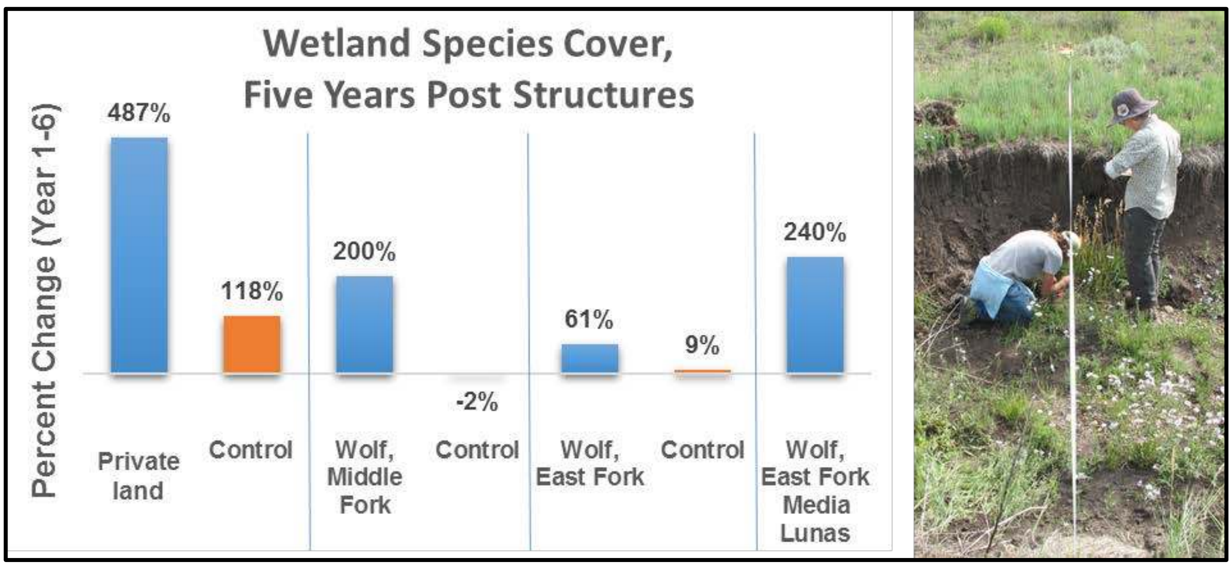

Figure 23. Wetland species cover change in treatment (blue) and control (orange) sites five years post-restoration in Gunnison Basin, CO (Rondeau et al. 2018). Figure and photo by: Renee Rondeau

To further quantify changes in riparian productivity and extent, Gunnison project partners applied an innovative approach using the Normalized Differenced Vegetation Index (NDVI) derived from NASA Landsat satellite imagery to compare pre- and post-treatment riparian vegetation within years of similar climate (for details, see TNC and GCWG 2017). NDVI is a common vegetation index calculated from a ratio of near infrared and red wavelength reflectance and ranges from -1 to 1. Healthy, greener, and more photosynthetic vegetation (a surrogate for increased soil moisture) reflects more near infrared radiation and therefore has a higher NDVI value. Gunnison partners used this approach to document changes in 'greenness' in treatment reaches and capture restoration outcomes at larger scales. In a formal comparison, researchers found restoration boosted productivity by 24% when compared to untreated, control reaches and extended the duration mesic areas remained productive throughout the year (Silverman et al. In Press). NDVI-based tools are increasingly accessible to practitioners and provide relatively inexpensive way to help prioritize projects and evaluate outcomes (e.g., Mesic Resources layer on map.sagegrouseinitiative.com, NDVI layer on app.climateengine.org).

Of course, monitoring transects should be randomly located, however, understanding the purpose of a structure, can help determine what variables are included for randomizing a site. For example, if the primary objective is to increase wetland acres, then monitoring should be associated with grade control and flow dispersal structures instead of headcut control structures, as these structures do not necessarily increase wetland species cover. Simply documenting no change above a headcut may indicate successful treatment.

Compliance monitoring

Permits issued for restoration projects often contain specific requirements for monitoring and reporting. Be sure to consider additional compliance information you may need to collect in the field while conducting other monitoring to make the most efficient use of time.

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IX. Glossary of key terms

Alluvial fan: a fan-shaped accumulation of alluvium (sediment moved by a stream) deposited at the mouth of a ravine or at the juncture of a tributary stream with the main stem.

Bank height ratio (BHR): the height of the top of the bank divided by the bankfull discharge height; a relative measure of the floodplain connectivity to the bankfull channel.

Bankfull: the point at which flow reaches the top of the channel banks and begins to enter the active floodplain.

Capillary action: the attraction of water molecules to the small voids between soil particles; it is responsible for moving water from wet areas of the soil to dry areas.

Floodplain: the flat area adjoining a stream channel constructed by the stream in the present climate and overflows during moderate flow events.

Footer: a layer of hard material, such a rock, placed beneath a structure to add stability; offset footers can serve as splash aprons to reduce energy of water flowing over a structure and help prevent scour.

Gully: an entrenched channel extending into areas with previously undefined or weakly defined channels.

Gully erosion: the erosion of soil along drainage lines by surface water.

Headcut: a sudden change in elevation or nickpoint at the leading edge of a gully. An active headcut point migrates in an upstream direction.

Incised channel: a stream that has cut down through its bed and no longer has access to its floodplain (Stage II, III, and IV in Schumm Channel Evolution Model).

Interflow: interflow is the lateral movement of water in the unsaturated zone, or vadose zone, that first returns to the surface or enters a stream prior to becoming groundwater.

Mesic area: an area having a moderate or well-balanced supply of moisture, such as, riparian and wet meadow areas.

Roughness: a measure of the texture of the stream bed; it can be quantified by the vertical deviations of the bed. If these deviations are large, the surface is rough; if they are small, the surface is smooth.

Stream power: the rate of energy dissipation against the bed and banks of a river or stream per unit downstream length.

Terrace: an abandoned or inactive floodplain due to channel incision or downcutting.

Valley: a depression on the earth surface drained by, and whose form is changed by, water under the attractive force of gravity, between two adjacent uplands or hillslopes. The valley is comprised of the valley bottom and the inactive floodplains (i.e. terraces) and fans.

Valley bottom: the part of a valley comprised of the channel and the active floodplain. The valley bottom represents the maximum possible extent of riparian vegetation under current conditions.

X. Appendices

A. Zuni bowl construction specifications
B. Rock rundown construction specifications
C. Rock layback construction specifications
D. Log and fabric construction specifications
E. One rock dam construction specifications
F. Media luna construction specifications
G. Summary of lessons learned from Upper Gunnison River Basin
H. Quarry rock recipe

Appendix A. Zuni bowl construction specifications (Sponholtz and Anderson 2013; courtesy of C. Sponholtz).

ZUNI BOWL

An in-channel headcut control structure composed of rock-lined step falls and plunge pools that prevents headcuts from continuing to migrate upstream. Zuni Bowls stabilize actively eroding headcuts by dissipating the energy of falling water at the headcut pour-over and the bed of the channel. The structure converts the single cascade at an eroding headcut into a series of smaller step falls. Zuni Bowls also serve to maintain soil moisture on the face of the headcut, encouraging the establishment of protective vegetation. Original concept developed by the people of Zuni Pueblo and Bill Zeedyk.

Design & Construction

1. Select a headcut for treatment. Shape and layback the face of the headcut to create a uniform surface on which to build.
2. Determine the height of the headcut. Next measure and mark the location downstream from the face of the headcut that is three to four times (3-4x) the height of the headcut. At this location dig a shallow trench and fill with one to two rows of rock, so that no rock protrudes more than 2 in/5cm above the bed of the channel. This will serve as the ***splash apron*** for the Zuni Bowl.
3. Scatter native grass and wildflower seeds in the area where the Zuni Bowl is to be built.
4. Gather the largest rocks available, and place them in a row just upstream from, and in contact with, the splash apron. These rocks should sit at an elevation approximately ½ the total height of the headcut. This will serve as the ***lower pour-over*** of the Zuni Bowl. Use keystones on the pour-over whenever possible.
5. Armor the bottom of the ***plunge pool*** with a single layer of rocks. Place these rocks at a uniform height to create a stable foundation for the rest of the Zuni Bowl. Smaller rocks may be used for this part of the Zuni Bowl.
6. Starting just upstream from the lower pour-over, lay courses of rock around the face of the headcut. This will form the walls of the bowl. Maintain contact with the shaped surface. The structure will have more integrity if built with layers of off-set rocks that form a sloping wall inside of the headcut, as opposed to merely lining the face with rocks. Improve the durability of the structure by avoiding gaps in the rock work. As an extra precaution, you can use biodegradable geotextile fabric to line the face of the headcut prior to laying down rocks.
7. Continue to lay courses of rock on the face of the headcut until you reach the height of the ***original headcut pour-over***. No rocks in the ***Zuni Bowl pour-over*** should protrude above this level to allow water to flow freely over the structure. Use keystones whenever possible.
8. Construct a ***ORD*** downstream from the Zuni Bowl. Place the upstream edge of the ORD approximately six to eight times (6-8x) the height of the headcut away from the Zuni Bowl pour-over.

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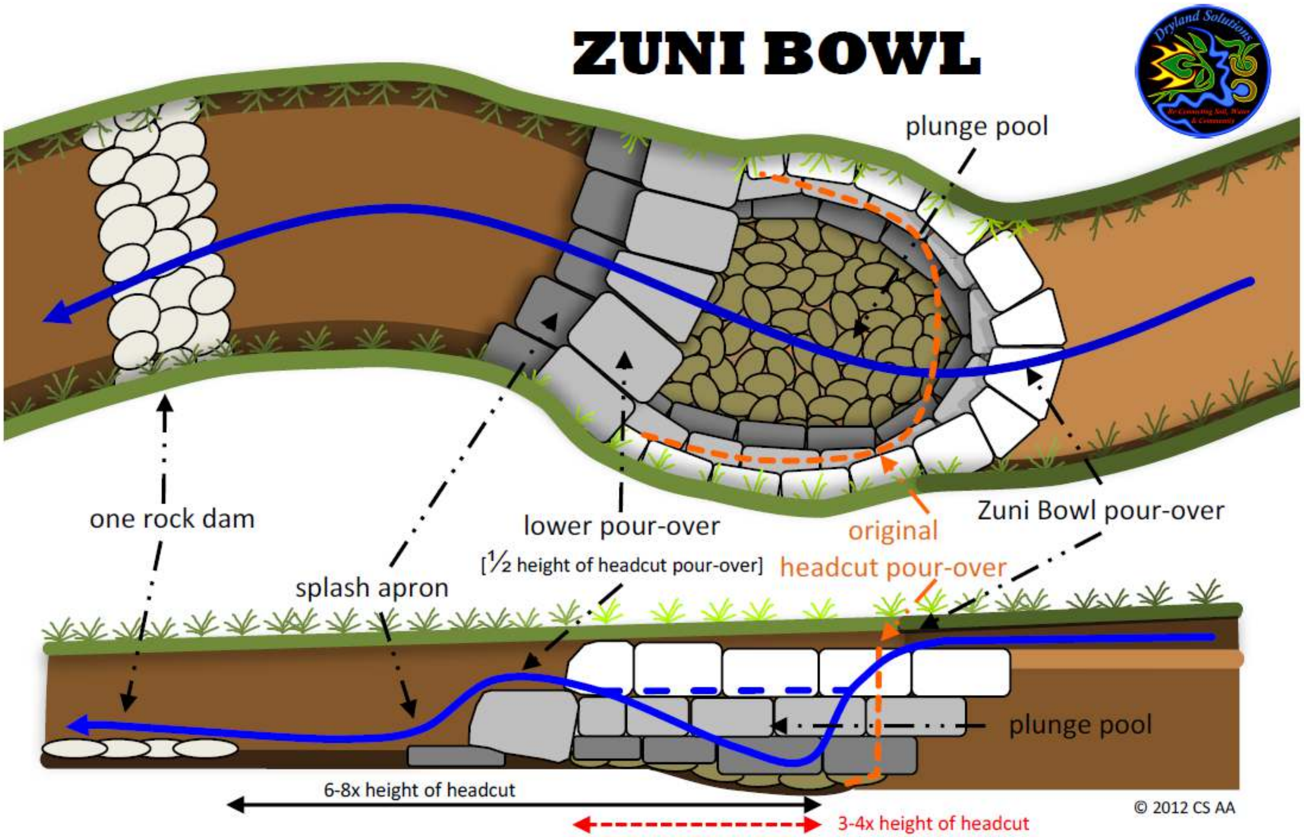

Appendix B. Rock rundown construction specifications (Sponholtz and Anderson 2013; courtesy of C. Sponholtz).

ROCK MULCH RUNDOWN

A headcut control structure where the face of the headcut has been laid back to a stable angle of repose (minimum of a 3:1 slope), and then covered with a single layer of rock mulch. The mulch serves to slow runoff, increase soil moisture, recruit vegetation, and ultimately prevent the headcut from migrating further up slope. Rock Mulch Rundowns are ONLY to be used on low energy headcuts, like those found in upland rills and gullies with small catchment areas, and where sheetflow collects and enters a channel. Original concept by Craig Sponholtz.

Design & Construction

1. Select a low energy headcut for treatment.
2. Determine the extent of the 3:1 slope. Take care to balance the cutting required to achieve a 3:1 slope vs. the potential disturbance to existing vegetation.
3. Layback the headcut by cutting away soil from the top of the face, and then use the cut material to fill the base of the headcut. Where possible, the Rundown should be the entire width of the channel below the headcut. Narrow headcuts may need to be widened to accommodate the rock work. Adjacent headcuts, separated by uneroded fingers of earth, but leading to the same channel, can be combined into a single Rundown structure. Knock down the uneroded earth between the headcuts, and use it as fill.
4. Compact the fill.
5. Scatter native grass and wildflower seed and rake the surface of the Rundown.
6. Dig a shallow trench on the down slope side of the Rundown and fill with one to two rows of rock, so that no rock protrudes more than 2 in/5cm above the bed of the channel. This will serve as the ***splash apron*** for the Rundown.
7. Cover the entire surface of the Rundown with a single layer of rock mulch. The center of the Rundown should be the lowest point in the structure so that water will not run around the edges.
8. Continue to lay rock on the surface of the Rundown until you reach the height of the ***headcut pour-over***. No rocks should protrude above this level to allow water to flow freely over the structure. It is very important to avoid gaps in the rock work because gaps cause weak points in the structure. Fill gaps with small gravel if needed. To improve durability, you can use a biodegradable geotextile mesh to line the surface of the Rundown prior to laying down rocks.

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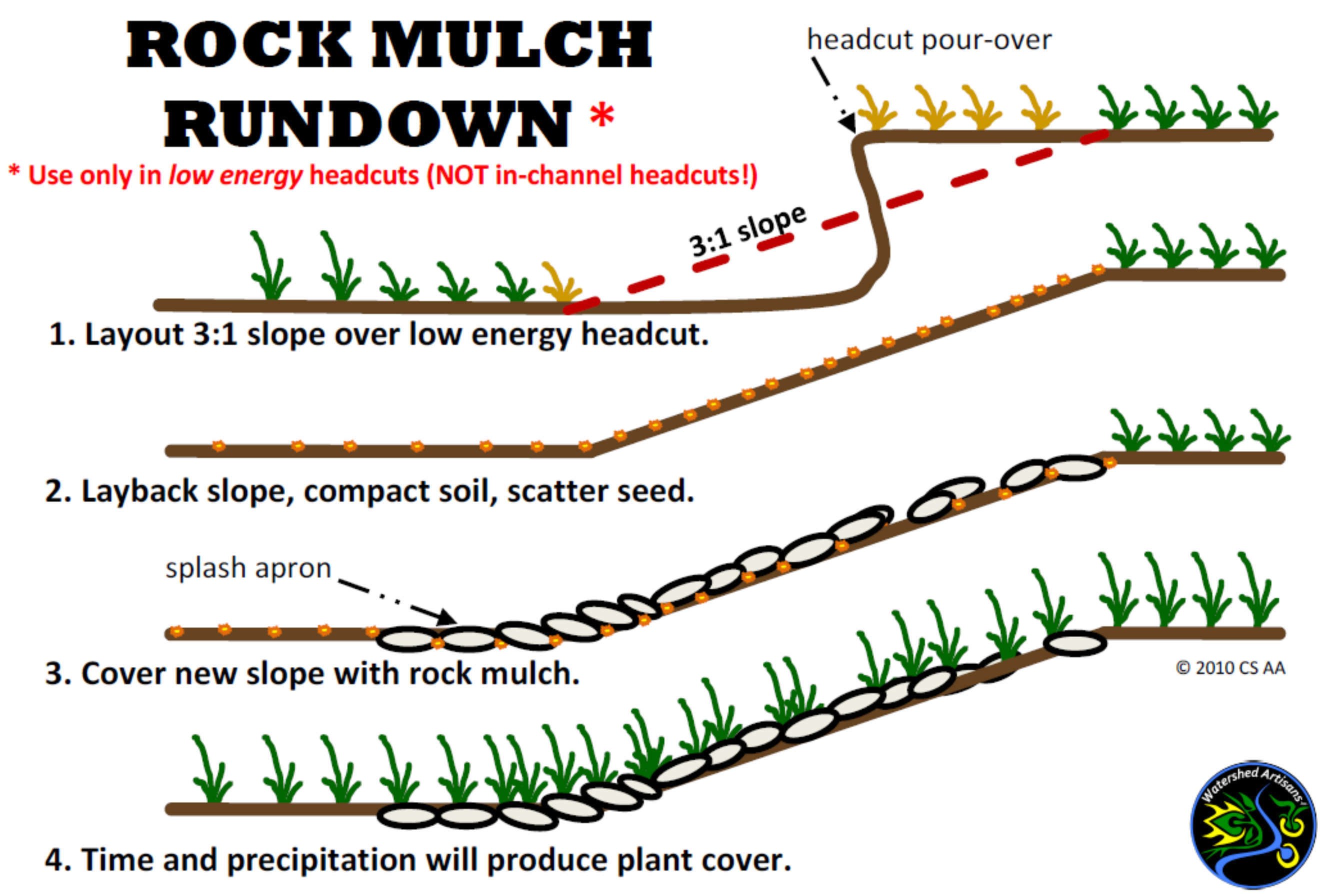


Appendix C. Rock layback construction specifications (From Zeedyk and Vrooman, 2017).

Rock Layback

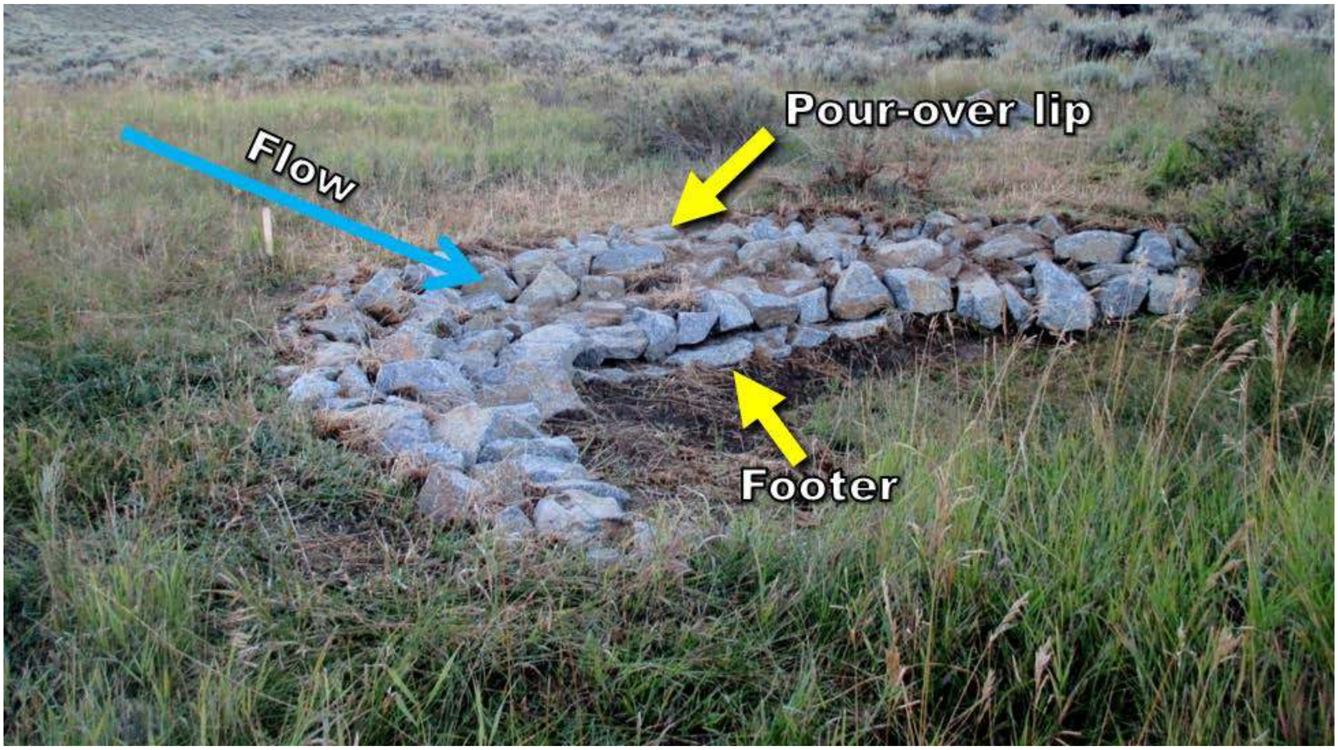


Photo by: Shawn Conner

Construction steps:

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.

Appendix D. Log and fabric construction specifications (From Zeedyk and Jansens (2009), Zeedyk and Clothier (2014).

Log and Fabric

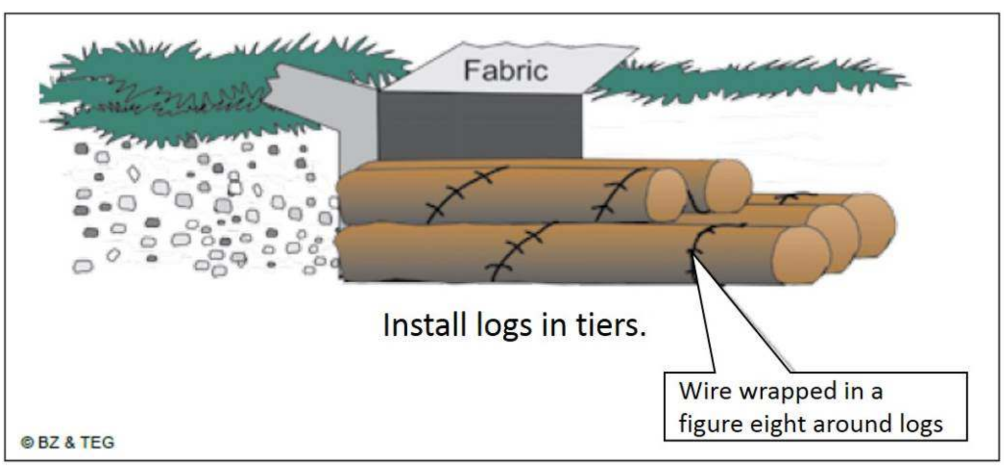
Materials Needed
1. Geotextile Fabric (silt fencing fabric in 3 foot widths works well and is convenient to use).
2. Logs: Logs 6 to 10 inches in diameter and varying lengths from 4 to 8 feet long. (For example, bottom tier, 8 feet long, second tier, 6 feet, third tier, 4 feet.) Logs should be straight, trimmed and green, or seasoned, but not rotten. Any protruding knots, limbs, or knobs make stacking very difficult and should be trimmed.
3. Wire: one roll of smooth fencing wire or barbed wire.
4. Fencing staples: 2 inches long, about 2 lbs.
5. Sod clumps: 6” X 6” X 3”. Dig locally.

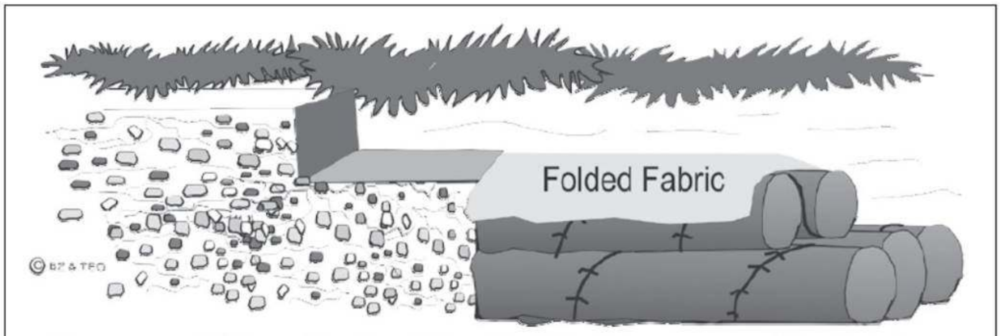
Tools Needed
1. Shovel (for digging)
2. Pick (for squaring sidewalls)
3. Crowbar (for wedging logs together)
4. Axe (for cutting roots, trimming)
5. Utility knife (for cutting fabric)
6. Claw hammer (for driving staples)
7. Fencing pliers (for cutting wire)
8. Wheel barrow (transport logs, tools, materials)
9. Log carrier (optional – for lifting, carrying logs)

Construction Steps:
1. Prepare the site by “squaring up” the headwall, sidewalls, and bottom of the channel. Eliminate the scour pool and any irregularities (rocks, roots, or indentations) in the channel bottom, sidewalls, or headwall. Use a shovel, spade, pick, or crowbar to shape the site. Save and stockpile sod clumps of wet soil grasses and sedges for use in the final step.

2. When preparation is finished, cut and drape geotextile fabric across the headwall, sidewalls, and channel bottom. Three pieces work better than one. The first should start about 2 feet above the lip of the headwall, extend down the headwall, and cover the channel bottom for 6-8 feet (the length of the bottom tier of logs). The second should be draped over one side wall and part way across the channel bottom. The third should be draped over the opposite sidewall in a like manner. Temporarily anchor the fabric in place by weighting the ends with rock or sod clumps. Once logs are placed, the extra flap of material will be folded back over the logs.

3. Install logs in the prepared site using as many tiers as necessary to stack them even with the lip of the headwall. (See Figures below). Logs within each tier should be of the same diameter; between tiers, they can be of different diameters. Logs in the bottom tier should be the longest; the top tier, the shortest. For example, if three tiers are needed, make the bottom tier 8 feet long, the middle tier 6 feet, and the top tier 4 feet long. It is important to wedge logs tightly against the face of the headwall and sidewalls. When all tiers are in place, fold the extra flap of fabric back over the top logs. Using smooth wire and fencing staples, wire each tier of logs together as you go. (Wire tier one logs before installing tier two, etc.) Tamp soil into any open spaces between fabric, headwall, and sidewalls.

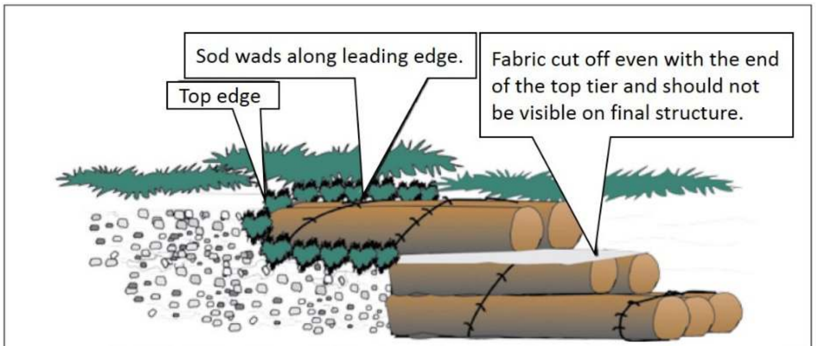




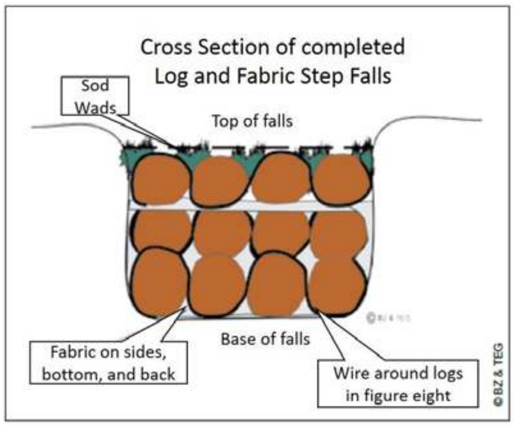
Prepare platform for final tier. Fold fabric over next to last tier.

4. Working upstream from the lip of headwall, excavate a smooth platform level with the top tier of installed logs and one log-diameter wider on either side of the channel. The platform should extend at least 4 feet upstream from the lip of the headwall. Line the platform with the fabric extending out over the installed logs by 3-4 feet and upstream for 1-1.5 feet.

5. Using logs of equal diameter, install the final tier by wedging and tamping each log firmly in place (see Figure below). The logs should be long enough to extend about 2 feet downstream from the lip of the headwall. Wire this tier together and to the rest of the structure. Tuck the upstream flap of fabric in place along the leading edge (upstream face) of the logs in the final tier.



Add final tier of logs slightly lower than top edge and wire down.
Tuck in fabric on lower tier and install sod clumps along leading edge and sides.



6. Transplant live green sod clumps of aquatic grasses, sedges, or rushes to the leading edge and sides of the final tier of logs. Completely fill any cracks or holes between the fabric and channel walls with live sod. **This is a key step.** The success of the log structure depends on your successfully establishing a living mat of wet soil grasses and grass-like plants along the upstream edge and sides of the structure.

7. After installation is complete, return to the site periodically (every 2-3 weeks initially, then less frequently) to fill any developing cracks or holes with fresh sod clumps until a healthy mat of vegetation is successfully established and no new cracks or holes develop.

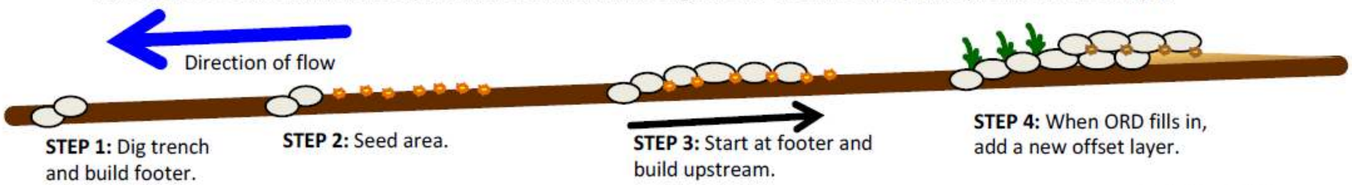
Appendix E. One rock dam construction specifications (Sponholtz and Anderson 2013; courtesy of C. Sponholtz).

ONE ROCK DAM "ORD"

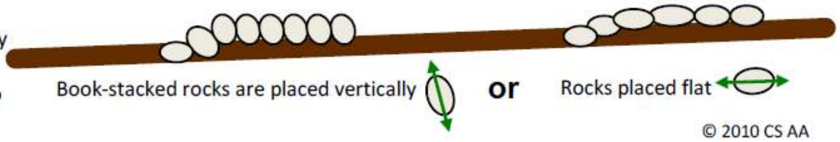
A low grade control structure built with a single layer of rock on the bed of the channel. ORDs stabilize the bed of the channel by slowing the flow of water, increasing roughness, recruiting vegetation, capturing sediment, and ***gradually*** *raising the bed level over time. ORDs are also passive water 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.*

Design & Construction

1. Select area to build the ORD. Dig a shallow footer trench and fill with one or two rows of rock, so that no rock protrudes more than 2 in/5cm above the bed of the channel. This will serve as the ***splash apron*** for the ORD.
2. Scatter native grass and wildflower seeds in the area where the ORD is to be built.
3. Start building at the footer and continue upstream, laying down one layer of rock, as if you were building a horizontal wall on the bed of the channel.
4. Over time, the ORD will fill with sediment. Once completely filled, another offset layer can be added to the ORD to further raise the bed of the channel and capture more sediment. The original ORD becomes the splash apron for the new layer.



Orientation of Rocks: Placing rocks vertically is called book-stacking. This makes for a very strong structure, especially when using small rocks. It is also a good way to make a slightly taller structure.



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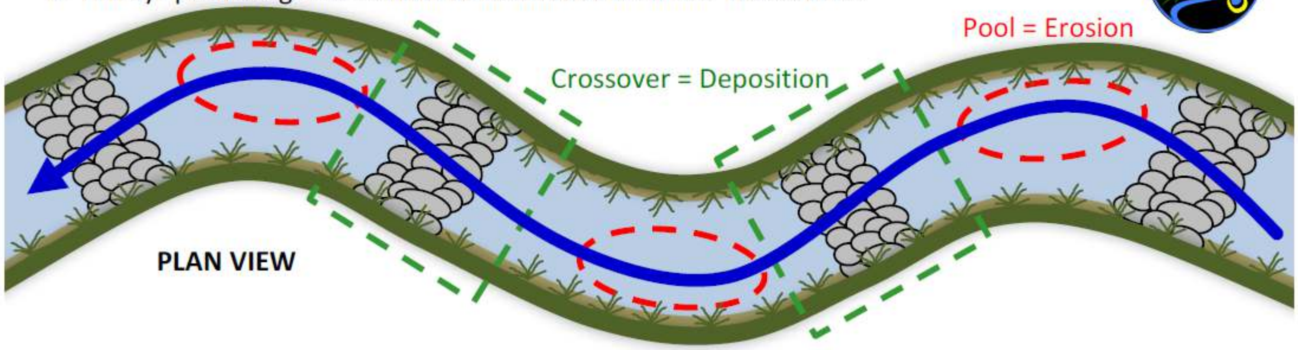
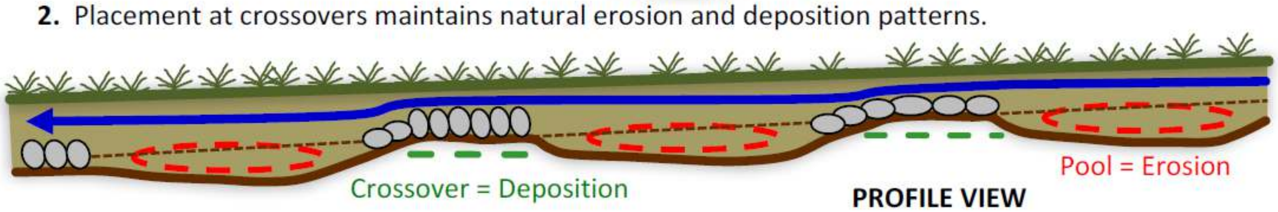
ONE ROCK DAM

1. Always position grade control structures at meander crossovers.



2. Placement at crossovers maintains natural erosion and deposition patterns.



3. Always maintain a low point in the channel cross section to prevent bank erosion.

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Appendix F. Media luna construction specifications (Sponholtz and Anderson 2013; courtesy of C. Sponholtz).

MEDIA LUNA

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

Design & Construction

1. Identify which type of Media Luna ("tips UP" or "tips DOWN") is appropriate for the treatment site.
2. If the treatment site is at the collection point of a network of rills (< 6 in/15cm deep) or small channels (< 1 ft/30cm deep) then use a ***sheet flow collector*** (tips DOWN). First lay out the down-slope edge of the structure by selecting two points on the banks of the main channel immediately down slope from where the rills enter. Using a leveling tool, lay out a level arc from bank to bank so that the tips point down slope, and the arc spans all of the rills that you aim to treat.
3. If the treatment site is located where runoff from rills or a shallow channel can easily be spread across relatively flat ground, then use a ***sheet flow spreader*** (tips UP). First lay out the down-slope edge of the structure by creating a level arc across the flat area with the tips on a slightly higher contour. The tips should be far enough up slope that they prevent water from running around the ends of the structure.
4. Layout the up-slope edge of both types of Media Lunas by tracing a level arc parallel to the down-slope edge to create a band that is at least 3 ft/1m wide. Media Lunas composed of wider bands of rock mulch offer more protection from erosion, improved infiltration and increased plant recruitment.
5. Scatter native grass and wildflower seeds in the area where the Media Luna is to be built.
6. To construct the ***splash apron***, start by digging a shallow trench from tip to tip along the down-slope edge. Fill the trench with one to two rows of rock, so that no rock protrudes more than 2 in/5cm above ground level.
7. For both types of Media Lunas, continue construction on the down-slope edge (by the splash apron) and work up slope covering the ground with a single layer of rock mulch to form a band at least 3 ft/1m wide. The tops of the rocks need to be level to ensure proper function of the structure.

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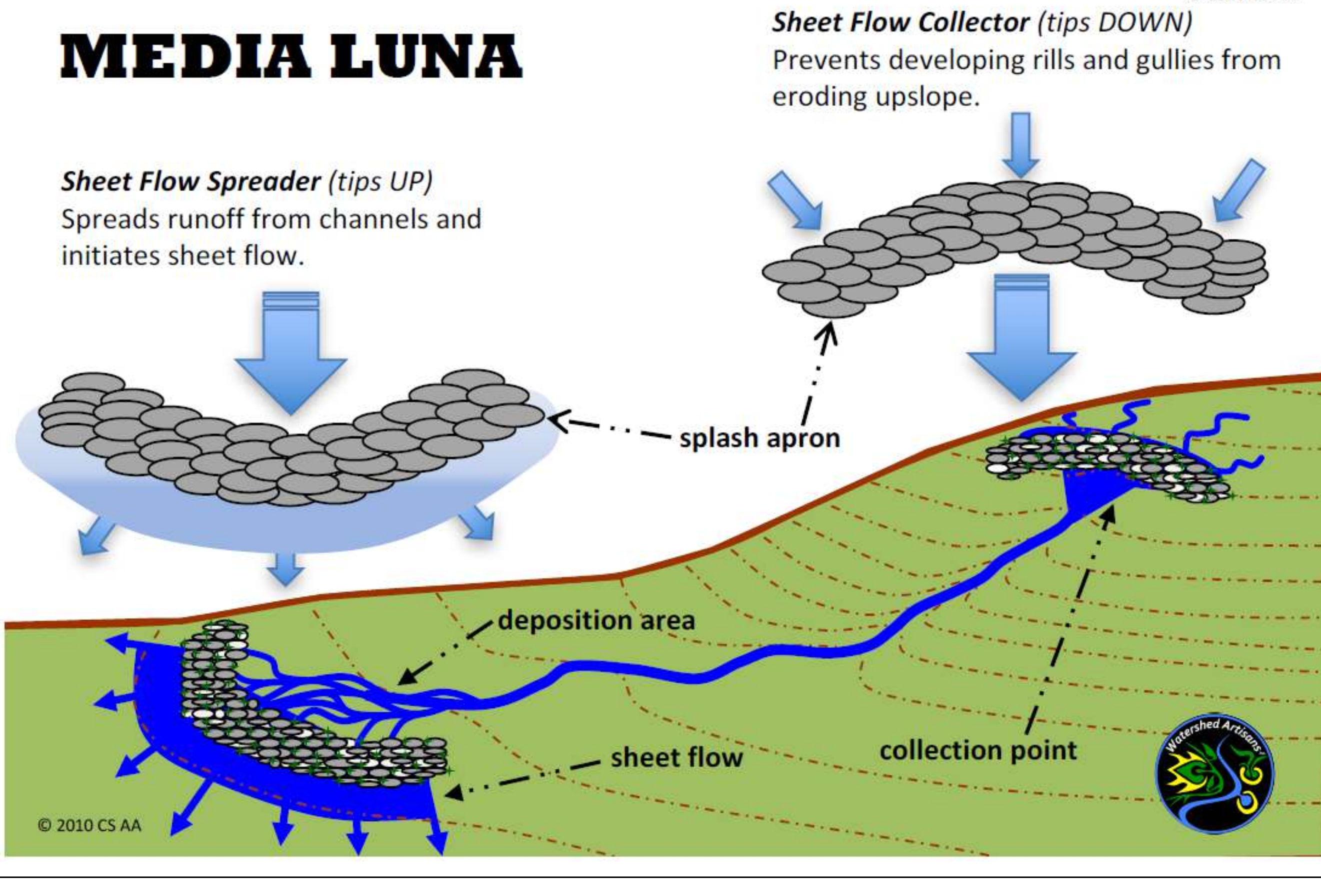

Appendix G. Summary of lessons learned from the Gunnison Climate Working Group based on six years of applying Zeedyk techniques in the Upper Gunnison River Basin, CO.

1. Collaboration and partner engagement are key to ensuring optimal response when working at the watershed-level across land ownership and management boundaries. Building trust and establishing credibility with local landowners is essential.
2. Conducting a climate-informed site selection analysis can identify streams that would benefit from these restoration techniques and can serve as a starting point for field evaluation and prioritization. Convene wildlife biologists, hydrologists, ecologists and restoration experts to review analysis and prioritize the potential sites based on local knowledge. The results provide an excellent starting point for field evaluation to further prioritize stream reaches for on-the-ground treatment.
3. Restoration expertise to design and oversee installation of structures is essential to successful projects. These experts are needed to evaluate sites, identify restoration needs and objectives, design specific treatments to address needs and objectives, train and provide oversight of field crews and volunteers in building structures.
4. Stake all treatments well in advance of arrival of field crews, volunteers and/or contractors to increase efficiency and effectiveness of installation.
5. Wetland delineation, permits, agency requirements and landowner agreements should be completed well in advance of work.
6. Technical training and building local capacity can help ensure long-term engagement and success. When working with youth field crews, focus on developing skill sets, e.g., leadership, land management, restoration, good stewardship, work ethic, and a positive attitude. Train local private contractors to build structures to help build capacity for building structures.
7. Projects require repeated visits to treated stream reaches to monitor effectiveness, determine needs for modification, and maintain structures to ensure long-term success. Monitoring, modification and maintenance of existing structures are all critical to ensure effectiveness. Revisit/monitor previously treated sites to determine needs for modification, adding a second layer, and/or expansion early in the season.
8. Vegetation monitoring is critical to document ecological response to the restoration treatments. At least five years of vegetation monitoring are needed to document trends in response. Coupling vegetation cover data with repeat photos is a powerful tool to validate success. Collecting vegetation data and before-and-after photographs help to convey the effectiveness of treatments. Control sites/transects are exceedingly hard to find; we recommend that the established control transects be considered permanent and no structures built on them for at least five years. Without these controls, it is very difficult to detect/document the effectiveness of the structures.
9. Critical to scaling up this effort across the region is technical expertise and training in planning, design and implementing restoration techniques. Many trainings are focused primarily on building structures, but training beyond the basics is essential for successful application of the techniques.
10. These techniques have demonstrated many benefits beyond the primary goal including improved habitat for livestock and many wildlife species, improved water quality, increased groundwater storage, and carbon sequestration.

Appendix H. Quarry rock 'recipe' for Zeedyk rock structures in the Upper Gunnison River Basin, CO (From Liz With, Shawn Conner, and Brooke Vasquez, June 2017).

Specification: The rip-rap rock mix for restoration structures shall be angular granitic rock between 6-18 inches (in length) with the following composition:

- 70-80% between 6-12 inches
- 10% should be 12-18 inches
- A small percentage (5-10%) should consist of gravel and rock fragments

Description: The recipe will slightly depend on the quarry the rock is being pulled from and the proportion of the size of the rock being blasted. For Gunnison quarries, we were able to use these ratios but you may need to adjust them a little to get the rock right for you.

70% of the material should be screened through a 6" grizzly (rock sorter with only vertical bars - see photo to right). This will allow mostly stuff less than 6" through. Then take the over-burden that was already screened off (so you minimize the amount of small stuff being added) and put it over a 1' grizzly for the remaining 30%. This will ensure that rock much larger than 1' will be removed. Since the grizzly only has vertical bars, there will be slightly larger material that is able to fit through on a smaller axis, but the majority of the materials delivered should be moveable by hand without the need for heavy machinery. It does mean sorting the material twice, which the quarry usually charge an extra fee for, but it makes it worth it because all the rock delivered is usable and without much waste. This means that you are able to reduce hauling costs which, in most situations, is much more expensive than material costs.

Other considerations: The pits need to be weed free and as little dirt as possible should be hauled with the rock. If you are working on a steeper area or one with more water, you may want to reduce the amount of small rock and increase the large stuff to deal with the increased velocities. If you have a quarry that you know your producers will be working with regularly, it is more than worth it to take a trip out to that quarry and look at the material available and talk with the operator about what the project needs. Since these are natural materials, people have to deal with a lot of variability—it's not like buying pipe. There is an increased need to ensure that the materials acquired are actually appropriate to completing the task at hand.

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