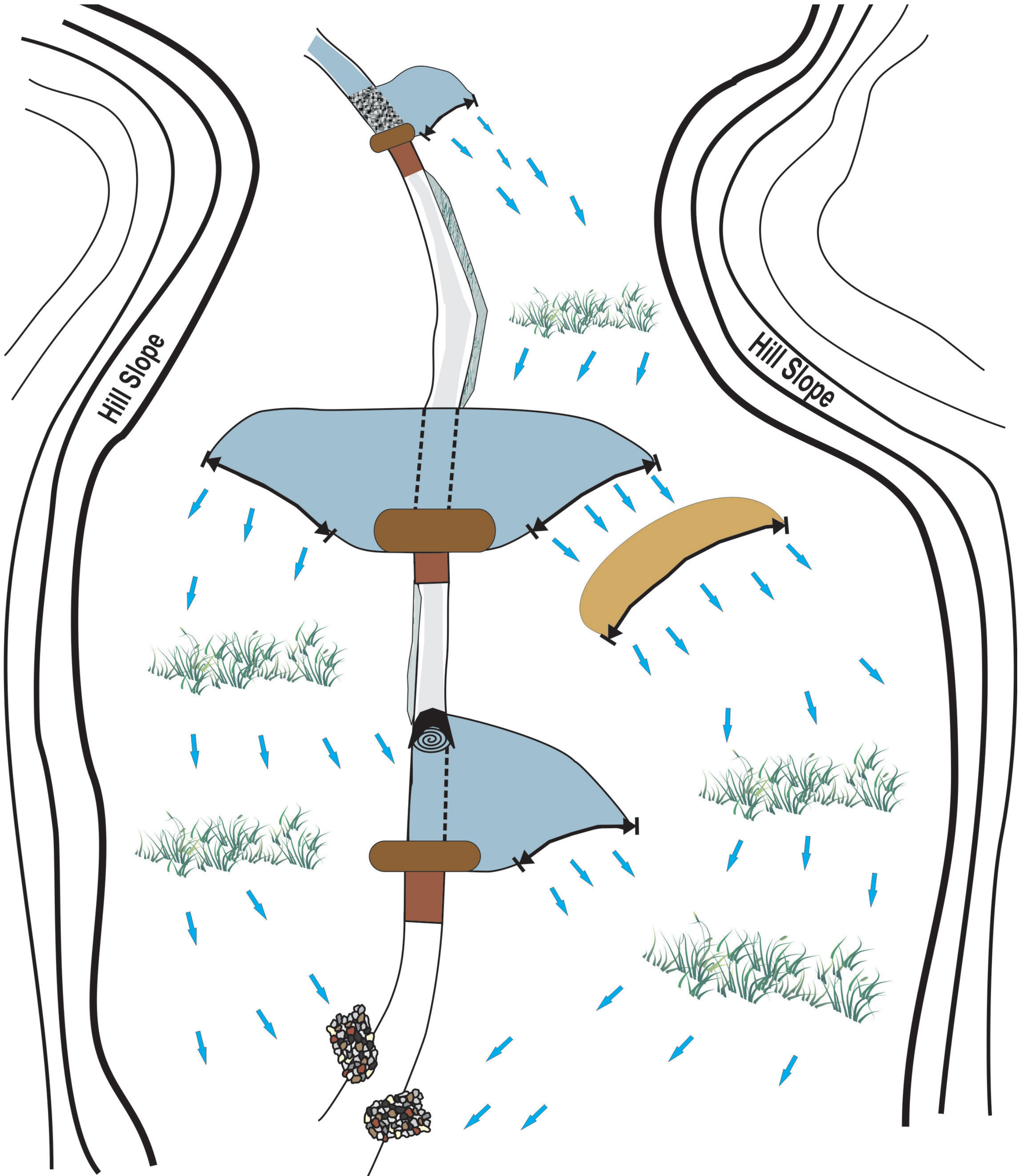
The Plug and Spread Treatment

Achieving Erosion Control, Soil Health and Biological Diversity

Bill Zeedyk



ZEEDYK Ecological Consulting, LLC

Restoring wetland, riparian, and upland habitats

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CHAPTER 1
THE PLUG AND SPREAD TREATMENT

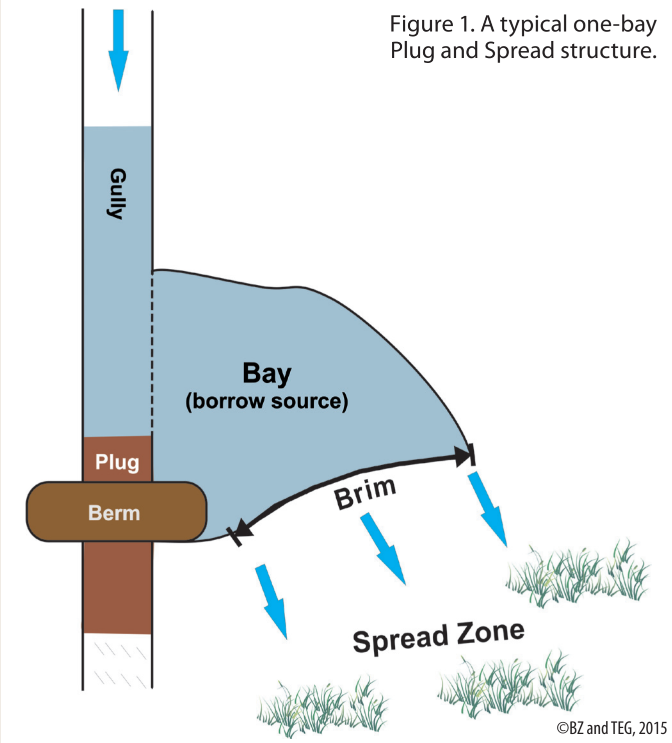
Introduction. Plug and Spread treatments are among many that can return seasonal runoff to meadows, rangelands and other landforms that have been drained by human activities. They are used to restore dispersed surface flow to gullied surfaces and also to increase infiltration and thus recharge shallow groundwater resources (Figure 1). Plug and Spread treatments are best suited for arid and semi-arid lands, where restoring dispersed flow, soil health and vegetation is increasingly important as flood events associated with climate change become more intense.

The Plug and Spread treatment was first used in New Mexico to reconnect an incised ephemeral channel to a former wetland surface. The channel, which had been captured by an unused irrigation ditch, was reconnected to the abandoned floodplain through the investment of one-half day of time using a D-4 dozer. The structure reconnected 12 acres of former wetland to the incised channel (gully). While some flow was intentionally impounded, the ponded area of the gully has since filled with sediment (comprised of sand and gravel sized particles) and ponding no longer occurs. Upland vegetation has been replaced by wetland species and forage yield has increased by about a ton per acre per year. The cost of reconnecting the gullied channel to its abandoned floodplain was approximately a thousand dollars.

This initial Plug and Spread project was funded by the New Mexico Environment Department, Surface Water Quality Bureau, as part of the New Mexico River Ecosystem Restoration Initiative and was implemented on public land administered by the Bureau of Land Management (BLM), U.S. Department of Interior. Originally privately owned, these lands had been intensely farmed during the Dust Bowl of the 1930s and were later acquired by the federal government through a land exchange. Implemented by Rangeland Hands, Inc. under contract to the Rio Puerco Alliance, a multi-agency cooperative, the treatment proved highly successful and other subsequent projects were based on lessons learned from the initial project.

Methods for restoring dispersed flow or sheetflow to gullied surfaces might collectively be termed "Connect and Spread" treatments. In addition to the Plug and Spread method described in this book, they include the Pond and

Figure 1. A typical one-bay Plug and Spread structure.



Plug treatment developed by David (Dave) L. Rosgen of Wildland Hydrology, Inc. The Plug and Spread method evolved as an adaptation from the Pond and Plug method, a treatment that reconnects perennial flows and perennial wetlands to adjacent abandoned wetland floodplains (*The Pond-and-Plug Treatment for Stream and Meadow Restoration: Resource Effects and Design Considerations*, May 2010, *http://www.wetlandsandstreamrestoration.org/Publications/Pond%20%26%20Plug%20Treatment%20for%20Stream%20%26%20Meadow%20Restoration.pdf*).

Connect and Spread also includes methods for collecting and redistributing, as sheetflow, runoff intercepted by roads and road drainage systems. These methods were developed by the U.S. Forest Service and are described in *Water Harvesting for Low-Standard Rural Roads*, Zeedyk, 2006 and *Managing Roads for Wet Meadow Ecosystem Recovery*, USFS, 1996.

Rosgen's Plug and Pond method is best suited for use in perennial streams and wetlands. The equipment needed normally includes an excavator and tracked skid steer machinery—both well suited for operating in wet soils. Alternatively, the Plug and Spread method has been developed for use in ephemeral and intermittent systems where soils are normally drier. Equipment can include a bulldozer, loader, backhoe, skid steer and even road grading machinery.

Connect and Spread projects related to road drainage opportunities use any suitable equipment. Their focus is on the proper distribution, sizing and placement of drainage structures to replicate normal patterns of sheetflow across the landscape, rather than capture flows in ditches and artificial drainages. This approach requires the proper placement, orientation, sizing and elevation of culverts, ditch outfalls, berms and rolling dips to disperse surface flow back across the landscape at depths, velocities, and patterns of distribution that would normally be expected for the landform affected. This method of Connect and Spread treats water crossing a road as a valuable natural resource rather than a costly nuisance.

Plug and Spread structures are intended for use in narrow, gullied channels that dissect a broad floodplain, alluvial fan, or slope wetland landform. These structures are most economical where the ratio of valley width to gully width is 6 to 1 or greater and the gully is less than 10 feet deep. For example, if the gully is 5 feet wide, the valley would need to be 30 or more feet wide. Where the ratio is less or the gully is deeper, construction costs may be excessive relative to expected economic benefits to be derived from increased forage production for livestock. However, potential positive environmental effects may justify treating sites with less favorable cost-benefit ratios.

Especially for the American Southwest, climatologists predict steadily increasing average annual temperatures and longer, more extreme droughts, interspersed by widely separated, but more intense, precipitation events that will result in severe flooding (Figure 2, Overpeck et al., 2012). Reconnecting storm runoff with former floodplains and alluvial fan surfaces offers an opportunity for slowing, spreading, infiltrating and storing water through subsequent drought periods, while also reducing the adverse impacts of floods.

The Plug and Spread method has been applied on a trial basis to gullied ephemeral and intermittent channels in Texas, New Mexico and Colorado. Text and graphics illustrating the treatment here are based on lessons learned and experiences gained at these original locations (Figure 3). Concepts and interpretations presented are those of the author, based on initial applications of the method. It is

Current and Predicted Climate Phenomena Trends

Projected Change	Direction of Change
Average annual temperature	Increase
Seasonal temperatures	Increase
Freeze-free season length	Increase
Heat waves	Increase
Cold snaps	Decrease
Average annual precipitation	Decrease
Spring precipitation	Decrease
Extreme daily precipitation	Increase
Mountain snowpack	Decrease
Snowmelt and streamflow timing	Earlier
Flooding	Increase
Drought severity	Increase

Figure 2. *Current and predicted climate phenomena trends discussed in Assessment of Climate Change in the Southwest United States: Summary for Decision Makers*, adapted from Table 1.1, Overpeck et al., 2012.

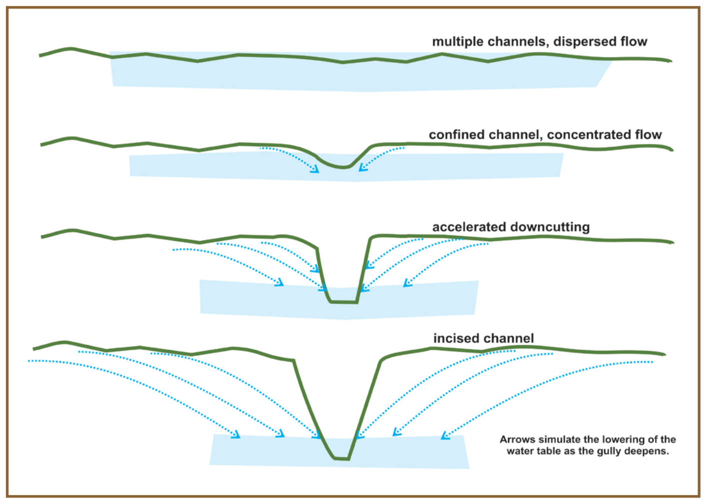


Figure 4. The evolving cross-sectional profile of an eroding slope wetland. As the gully deepens, flow rates accelerate (from *Characterization and Restoration of Slope Wetlands in New Mexico*, Zeedyk, Walton and Gadzia, 2014).

hoped that these will be refined as use becomes more widespread across arid landscapes.

The Plug and Spread treatment is especially applicable where ephemeral or intermittent streams or gullies leave the upland and cut across alluvial fans or floodplains before intersecting the main stream or gully further down valley (Figure 4). Dissected alluvial fans are well suited to the Plug and Spread treatment, which is similar to the natural geomorphology by which alluvial fans are formed. That is, abundant sediment from upsteam sources may randomly plug shallow channels causing stream flow to spread to another portion of the fan surface, only to be redirected again at some time in the future.

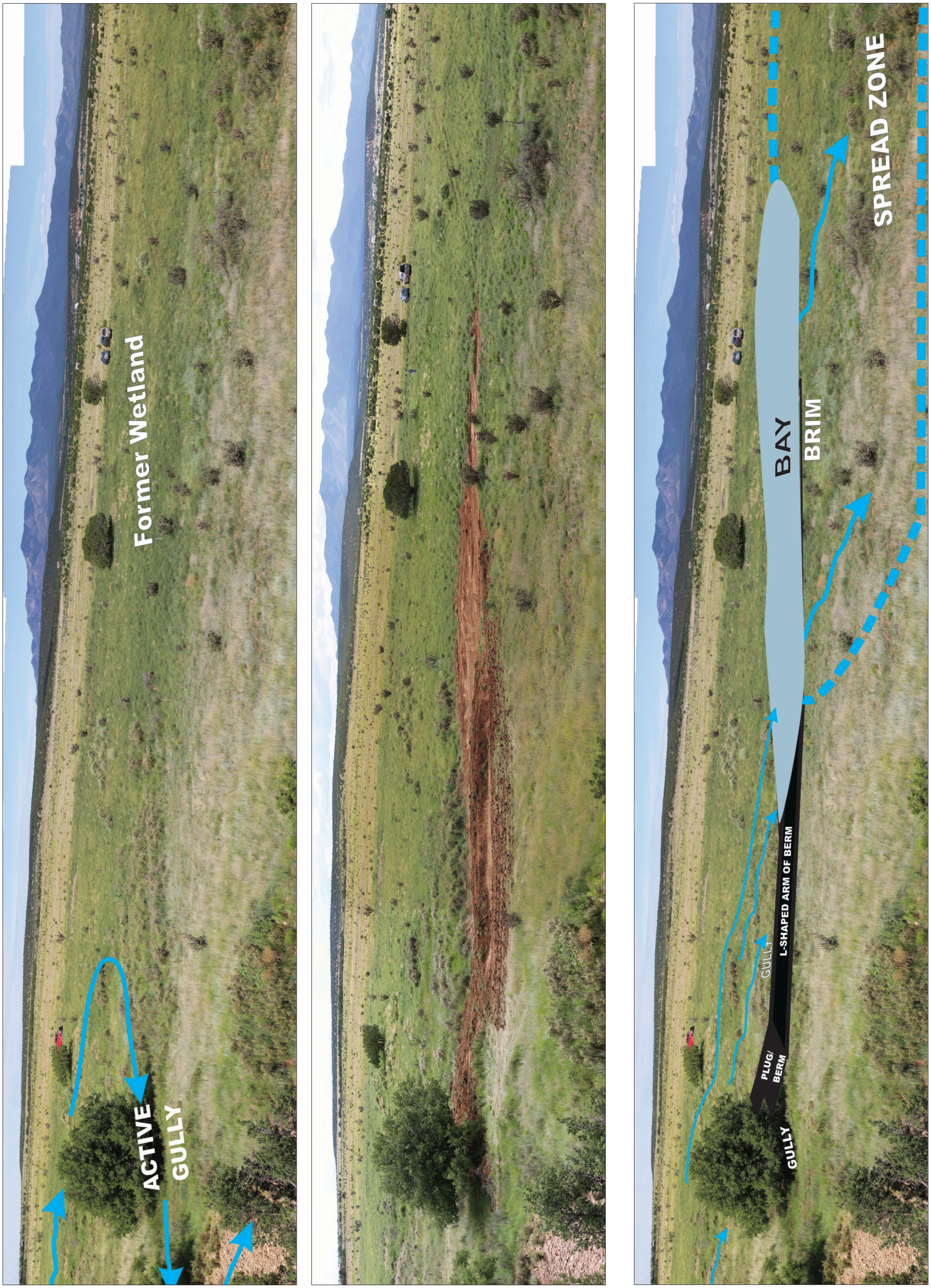


Figure 3. Top, pre-treatment. Gully due to old road diverts flow from former wetland surface. Middle, Plug and Spread structure as built. Bottom, post-treatment. Path of sheet flow across the spread zone.

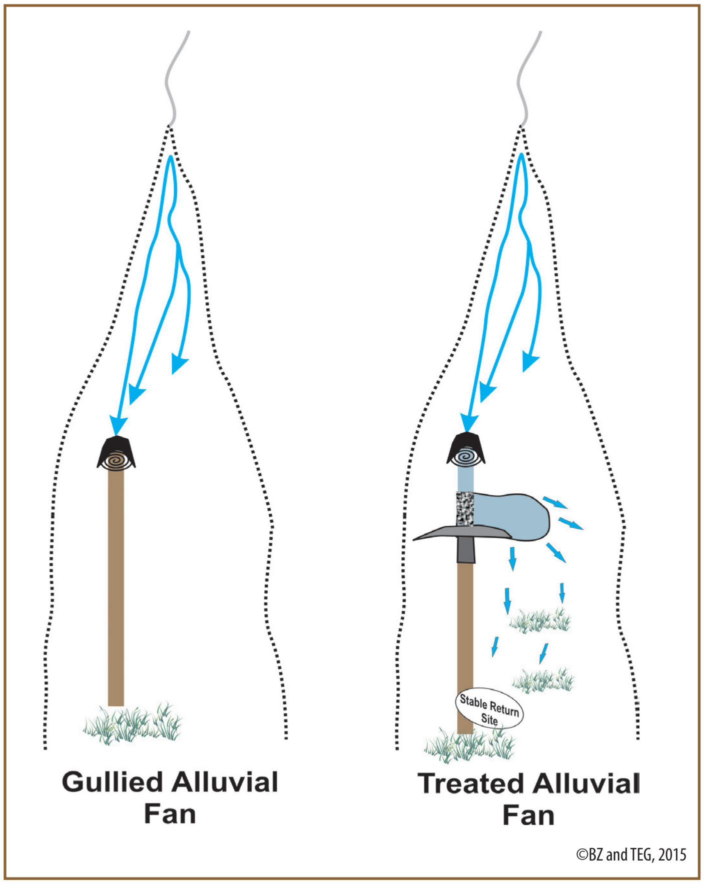


Figure 5. A gullied alluvial fan and a treated alluvial fan. (An alluvial fan is the term for a fan-shaped accumulation of alluvium deposited at the mouth of a channel, gully or at the juncture of a tributary stream with the main channel of a riverine system.)

The Plug and Spread treatment can be used to reestablish this process on damaged alluvial fan surfaces (Figure 5).

Depending on the situation, Plug and Spread structures can increase forage yields for livestock, improve habitat for wildlife, increase groundwater storage, attenuate floods and dissipate flood energy (Figures 6-7). Reconnected wet meadow soils can produce up to twenty-five times more forage than adjacent upland soils, 3000-5000 pounds per acre per year as compared with 100-200 pounds per acre from nearby uplands. Thus, such treatments can be highly economical where correctly applied to suitable sites. Rangeland or pastures improved by installation of Plug and Spread structures may be expected to produce higher yields and better quality forage than adjacent uplands, and with increased reliability.

Creation of Varied Microhabitats. Between floods, other smaller runoff events can have a beneficial impact on the restoration site. The gully bottom between structures has a microclimate different from the floodplain surface (Figure 8). The area is subject to less heat and wind and is therefore cooler and has a lower evaporation rate than the landscape above. Wetland

Figure 6. Pre-treatment. Dominant vegetation is tumble weed (Kochia) on a former wetland site, soon to be rehydrated by a Plug and Spread treatment.

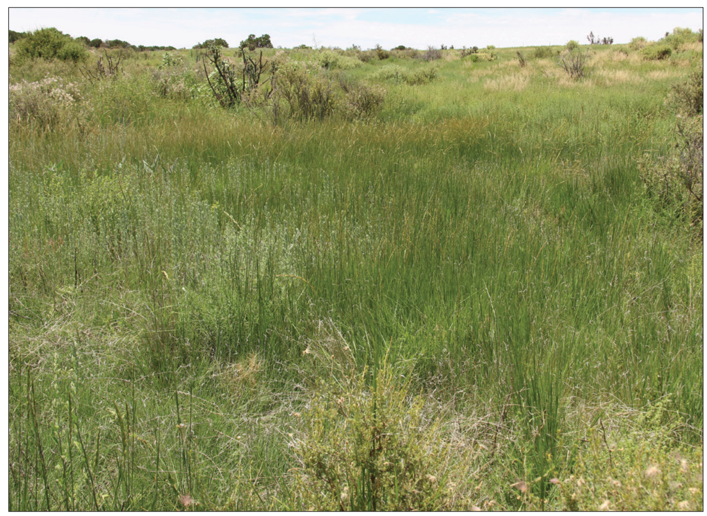


Figure 7. Post-treatment. Dominant vegetation consists of moist soil grasses (Western wheatgrass) responding to sheetflow distributed across the spread zone.

Figure 8. A microhabitat in a gully.

vegetation will take advantage of additional stored moisture and favorable growing conditions to increase plant species diversity, density and resiliency. Wildlife density and diversity can be expected to change as well. The gully section between structures could also be used as a mini-garden; providing a place to grow drought-tolerant crops.

Depending on the size and depth of the bay, this portion of the Plug and Spread structure could create its own unique wetland habitat. Also, vegetation types can be expected to vary between adjacent wetlands within a complex of structures due to different moisture regimes or soil types.

Carbon Sequestration and Carbon Offsets. There is increasing information supporting the importance of wetlands and hydric soils in sequestering carbon from the atmosphere, whereas the loss or drying of wetlands releases it (Ogle, Hunt, and Trettin, 2011).

Anyone considering a Plug and Spread project should evaluate the potential benefit to enhance carbon storage. Perhaps, someday moist soil management for the associated carbon storage benefits will be publicly supported and subsidized as an approved carbon offset measure.

Water—A Finite Supply. The supply of water available for restoration projects using Plug and Spread techniques is finite, extremely variable from site to site and from time to time, and usually subject to regulated use. Total discharge per storm event is dependent on many variables, including watershed size and condition, storm size and intensity, antecedent soil moisture conditions, seasonal variables and other factors. As a result, the expected benefits of a proposed Plug and Spread treatment may be difficult to predict and variable from year to year, but cumulative over the long run.

Water Rights. The planning and design of Plug and Spread treatments soon raises the question of water rights. This question must be resolved between the designer and landowner with appropriate legal advice as needed. Water rights laws differ between states and can be variously interpreted between river basins within states. In addition, landowners may have the option to change the point of diversion, for example, to redirect water use from a stock pond to use at the treated spread zone. Water rights issues, if any, must be addressed but do not change the validity of the Plug and Spread concept or potential land use benefits that might be realized by its application within the United States or more broadly. Also, initial reductions in discharge from a treated watershed may be offset over time with increases in base flow to the affected stream due to increased storage within the valley alluvium resulting from applied Plug and Spread treatments. As a result, effects upon water use and appropriation may be difficult to measure or assign.

Summary

Potential benefits of Plug and Spread treatments include:

- Returning sheetflow to formerly wetted land surfaces now drained by gullies
- Increasing the diversity, growth and density of vegetation on eroded surfaces
- Increasing the occurrence, size and distribution of wet meadows and wetland habitats
- Recharging shallow aquifers, wet weather springs and spring seeps
- Increasing base flow to receiving streams and tributaries
- Improving soil health and increasing the rate of carbon sequestration
- Increasing profitability for ranchers and farmers through increased forage yields and improved reliability
- Restoring or improving habitat for dependent wildlife
- Arresting gully formation
- Creating microhabitats within the bay and gully providing increased species diversity (both plant and animal)
- Enhancing scenic and aesthetic values

Possible detrimental effects may include:

- Increased surface erosion where water is concentrated and flow rates become accelerated before vegetative cover can respond (especially if compounded by overgrazing)
- Invading exotic vegetation which may colonize during construction. (e.g. plants propagated by windblown seeds, such as thistles, which can be especially problematic)
- Further dispersal of invasive species already present on the site
- Damage to roads, fences and infrastructure in places where water spreads across or saturates the land from below
- Loss of preferred forage species—such as Kentucky bluegrass, clovers or alfalfa—if the site becomes too saturated
- Soil too wet to graze or harvest hay

Although the Plug and Spread treatment is new, lacks scientific validation and has yet to stand the test of time, the treatment promises to help mitigate the predicted impacts of climate change. There is good reason to test the method and gain more varied experience in its use before these impacts increase.

CHAPTER 2
PLUG AND SPREAD KEY FEATURES AND TERMINOLOGY

Each Plug and Spread structure contains certain key features that determine its overall performance (Figures 9-10), and (Figure 11, page 8). The sizes, shapes and locations of these essential features will vary from structure to structure and site to site. Basic principles must be understood and adhered to when applying the Plug and Spread method.

Key Features

- A suitable location where the length and width of the spread zone can be maximized for the least cost
- A well-compacted plug and berm
- Appropriate height of the berm for adequate freeboard to prevent flows from overtopping the berm during flood events
- A shallow borrow area (bay)
- A wide, level brim installed at appropriate elevation to assure adequate freeboard
- A backfilled gully using soil gathered from the borrow area (bay) or other source
- Minimal storage, maximum spread

Terminology

Backfill. Backfill is material placed within the preexisting gully upstream from the plug. Backfill is usually excavated from the borrow source and used to render the ponded portion of the gully more shallow in order to minimize storage and create conditions favoring the growth and survival of wetland or riparian vegetation. Backfill should come from the borrow source (bay) above the brim elevation and not the gully wall.

Borrow Source or Bay. The plug and berm are built with fill material excavated from a borrow source. When flooded or ponded during a runoff event, the borrow source becomes a bay of the pond. Key features of the bay are its area, depth and brim elevation. For the purpose of this publication, the ponded area upstream of the plug can have one bay or two, depending on whether subsequent flows will be spread across one bank or both.

Berm. The berm is the portion of a plug extending above the gully banks and used to deflect flow onto the adjacent land surface. The berm assures that water does not spill onto the downstream side of the plug.

Figure 9. Key features of a typical Plug and Spread structure.

Brim. The brim is created during the construction of the bay or borrow source. It is the down valley edge of the bay which forms the spillway. Key features of the brim are its elevation, length and orientation perpendicular to the slope of the land that will be wetted by water spilling from the Plug and Spread structure.

Brush. Brush harvested from the bay can be used to armor the downstream side of the plug or gully banks where needed.

Ephemeral Stream. An ephemeral stream flows only for a short time, usually less than 30 days, and in direct response to overland flow resulting from a storm event or snowmelt runoff. Ephemeral stream beds and gullies are normally dry. In the southwestern United States, they may also be called arroyos. Most ephemeral streambeds are populated by upland plant species and do not always support riparian vegetation.

Freeboard. *For the purpose of this book*, freeboard is defined as the difference between the elevation of the brim and the elevation at the top of the berm (Figure 11, page 8).

Gully. An incised channel or water course, either naturally occurring or man-made, which has eroded the terrain and now flows below its natural surface elevation.

Headcut. A headcut is an advancing nick point created by the erosive force of falling water as it scours away soil that composes the affected streambed or the eroding landform. The height of the headcut at the nick point is usually determined by the depth of the gully. Headcuts advance up valley in direct response to the erosive power of successive flood events. The advance of a headcut can be controlled by installing features that resist erosion or lessen the scouring effect of the falling water.

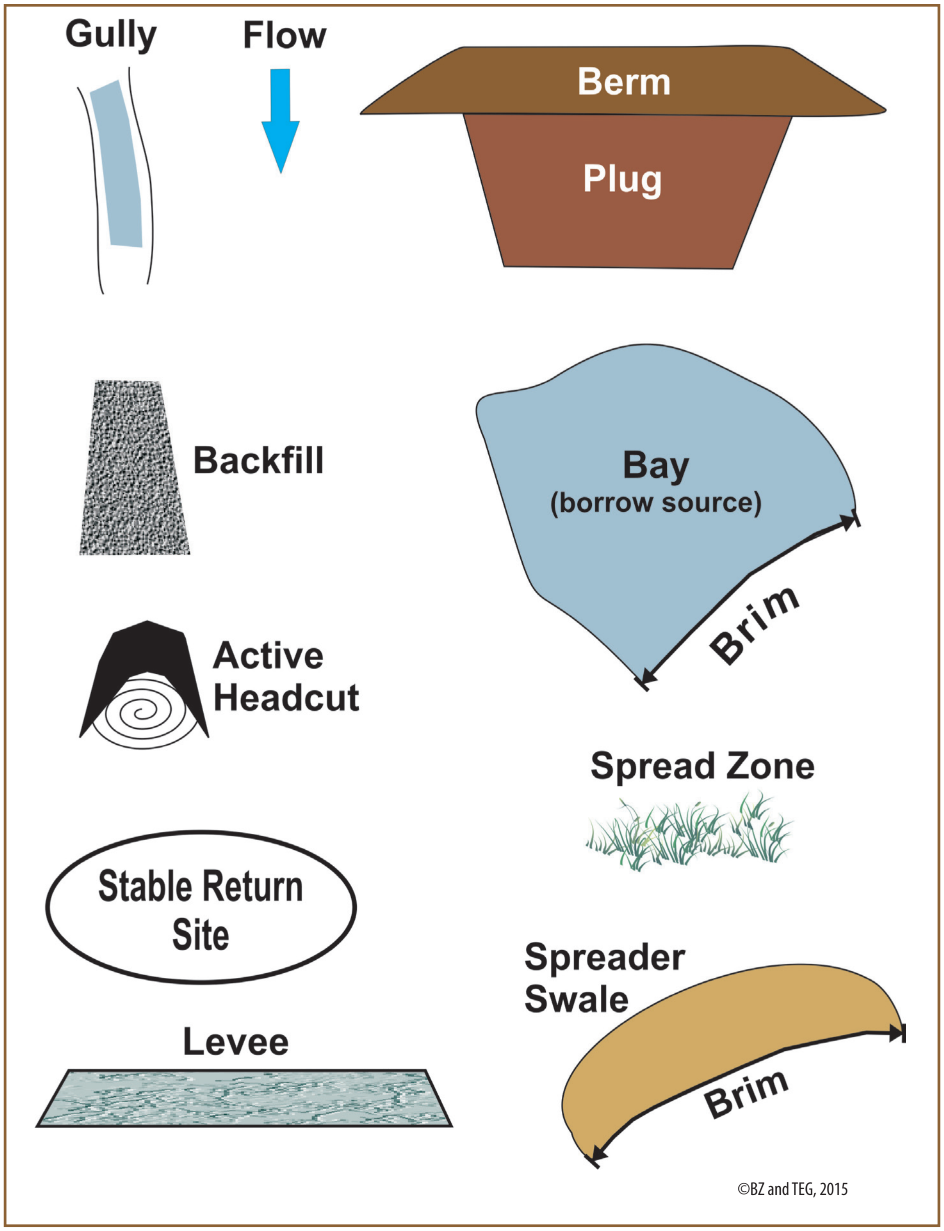


Figure 10. Legend. Plug and Spread schematics used in this publication.

Intermittent Stream. An intermittent stream normally flows for longer than 30 days but less than year-around and is fed both by storm events and base flow stored in adjacent valley alluvium. Intermittent streams may support riparian vegetation.

Levee. An elongated naturally occurring ridge or artificially constructed fill or wall that regulates water level. A levee is usually earthen and lies parallel to the course of the gully. Its purpose is to contain surface flows on the floodplain surface rather than within the gullied channel.

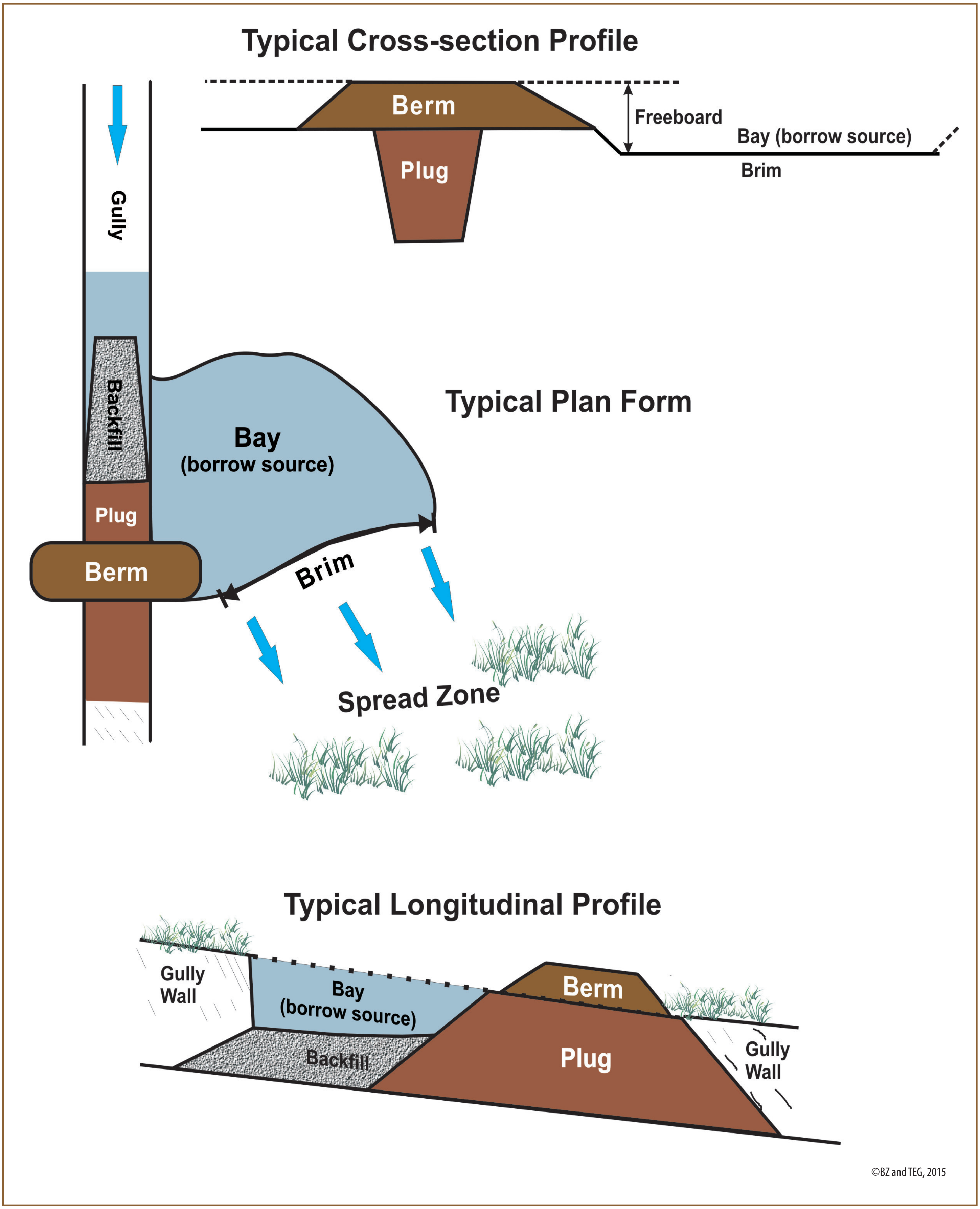


Figure 11. Schematic of a typical one-bay Plug and Spread structure in cross-section profile, plan form, and longitudinal profile.

Perennial Stream. A perennial stream is one that flows year-around but which may cease to flow as rarely as one year in ten. It may support a floodplain. Perennial streams are sustained by spring flow and base flow originating from valley alluvium and are populated by wetland species. Plug and spread treatments are only appropriate for ephemeral and intermittent stream systems, not perennial systems. With climate change, perennial streams may cease to flow more often and for longer periods of time, i.e., become more intermittent (National Climate Assessment, 2014).

Pond. The pond or ponded area includes the bay or bays and some portion of the gully upstream of the plug to the elevation of the brim. Placing backfill in the gully above the plug reduces the volume of water needed to fill the pond and hastens the loss to evaporation and seepage. Keeping the bay shallow serves to reduce ponding. Depending on goals and in the absence of water rights issues, it may be desirable to create a ponded area for wildlife or other purposes.

Plug. An artificial structure built of compacted soil used to block water flow within an incised channel or gully. As used throughout this publication, the purpose of a plug is to block stream flow within a gullied water course and reconnect that flow with surface or subsurface features that would be naturally wetted had the gully not evolved. The main purpose of a plug is not to impound water, but to redirect it, although some ponding may be unavoidable.

Spreader Swale. A spreader swale is a shallow, excavated depression used to temporarily impound and redirect sheetflow across the spread zone. Spreader swales are normally much longer than wide and aligned on the contour, that is, perpendicular to the direction of flow.

Spread Zone. A spread zone is the land surface down valley from the plug that is subjected to sheetflow caused by water diverted across the valley floor by the plug and passing over the brim of the bay. The goal of the Plug and Spread structure is to create a broad and effective spread zone subject to periodic flooding by water deflected from the treated gully.

Stable Return Site. A stable return site is a natural or constructed feature that resists the erosive force of falling water and thus prevents formation of a headcut at the point where sheetflow returns to the gully or incised channel. A stable return site can be exposed bedrock, boulders, a willow thicket, ponded water or other natural features that resist erosion. Or, it can be a constructed feature such as a Zuni Bowl, one rock dam, rock rundown or a lay-back rock structure (see page 21). Selecting or constructing a stable return site, or sites, is essential to a successful Plug and Spread project.

Taper. The taper adds mass to the plug and helps to stabilize the upstream and downstream edges against slumping and trampling by livestock or wildlife (Figure 12).

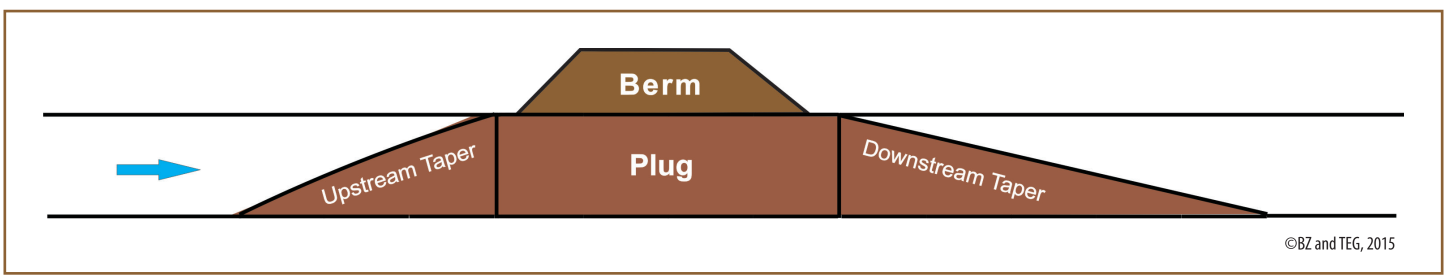


Figure 12. Upstream and downstream taper of a gully plug.

CHAPTER 3
SITE ASSESSMENT AND READING THE LANDSCAPE

Plug and Spread treatments are appropriate for broad floodplains and alluvial fans that have been eroded by gullies resulting from various human activities. Care should be taken when applying a Plug and Spread treatment where the valley slope is greater than 3 percent. If the land surface is well vegetated, especially with grasses and grass like species, steeper slopes may be acceptable. Site selection for individual structures or groups of structures requires a careful assessment of on-the-ground conditions and the ability to recognize the effects of past uses. Land uses which have caused or which contribute to gully formation include roads, abandoned roads, livestock trails and abandoned irrigation ditches. Read the landscape!

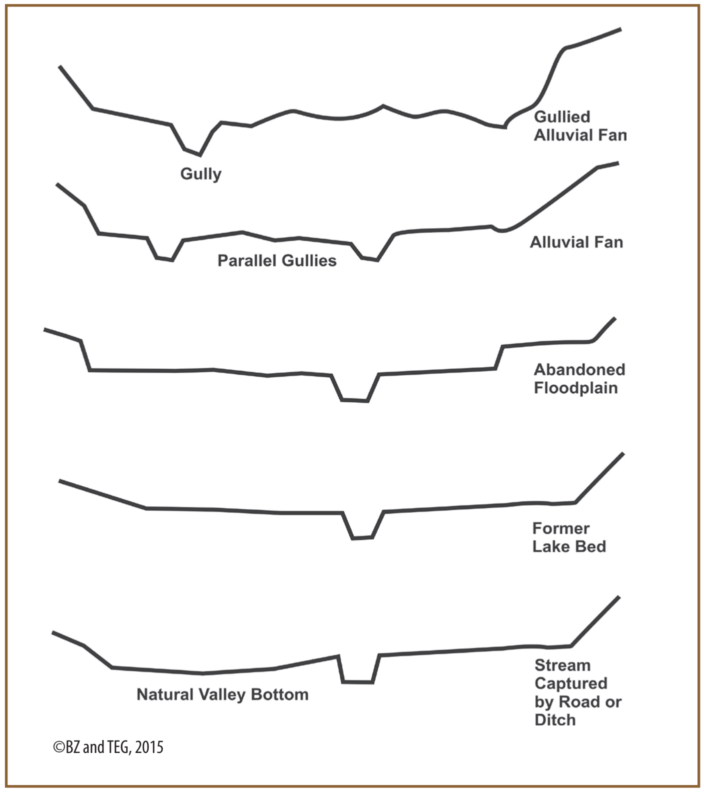


Figure 13. Valley cross sections ***suitable*** for the Plug and Spread treatment.

This Type of Treatment is Appropriate for:

- Alluvial fan and other floodplain surfaces that were originally created by perennial or intermittent streams but are now dissected by gullies or deeply incised ephemeral and intermittent channels
- Former wet meadow locations as indicated by typical soil profiles or the presence of moist soil indicator and transition species. Seek professional assistance in preparing a species list appropriate to your area for use in identification of indicator species.
- Gullied sites damaged by abandoned irrigation ditches, old roads and cartways, livestock trailing or deliberate land drainage projects (Figure 13)

Evidence supporting one or more of these conditions is usually apparent at sites and land forms suffering from downcutting, eroding surfaces, and headcut proliferation.

This Type of Treatment is Not Appropriate for:

- Perennial channels and wetlands
- Narrow floodplains
- V-shaped or bowl-shaped valleys where the land surface slopes toward the gullied channel rather than parallel to it (Figure 14).

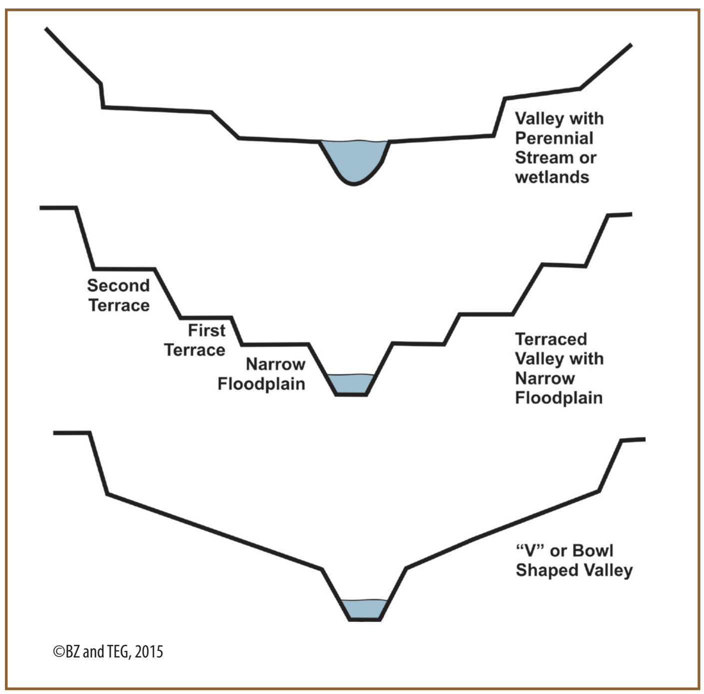


Figure 14. Valley cross sections ***not suitable*** for the Plug and Spread treatment.

Key Questions to Consider

- Is this a formerly hydric soil? Is this a soil that developed under saturated conditions but is now drained (typically dark in color and high in organic content)? A formerly hydric soil may be buried under a thin layer of recently deposited mineral soils washed in from an upland source.

- Is the natural channel alignment or former channel alignment visible on site? How does the present gully system relate to the natural alignment? Human-caused gullies are often deeper, straighter and steeper than natural channels and are not in the valley bottom.
- How does the width of the active gully compare with the breadth of surface that might be wetted? To be economical, the width of valley surface to be wetted should be at least 6 times the width of the gully to be plugged.
- Where is the water coming from and what is the sediment supply? An abundant sediment supply will quickly fill the plugged gully.
- How deep is the gully? The deeper the gully, the more costly the treatment and the higher the probability that the water will be permanently ponded rather than temporarily detained.
- Would a series of structures increase the benefit of treatment over a single structure?
- Is there a stable return site? A stable natural return or constructed return site will be needed to prevent or control potential erosion caused by re-routed flow on the spread zone surface.
- Are suitable materials available on-site to construct a stable plug? Loam, clay, and clay loams are acceptable. Sand, gravel or sandy loams are not acceptable.
- Are there possible limitations on operation or use of equipment? Difficult access? Excessive soil moisture? Other?
- Are there potential impacts to existing infrastructure such as roads, stock tanks, houses, barns or fences? Will traditional, social or economic uses of the sites be affected? For example, a Plug and Spread project might cause a stock tank to not receive water as customary.
- Would neighbors welcome changes resulting from the proposed project?
- Are there legal requirements regarding dam safety, water rights, endangered species or archeological resources that might be required? Once planning is complete, it will be necessary to secure required federal, state and local permits before construction begins.
- The use of Google™ Earth Pro and/or Light Detection and Ranging (LIDAR), may be very helpful in the identification and evaluation of alternative sites or groups of sites.

Plug and Spread treatments can diversify and improve habitat for many species of wildlife both seasonally and spatially. Spread zones can provide nesting habitat or brood rearing habitat rich in the forbs and insects that are important to such species as sage grouse, wild turkey and scaled quail. They also offer attractive nesting habitat for migratory birds. The same areas can provide early spring forage rich in essential nutrients for elk, mule deer, and white-tailed deer.

Bays and ponded areas can be seasonal water sources for big game species as well as key feeding areas for birds such as the common snipe. In spring, northward bound waterfowl such as pintails, widgeons, mallards and teal will use any resulting seasonal "pop-up" wetlands for feeding and pair bonding prior to their arrival on more northerly breeding areas. Because ponded areas will dry quickly, they have little value to waterfowl for nesting or brood rearing purposes.

Amphibians (frogs, toads and salamanders) may use a Plug and Spread location for breeding in areas where tadpoles can mature with minimal predation loss. Water seeping back into treated gullies may provide key habitat and water sources for many species.

Economic and Environmental Benefits

If the restoration goal is environmental, the benefits may include: wetland/riparian restoration, wildlife habitat improvement, groundwater recharge, flood attenuation and abatement, base flow augmentation, and improved water quality. Many of these benefits are difficult to translate into dollars but are very real nonetheless. The cost of achieving these environmental benefits might be justified in instances where the cost of additional forage production for livestock use would not.

Environmental benefits may be variously priced according to the values assigned by the funding agency or organization. In that case, the cost of Plug and Spread treatments would be evaluated against the cost of alternative treatments that might be used to accomplish similar objectives in the same area. For example, how would hand-built rock erosion control structures compare in cost to Plug and Spread treatments? How would the purchase and delivery of rock and other materials, labor, travel and overhead compare with the cost of equipment used to install a Plug and Spread project?

CHAPTER 4

PLANNING AND DESIGN

Proper planning and design is the key to a successful Plug and Spread project. Take the time to fully consider all aspects of each potential site and how it might relate to other possible structures in the complex. Remember that the spread zone, not the structure, is the primary producer of the desired economic and environmental benefits. How can you create the most effective spread zone area for the least cost? What kinds of equipment will be needed and what limitations on equipment use will need to be accommodated? What other issues or concerns must be addressed?

Number, Type and Placement

- Read the landscape—study the landforms and drainage patterns. What areas were naturally wetted by sheetflow or overbank flooding before channel incision, gullying or manipulation drained them?
- Assess the likely effects of a proposed structure and its potential to modify the landscape in a positive or negative way. Imagine different locations, different sized structures and the potential spread zones resulting from each treatment.
- Where might the water spread and what landforms would benefit from periodic inundation?
- Were the areas to be treated periodically flooded prior to gully formation? Examine the soil profile for evidence of prior flooding, including hydric soils, stratified alluvial deposits or remnant indicator vegetation.
- The goal is to recreate hydrological conditions that were natural to the site prior to drainage, not to irrigate an upland area that was never wet, as evident in the absence of hydric soils or indicator plant species.
- In any given arid location, there is a finite supply of water. When selecting potential Plug and Spread sites or site complexes, do not over-commit. Choose the sites that make the best use of expected water supplies.

Freeboard Height versus Length of Brim

- A Plug and Spread structure must be constructed to accommodate high flows and high velocity flood events by spreading water broadly across the spread zone without overtopping or eroding through the plug and berm. Therefore, the height of freeboard is directly proportional to the length of the brim…both of which are related to the Velocity (**V** feet per second) and Discharge (**Q**, cubic feet per second) of the gully and the valley (Figure 15). Another equation to compute runoff is provided by the Natural Resources Conservation Service and uses the NRCS Curve Number (CN), which is based on soil permeability, surface cover, hydrologic condition, and antecedent moisture. Download this software at *http://www.ars.usda.gov/services/software/download.htm?softwareid=8*
- The suggested minimum height for freeboard is 1 foot, but it is best to compute freeboard height if the brim length is known (Figure 16).
- The brim length should be as long as necessary to wet the desired spread zone area.

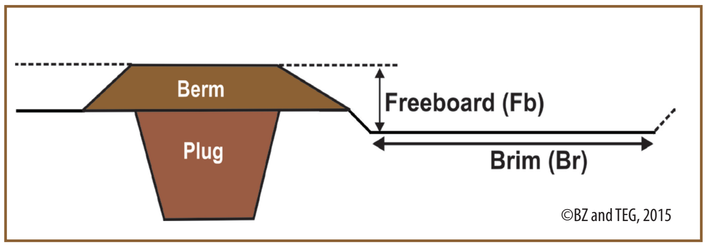


Figure 16. Freeboard and brim cross-section schematic.

- The longer the brim, the greater the confidence in the capacity of the freeboard.
- If the length of the brim is too short, be prepared to create a higher freeboard. The berm must be raised and both plug and berm must be armored with rock to withstand erosion or overtopping during larger flood events.

Soil Types. Before proceeding with design and construction, it is important to determine whether the local soil type has sufficient moisture to achieve adequate compaction. Soils high in sand or gravel cannot be compacted, nor can dry soils. In-hauled material may be needed to construct an impervious core in the plug or to insure compaction. Plan on using a water truck to gain adequate moisture for compaction if the soils are too dry to compact.

Measurements you may need to calculate the height of freeboard:

- Flow area of the gully (square miles)
- Percent Gully Slope (S)
- Gully Height (Gh) in feet
- Gully Width (Gw) in feet
- Maximum height of high water mark (Hhw) in feet
- Valley Width (Vw) in feet
- Brim Length (BrL) in feet
- Velocity (feet per second)
- Discharge (cubic feet per second, cfs)

CALCULATE THE RELATIVE VELOCITY AND DISCHARGE USING MANNING'S EQUATION CALCULATORS
http://www.lmnoeng.com/manning.php

NOTE: For the purpose of this book, **freeboard** is defined as the difference between the elevation of the brim and the elevation at the top of the berm.

$$V = \frac{k}{n}\left(\frac{A}{P}\right)^{2/3} S^{1/2}$$

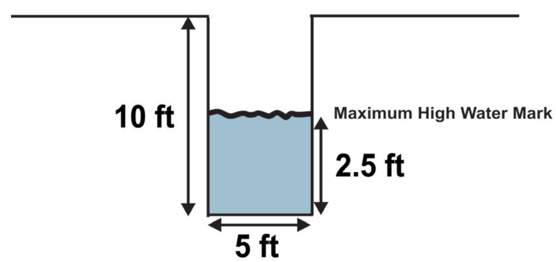
- **k** is a unit conversion factor: k=1.49 ft
- **A** = Flow area of the gully
- **P** = Wetted perimeter which is the portion of the circumference that is in contact with water
- **Q** = Discharge (flow rate)
- **S** = Downward (longitudinal) slope of the gully
- **V** = Average velocity in the gully
- Manning "***n***" = varies with the roughness of the gully. The higher the ***n***, the rougher the material. *http://www.lmnoeng.com/manningn.htm*

Natural Stream		Excavated Earth Channels	
Material	**Manning "*n*"**	**Material**	**Manning "*n*"**
Clean and Straight	0.030	Clean	0.022
Major Rivers	0.035	Gravelly	0.025
Sluggish with Deep Pools	0.040	Weedy	0.030
		Stony, Cobbles	0.035

COMPUTE HEIGHT OF FREEBOARD
EXAMPLE:

1. **Use Manning's equation to calculate the velocity and discharge of the gully.**
   - k = 1.49
   - Known–slope (S) of gully, 2% (0.02)
   - Known–gully bottom smooth, Manning "***n***" = 0.025
   - Known–width of gully, 5 ft
   - Known–height of gully at berm location,10 ft
   - Known–maximum height of high water mark in gully, 2.5 ft
   - **Calculate Area of gully** (A):
     5 ft (width) * 2.5 ft (Hhw) = 12.5 ft^2
   - **Calculate the Plugged Gully Wetted Perimeter in feet** (P):
     2.5 ft (Hhw) * 2 + 5 ft (width) = 10 ft
   - **Calculate velocity** (ft/sec):

Gully Cross-section



$$V = \frac{1.49}{.025}\left(\frac{12.5}{10}\right)^{2/3} 0.02^{1/2} = \sim 9.8 \text{ ft/sec}$$

2. **Calculate Discharge where Q = VA**
   - 9.8 ft/sec ∗ 12.5 ft^2 = 122 ft^3 per second (cfs) of water coming down the gully at flood stage

3. **Calculate Sheetflow–Valley Velocity (VV)**
   Sheetflow is defined as flow over plane surfaces. Due to a myriad of factors, sheetflow can be complicated to calculate. The Natural Resources Conservation Service (NRCS) has provided a method in the publication TR-55, "Urban Hydrology for Small Watersheds." You can also find equations and calculations at *http://culvertdesign.com/how-to-calculate-sheet-flow*

   Since Valley Velocity (Vv) (sheetflow) will always be less than the gully's flow velocity, you could use an assumed measurement to calculate Valley Velocity (Vv) — *assume* **valley velocity is 1/5 that of gully velocity (V).**
   - **Using this assumed measurement and continuing our example, valley velocity (Vv) would be 9.8 ft/sec X 1/5 = 2 ft/sec (Vv).**

4. **Now, calculate height of freeboard (Fb) where Fb = Q/Vv/BrL**
   - Brim Length (BrL), 41 feet

$$\frac{122 \text{ ft}^3}{\text{sec}} \Big/ \frac{1 \text{ sec}}{2 \text{ ft}} \Big/ 41 \text{ ft} = 1.5 \text{ ft of freeboard}$$

Freeboard and Brim Cross-section

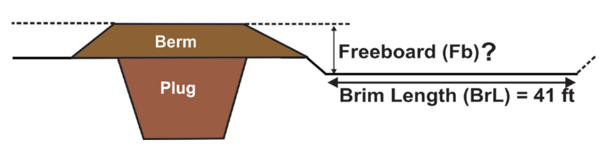


Figure 15. How to calculate height of freeboard if the brim length is known.

Alternative Plug and Spread Layouts. Plug and Spread structures should be configured to fit the landscape and goals of the restoration project. The following are examples of alternative designs for a Plug and Spread structure:

- A one-bay structure can serve as a headcut control device by matching the brim elevation to the headcut lip elevation (Figure 17).
- A one-bay structure can reconnect an active gully with an abandoned natural channel (Figure 18).
- A one-bay structure can spread water from a tributary gully onto a spread zone above the main channel (Figure 19).
- A two-bay structure can spill water onto both sides of the valley (Figure 20). Length of brim can be proportionate to the desired flow distribution for each side of the valley.
- A two-bay structure that gathers the combined flows originating from two or more parallel gullies can route the combined flow across a single spread zone (Figure 21).
- A simple spreader swale may be used on smaller, more shallow gullies or to disperse flow more widely below a structure (Figure 22).

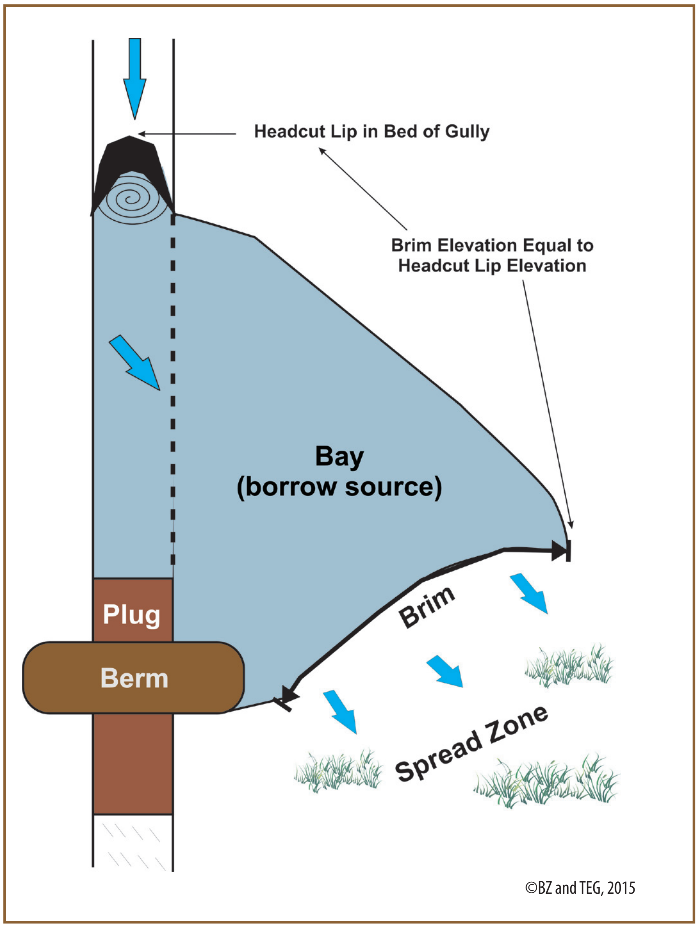


Figure 17. A one-bay structure used to control a headcut in a gully.

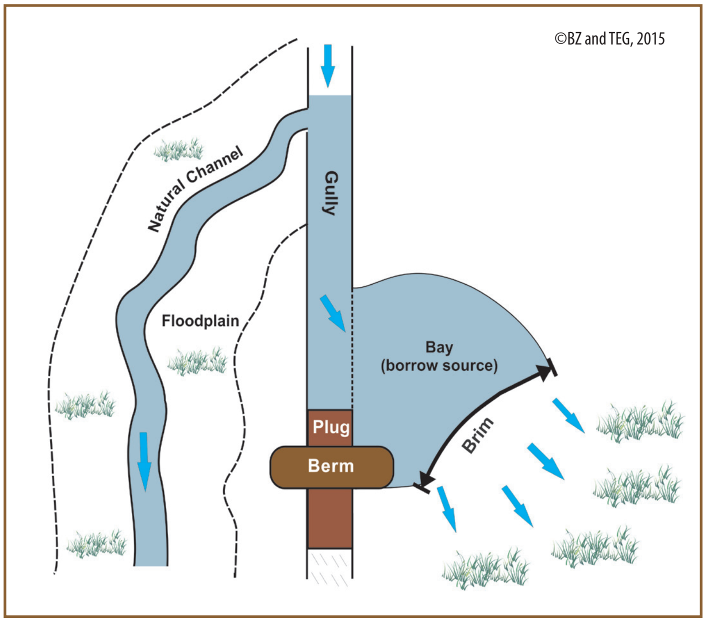


Figure 18. Plug and Spread structure sized to reconnect a gully with its natural channel and floodplain.

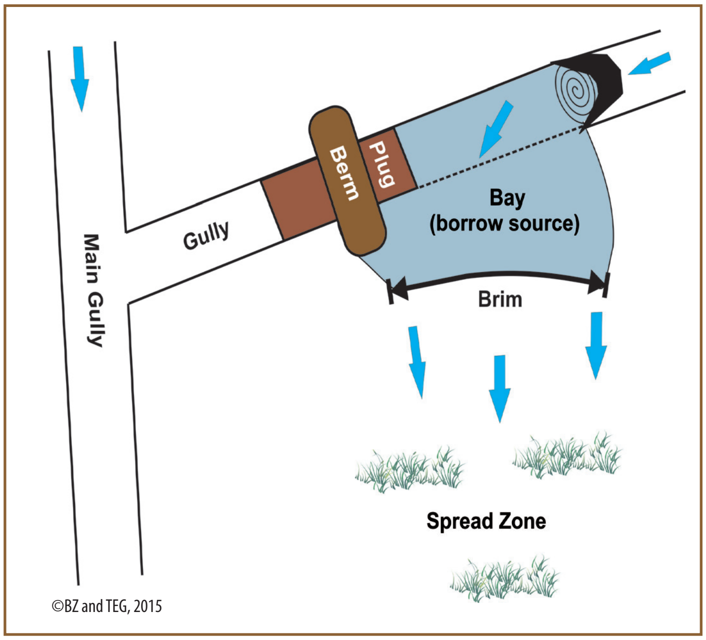


Figure 19. Typical design of a Plug and Spread for a tributary gully.

Other Considerations

- Can any other structure or structures be used to control a headcut or headcuts?
- How could a Plug and Spread structure be used in conjunction with other restoration treatments to mitigate or accommodate other improvements? For example, installing a porous-fill road crossing, a raised culvert or raised culvert inlet may enable the re-wetting of a potential spread zone.

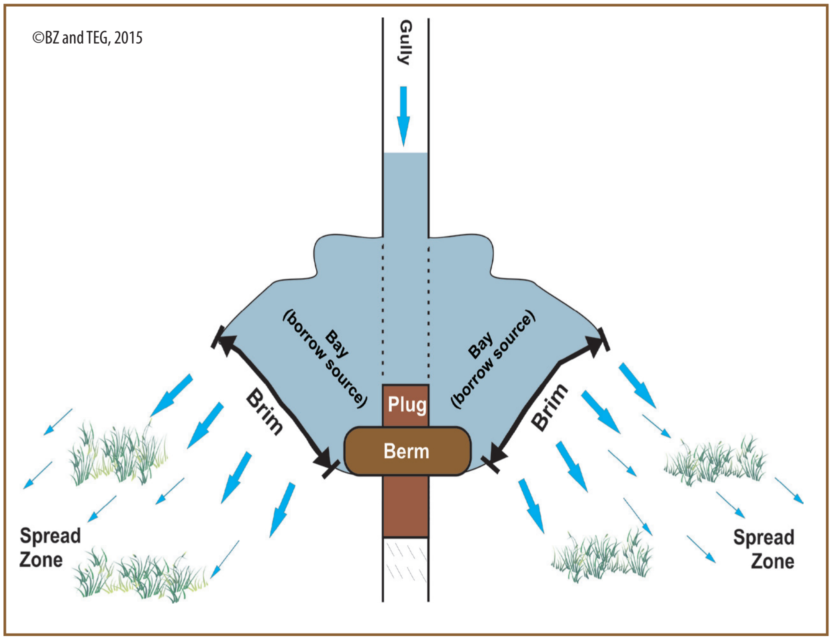


Figure 20. A two bay structure that spreads water to valley right and valley left.

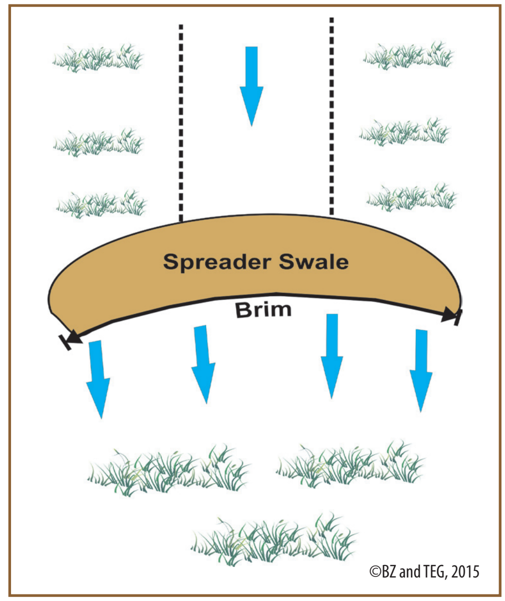


Figure 22. Use a spreader swale to spread flow more widely.

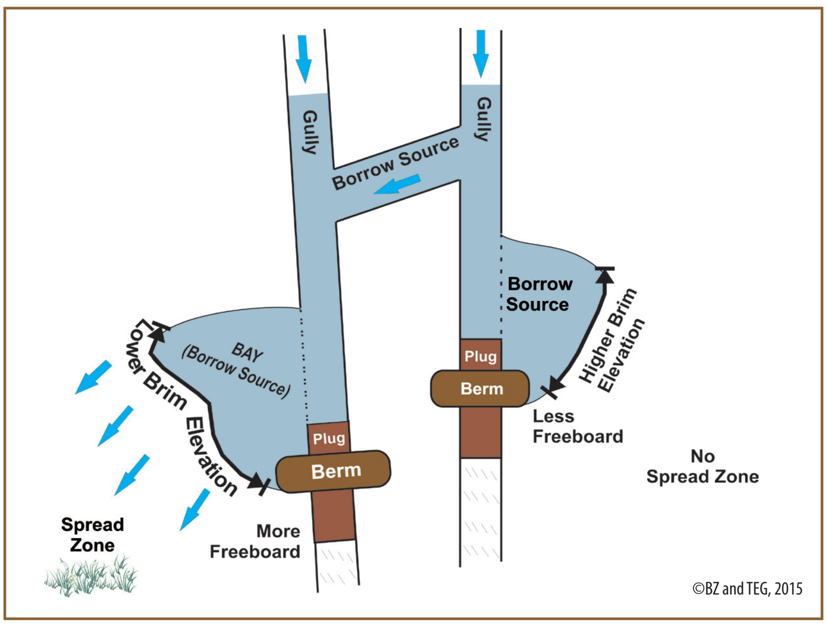


Figure 21. Plugged parallel gullies with a single outlet as used to spread water to only one side of the valley.

- Each Plug and Spread structure, or complex of structures, must be linked to a stable feature that will eliminate the potential for a new headcut by safely returning runoff from the spread zone to the channel. Examples of an existing stable return feature include exposed bedrock in bed and banks, boulder-lined gully banks, a beaver pond, a low-water road crossing, a culverted road crossing, or a gently sloping bank well vegetated with willows (Figure 23, page 16). A constructed return site might include a Zuni bowl, a rock rundown, or other treatments (Figure 24, page 16). Any feature that is not easily eroded will do. ***Spilling the water over a vertical gully bank onto easily eroded material such as clay, silt, sand or gravel, is an example of what NOT to do.***
- No two sites are alike. Consider what can be gained from various treatment combinations. This is the time to get creative. Try to anticipate potential problems and address them before they happen.

Multiple Structures Built as a Series or Complex

In a complex of Plug and Spread structures, each will relate to the one above and the one below. The upper structure detains runoff, losing some flow to seepage (recharge of the shallow groundwater aquifer) and evaporation. Each structure delays arrival of flow to the next downstream structure. The lower structures **will not** collect flow from above until the upper bay(s) fill and redistribute runoff across the spread zone(s) below (Figures 25, page 17 and Figure 26, page 18). Spreading the flow will further delay the flood peak and reduce its crest. This effect will magnify until the discharge from a given event is used up or until water spills across the stable flow return. Be sure to spread the flow as widely as possible. Response at each site will depend on minor surface variations, soil porosity, species diversity, plant densities and other variables.

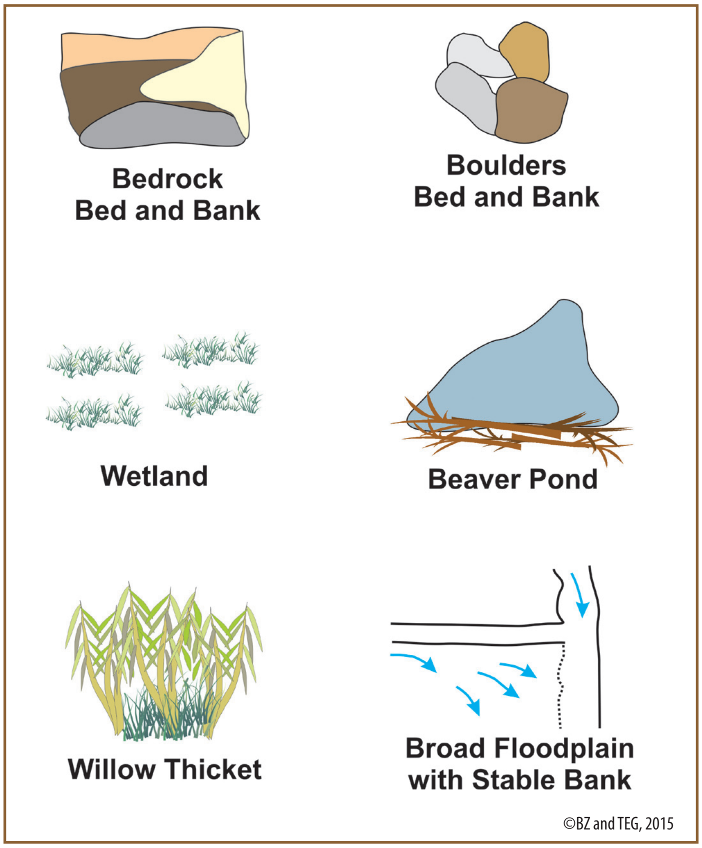


Figure 23. Examples of natural or pre-existing stable return sites.

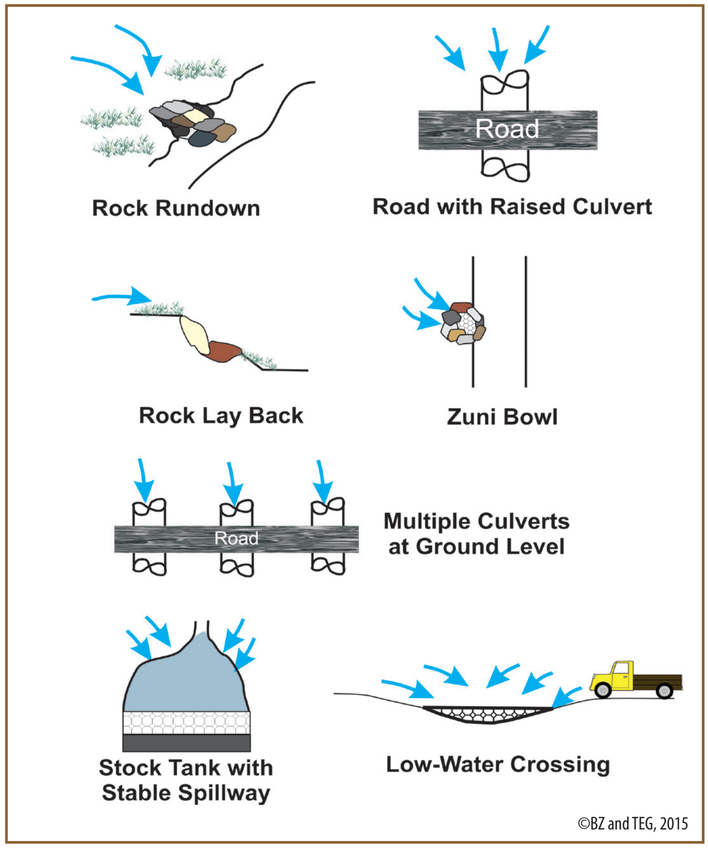


Figure 24. Examples of constructed stable return sites.

Designing a Plug and Spread Complex

- Choose the most effective location; simply moving a structure a short distance up or downstream can make a big difference in the area of the spread zone affected by a single structure.
- Map all suitable structure locations and determine whether additional information is needed about any candidate site before making the final selection. Google™ Earth can simplify the mapping task.
- Consider which locations will yield the most value (widest spread zone for smallest structure and least cost).
- Total runoff from an average storm or snowmelt event is limited, but with climate change, total discharge from maximum flood events may greatly increase, and this will require greater floodplain capacity.

Auxiliary Treatments in the Spread Zone. Different types of auxiliary treatments can be used to widen the path of runoff across a spread zone. These include keyline plowing, spreader swales, rock spreader devices such as media luna (tips up), and rolling dips (Figure 27, page 18 and Figure 28, page 19).

- Keyline plow treatments, on the contour, can be used to cause runoff to more easily infiltrate into the soil , linger longer on the wetted surface and/or shape the landscape to lead runoff outward to the edge of the hillslope to saturate a wider area Rock rundowns and one rock dams may be used to stop small headcuts and stabilize evolving gullies within the spread zone.
- Media luna and rock spreader structures can be used to disperse sheetflow more widely.
- If livestock or elk trailing is creating gullies, drift fences can be built to redirect the trailing pressure to less vulnerable areas.
- The site could be reseeded using species better adapted to variable soil moisture conditions.
- Change the timing, frequency or intensity of grazing use to favor desired plant species. If the unit is wetted primarily by snowmelt runoff, schedule grazing entry to maximize stubble height at the end of the growing season. Do not graze during the dormant season.

  If the unit is primarily wetted by monsoon events, schedule grazing to maximize stubble height by the peak of monsoon season. Permit dormant season grazing, assuming that spring and early summer plant growth will restore desired stubble height.

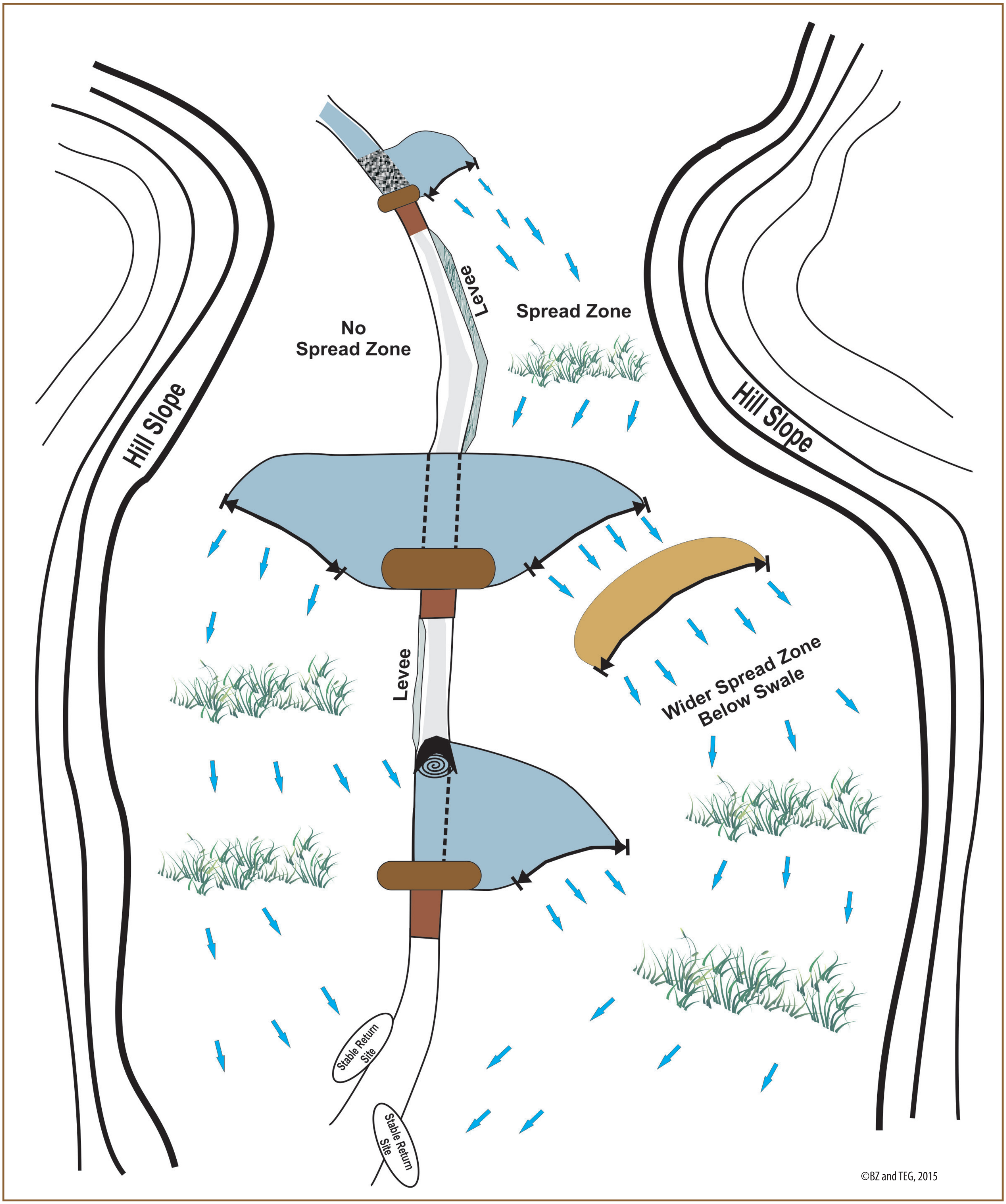


Figure 25. A typical Plug and Spread complex.

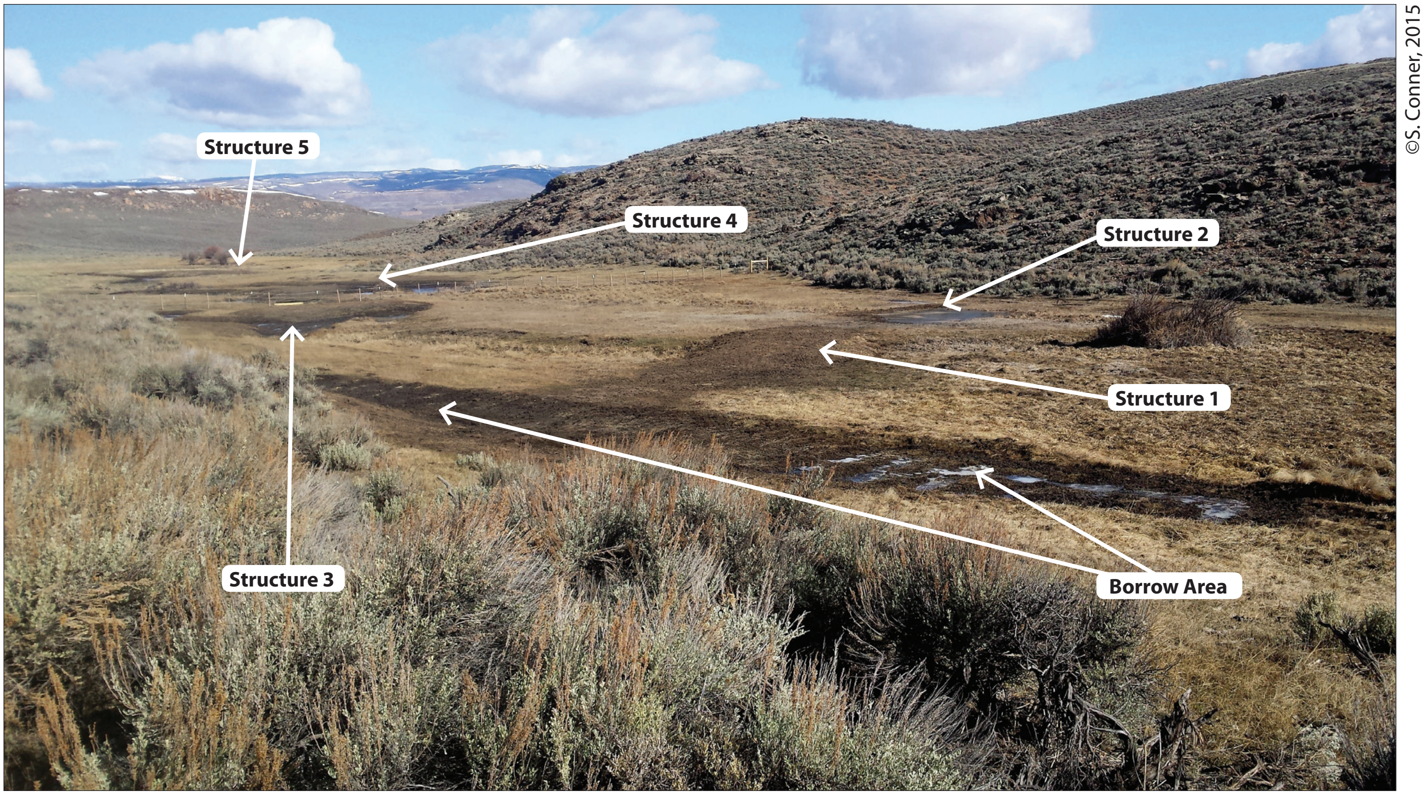


Figure 26. A completed Plug and Spread complex after the first snowmelt event, Colorado.

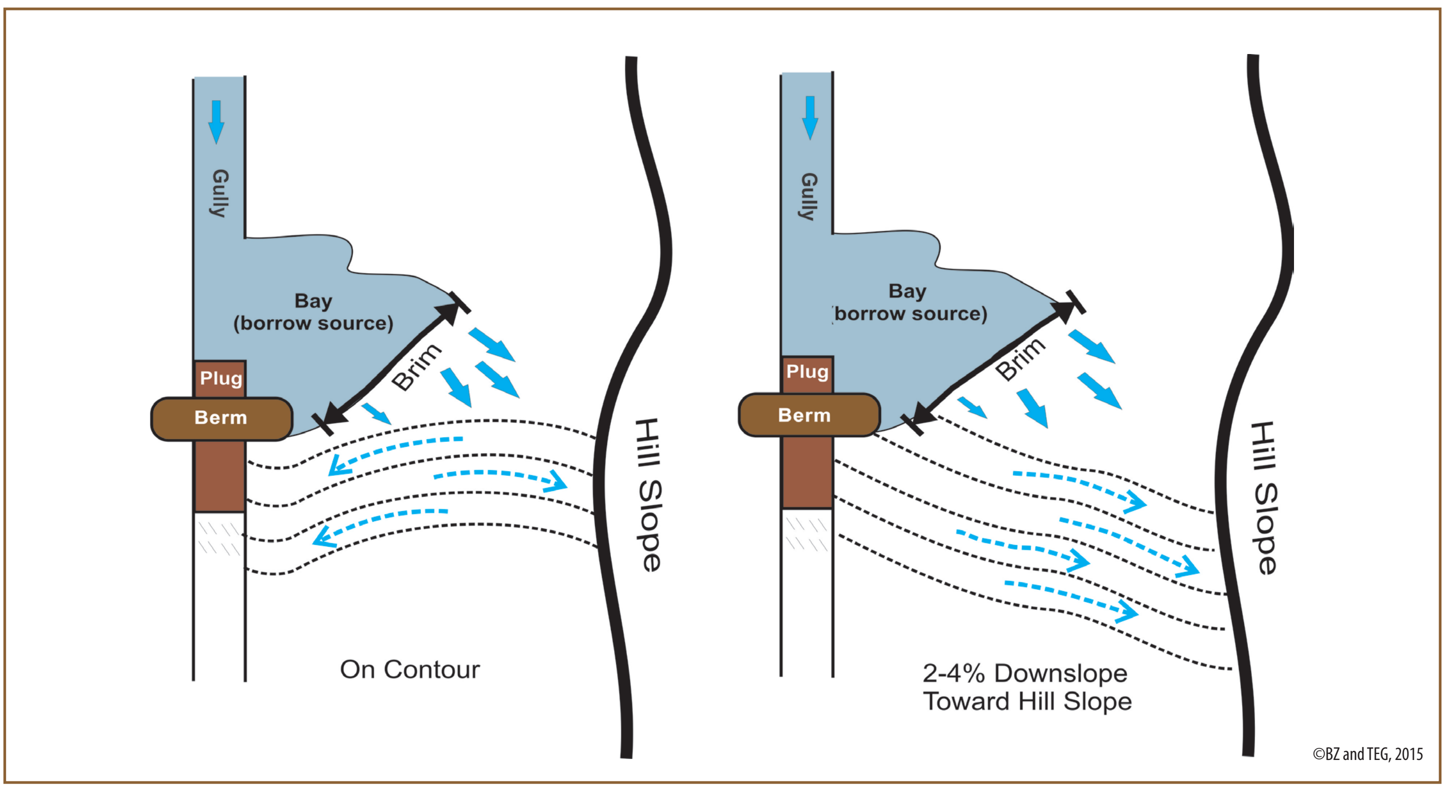


Figure 27. Keyline furrows to spread sheetflow.

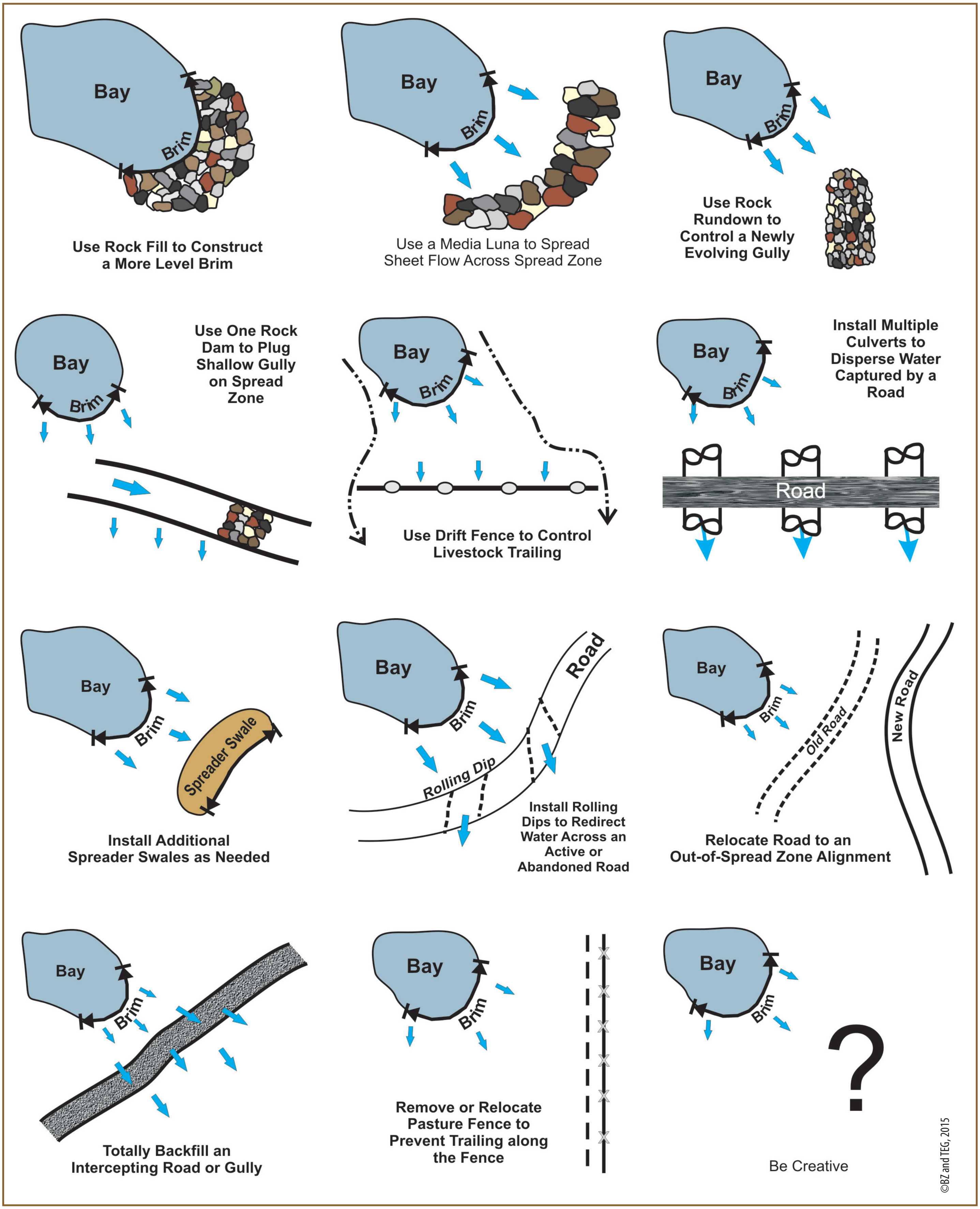


Figure 28. Spread zone treatments that can be installed during initial construction or built later as needed. (Arrows indicating the location of the brim are conceptual; actual shapes and dimensions will vary by site.)

Design Considerations

- Design for the maximum spread zone. The goal is to spread flood flows across the valley floor, not to maximize storage.
- Design for optimum capacity with climate change and the potential for more intense flows in mind. For example, a 50-year flow event versus a 20-year event.
- Make the pond as shallow as feasible, not as deep as possible.
- Build a brim that is level (not tilting to one side). If the brim tilts, flows will concentrate at the low point and create surface erosion leading to gully formation and head cutting.
- Armor vulnerable brims and berms with rock (4-6 inches in diameter).
- Route the water to a return site that can be stabilized and protected from erosion. Levees may be needed to keep water on the floodplain surface (Figure 25, page 17).
- Re-vegetate disturbed soils as soon as possible! Mulching may aid in seed germination success.
- Control invasive species. If invasive species such as Russian olive or tamarisk are present on site, control efforts prior to construction must be timely and effective. It may be necessary to seek expert advice before proceeding.

Permits and Clearances. Various federal, state, tribal and local laws or regulations may apply to planning, design and application of a Plug and Spread project. Within the United States, these include the Clean Water Act, administered by the United States Army Corps of Engineers (USACE); the Endangered Species Act, administered by the US Fish and Wildlife Service (USFWS); the Antiquities Act, administered by the New Mexico State Historic Preservation Office, and local zoning regulations administered by the city or county. For sites affecting "Waters of the United States," it is best to inquire with the local office of the USACE early in the planning process to determine if the channel in question falls under the agency's jurisdiction, and then proceed accordingly. Similarly, it may be necessary to consult with the USFWS to gain advice regarding the presence of listed threatened or endangered species or to consult an archeologist to assess potential effects upon archeological resources. If the proposed project will be implemented using federal funds, the above planning requirements are mandatory, and permits must be obtained. The likely effects of a proposed project will be variously interpreted from place to place based on the on-site situation and applicable regulations. Field visits to past projects may help to familiarize regulatory officials with the use and application of treatments and the likely results to be derived from proposed actions. Such a visit could help to expedite the permitting process.

Timing of Installation. When implementing a Plug and Spread project (including determining the number, size and locations of structures that make up the entire complex), timing, soil moisture, rainfall and vegetation cover are of utmost importance. If moisture content is not sufficient to achieve proper compaction, it may be necessary to wait for increased moisture following snowmelt or the rainy season or to rely on a water truck to wet down the plug and berm during construction. It may be possible to dredge moist soil suitable for compaction from the bed of the gully. If this is done, then the pit created should be backfilled from the borrow area once the plug has been completed.

In a **monsoon-driven system**, the best time to build a structure would be in the spring or late fall. If building in the spring, the soil will be moist from winter precipitation and there will be time to grow vegetation before the summer rains come. The risk of building during the monsoon season would be the potential for flooding during construction.

In a **snowmelt-driven system**, the best time to build a structure is July and August. There will be moisture in the ground from snowmelt and time to grow vegetation to stabilize the structure before winter. It will then be ready for the next spring runoff event to spread the water across the meadow surface (Figure 29).

For best results, each treatment must have time for vegetation to grow before it is tested by a high water event. Treated sites can be reseeded with annuals like oats, wheat or rye grass, or a native sunflower mix. These will germinate quickly and are drought tolerant. The goal is to jump start ecological succession and hold soil in place. The landowner may need to manage for exotic species, but having ground cover is better than no cover. Remember that restoration is a long-term process.

On lands that are grazed by livestock, it is also important to manage grazing to maximize stubble height at the time of runoff. The more dense and tall the vegetation, the slower the runoff will be over the spread zone, thereby increasing infiltration and sediment deposition. Livestock managers should consider using portable fencing to exclude grazing, using an alternative pasture, or deferring grazing altogether until disturbed soils revegetate.

Other considerations for time of implementation may include seasonal recreational uses and use by wildlife species sensitive to human disturbance.

	Snowmelt-Driven System	Monsoon-Driven System
Active Growth Season	April-September	March-April-May (cool season grasses) July-September (warm season grasses)
Dormant Season	October-April	October-March
When to Graze	May-June-July	September-March (appropriate timing, intensity and duration)
When to Defer Grazing	August-September-October	March-June

Figure 29. Scheduled grazing for maximum stubble height at time of runoff for Southwest grazing lands.

Examples of auxiliary structures.

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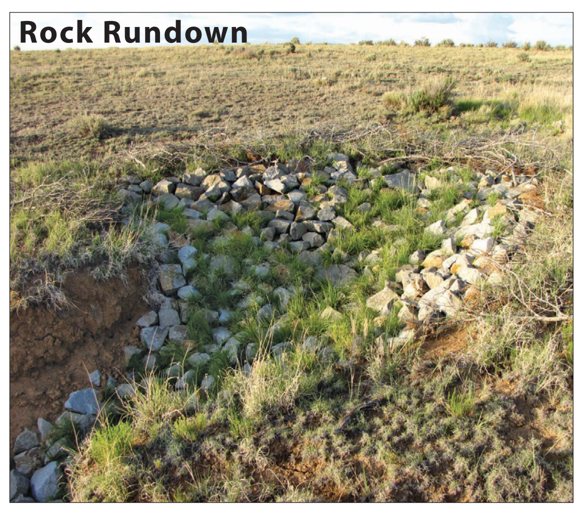
Karen Menetrey, 2014 (NMED-SWQB) 2009



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CHAPTER 5
IMPLEMENTATION

Each step in the implementation process should be completed carefully and deliberately with the full mutual understanding of the equipment operator, designer and landowner. Careful attention to detail will help to assure proper long-term function of the Plug and Spread structure.

It's a Team Effort. It is very important to develop a good working relationship between the designer, the equipment operator and the landowner. The operator must understand all of the steps along the way and the desired outcome. The designer must understand the capabilities and limitations of the machinery and welcome the knowledge and skills that the operator can bring to the process. The landowner must have confidence in all aspects of the project and express any concerns before structures are built.

Prepare a Treatment Plan Defining the Order of Work

- Have plans in hand ready to go and on site including all necessary permits.
- Mobilize equipment appropriate to that project. This may include:
  - Dozer with ripper, appropriately sized for the job
  - Tracked skid steer
  - Loader or backhoe
  - Roller
  - Water truck
  - Laser level
  - Stakes
  - Measuring tape
  - Paint
  - Flagging
  - Pin flags
  - Seeds
  - Rake
- Have the operator and designer on site at the same time to discuss construction guidelines.
- Stock-pile any in-hauled materials needed for backfill, berm, mulch, rock armor, etc.
- Stake strategic points, elevations, and dimensions before earth work begins.

Preconstruction Visit. The project designer should carefully review and thoroughly discuss all aspects of project construction with the equipment operator and landowner. The discussion should cover project layout (purpose and location of structures), soils, soil moisture requirements for proper compaction, dimensions of the plug and borrow areas, elevations, brush disposal, seeding, mulching, weed control, and guidelines for proper storage, refueling and servicing of equipment. All permit requirements must be adhered to.

Staking. Staking of each site must be completed before operations begin. At a minimum, staking should include the four corners of the plug and the periphery of the borrow area, or bay with emphasis on staking the brim or downstream lip of the borrow area. Use a laser level to locate the proper contour elevation for the brim. This can be marked with pin flags. It is important to maximize the cross-valley width of the brim so that water pouring over it spills as widely as possible across the spread zone below.

Because staking must be readily visible to the dozer operator, the use of 4-foot lath stakes clearly marked with paint and/or flagging is recommended. As excavation proceeds, it may be necessary to reset stakes to maintain locations and visibility.

Clear Brush, Remove and Stockpile Topsoil. The removal of all brush and woody material will facilitate construction. These materials can be piled for disposal later or placed in the gully immediately downstream from the plug, and compacted in place. Brush can also be placed as needed to stabilize the gully banks at other location between structures.

After woody materials are removed, the borrow area can be ripped to a depth of 1 to 1.5 feet and the loosened topsoil temporarily stockpiled at locations convenient to the borrow area(s) and the plug. After construction is complete, soil should be respread. Seeds and plant propagules distributed through the topsoil will help to revegetate the site. If invasive species are present these should be treated as appropriate. Seek knowledgeable advice on proper, effective treatment.

The following photos in this chapter illustrate the building of a Plug and Spread complex on Mesteño Draw Ranch, Mountainair, New Mexico, Joan Bybee, owner. The project was implemented by Reineke Construction, 2015.

Initial stage of construction. Dozer is removing and stockpiling top soil from surface of **borrow source**.

Backhoe removing brush from **plug** location. Lath stake marks northeast corner of **plug**.

Dozer clearing topsoil from **plug**. Three of four stakes outlining dimensions of plug are visible in the photo.

Backhoe hauling fill to start first lift of **the plug**. Stake at lower left marks the northwest corner of the **plug**.

Shape Gully Walls at Plug Location. Shaping and widening the channel walls, at the plug location, will create the space needed for the dozer to operate. The walls should be widened to a minimum of 1.5 times the width of the dozer tracks to enable uniform compaction, allowing the operator to compact all fill material across the full width of the plug while tracking up and down rather than across the gully. A narrower plug width will prevent the uniform tracking and packing of fill material. Care should be taken to remove any large roots, stumps, boulders, or other materials that would prohibit uniform and effective compaction of fill materials.

Build the Plug. The plug is built in 3-6 inch deep lifts using soil removed from the borrow area (bay). A lift is defined as a layer of fill material spread evenly across the surface under construction and then compacted before adding the next layer. Each lift must be thoroughly compacted before the next lift is added. This can be accomplished by rolling back and forth with tracks of the dozer, parallel with the length of the gully. However, a rubber-tired vehicle such as a backhoe or front-end loader, delivers more pressure (pounds per square inch) than dozer tracks. Thus, if the construction team is using a rubber-tired vehicle in conjunction with the dozer, it is a good idea to pack each lift by wheel rolling after soil is spread by the dozer.

Soil must be of proper composition, containing sufficient clay for adequate compaction and moist enough to pack well. Gravel or sandy soils will not pack and are not suitable. Often clay soil will occur in seams or layers and should be carefully sorted and carefully placed in the plug and berm. If the supply of clay is limited, build at least the core of the plug with the available amount. If none is available, it will need to be hauled in.

First lift of the **plug** completed and wheel-tracked for compaction of fill. Color of soil is due to a high clay content, which will pack well.

First lift **upstream taper** of **plug** in foreground has been compacted. Backhoe is adding fill to the **downstream taper**.

Adding fill to second lift of **upstream taper**.

Tracking **upstream taper** and top of the **plug** for compaction. Note 3:1 slope on **upstream taper**.

Spreading final lift, top of **plug**. Note that the top surface of the **plug** matches elevation of the top of the gully.

Final lift is spread. Note that the dozer in background is gathering fill from the surface of the **borrow source** for construction of the berm by the backhoe.

Three alternatives are available to insure proper moisture content:

1) implement construction following snowmelt or soon after the rainy season;

2) use a water truck to moisten fill material after each lift is added, but before compaction is complete; or,

3) borrow moist soil from below the bed of the gully.

It is important that the plug be properly sized. The plug should be 4 feet long per 1 foot of depth. A plug in a channel 5 feet deep would be 20 feet in length, plus a 15 foot (3:1) tapered slope upstream and a 25 foot (5:1) tapered slope on the downstream side (Figure 30).

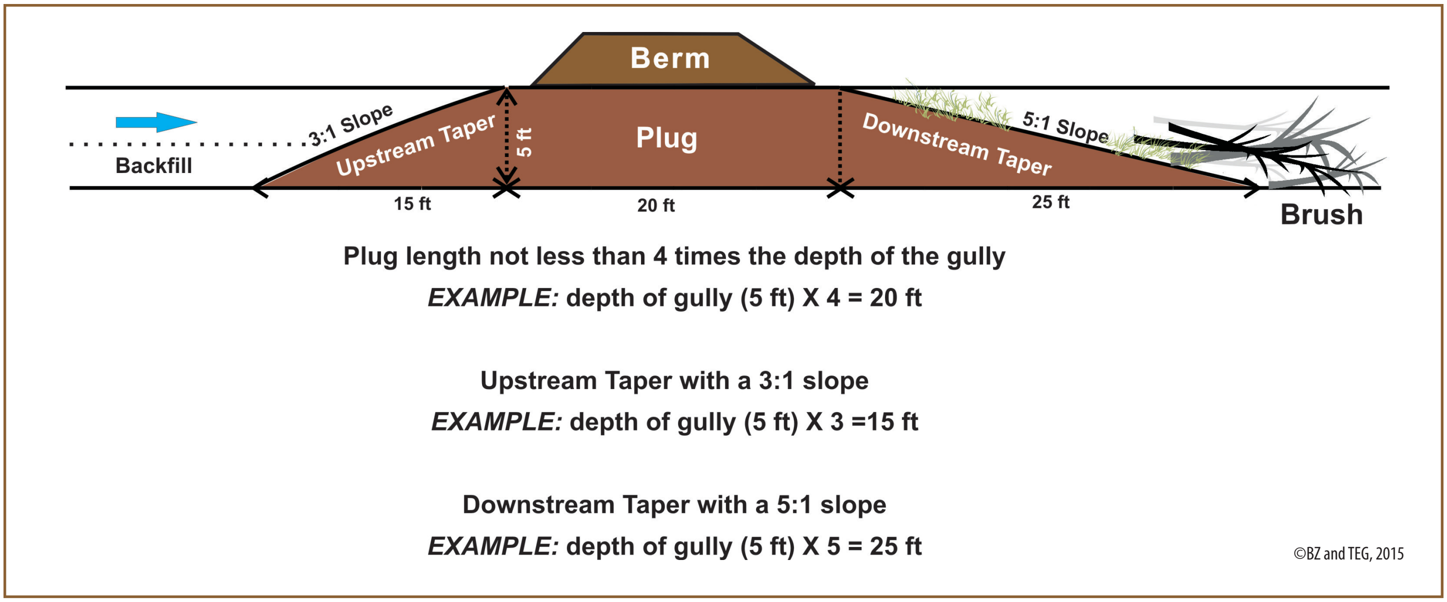


Figure 30. Gully plug and taper schematic.

Build the Berm. Once the gully has been plugged, compacted and tapered, begin to build the berm. The berm is built perpendicular to the plug and should be at least 1.5 times the width of the dozer to insure proper compaction. The berm is built tall enough to insure sufficient freeboard to route expected flood flows around the berm. A minimum of 1 foot above the elevation of the brim is recommended. More may be needed (Figure 15, page 13). The berm should also extend onto natural soil on each side of the plug; 20 feet is usually sufficient.

A taller, drier berm may facilitate the growth and establishment of invasive exotic plant species. However, building the berm to a lesser height, and thus with less freeboard, invites damage by subsequent flood events. Therefore, it is better to manage invasive species rather than to lower the berm height. Taller berms are more esthetically intrusive.

The first lift of the **berm** evenly spread.

Shape the Bay. Shape the bay to the width needed to spread the water as widely as possible across the spread zone. If creating a two-bay structure, shape the second bay and match the elevation of its brim to that of the first brim. If convenient, stockpile some gravel or cobble nearby for future repairs, in case the brim or berm are damaged or eroded by a future flood event.

The **berm** nearing completion.

Backfill the Gully. The primary goal of the project is to spill water back across the spread zone, not to impound water in order to create a permanent pond. Therefore, the gully may be backfilled with soil from the borrow area, leaving a shallow depression. If the soil stays moist during the dry season, wetland vegetation and wet meadow species can survive in water of this depth. If water rights limitations require it, completely backfill the gully to prevent ponding in excess of requirements.

Plug with Two Bays. Where plans call for two bays, one on either side of the gully, complete the brim of one bay first before building the second brim. After carefully measuring the elevation of the first brim, excavate the second brim to the same elevation. A small difference in brim elevations can have a large effect on the distribution of flow (to valley left or valley right). Varying the length of brims built at the same elevation can also affect the distribution of flow. That is, more flow will be routed across the longer brim if both are of the same elevation.

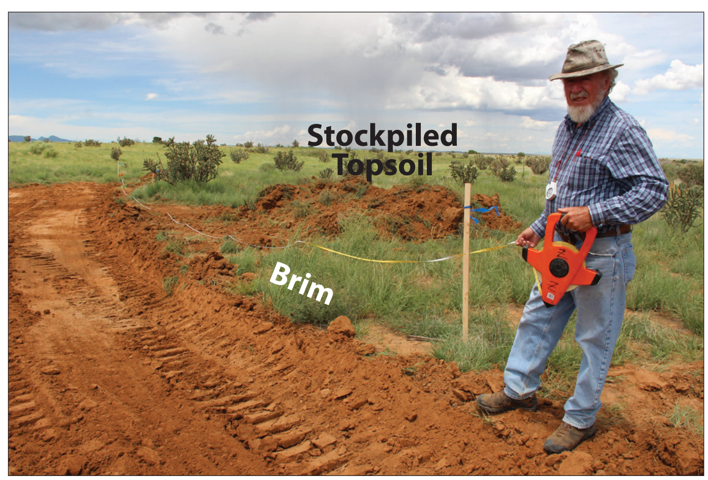
Level the Brim. Using a laser level, check the elevation of the brim to be certain that it is smooth and flat from edge to edge and has the proper elevation for the desired freeboard. The dozer can remove any high spots and fill any low spots, especially any rills or shallow gullies. The valley surface may tilt slightly toward the gully. In this case, a short dike may be needed to keep future flows trapped on the land surface and evenly dispersed across the spread zone. Gravel can be dumped in shallow rills or gullies and smoothed to ensure a level surface.

Match Brim Elevation to the Lip of the Headcut. If the plug is used for the purpose of controlling a headcut, the brim of the borrow area (bay) should be installed at an elevation equal to the lip of the headcut (Figure 17, page 14). This will prevent further scour when ponded water pours over the lip of the headcut. In addition, the lip of the headcut will revegetate with time, helping to hold soils in place.

Spread Soil, Seed and Mulch. The final step in the process is to spread stockpiled topsoil back across the surface of the borrow area, the plug and the berm. If possible, use a skid steer, backhoe or the bucket of a front-end loader. If not, use the dozer. Once spread, the soil (especially on the downstream slope of the plug and the berm) should be seeded and mulched using weed-free straw or other suitable material, such as bark or wood chips. It is recommended that the

Checking elevation of **berm** against first cut at brim elevation.

Dozer smoothing the surface of **borrow source (bay)**. Dozer located on valley left corner of the **brim.**

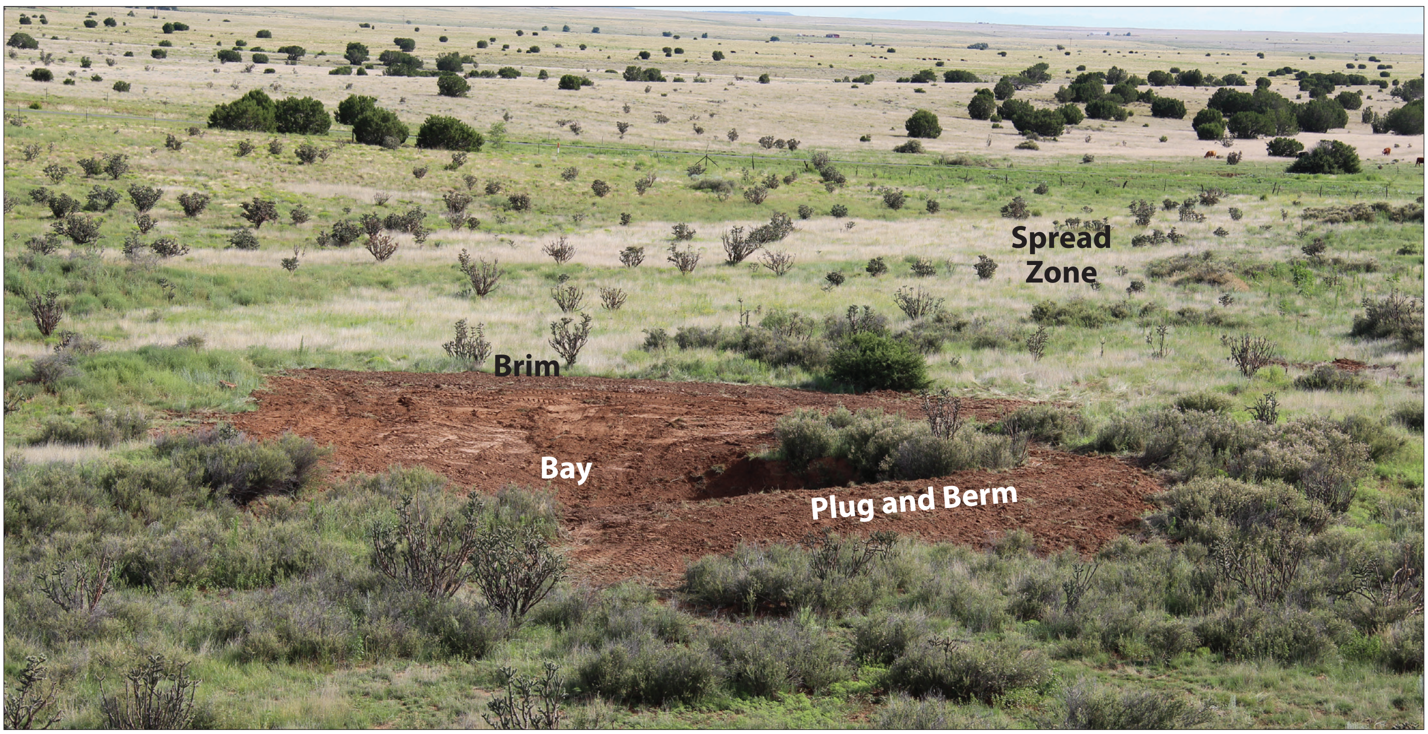


Measuring length of **brim** to check cross sectional area available to accommodate a flood event. Topsoil will be respread.

Spreading stockpiled topsoil back across finished surface of **berm**.

seed mix include native perennial grasses and forbs, as well as an annual grass not likely to reproduce (for example, annual rye, oats or winter wheat). These species provide quick cover and ample stubble height to disperse flow, if the area is flooded before native species become well-established. Be careful not to over mulch, which could suppress vegetation. Seek knowledgeable advice.

Check and Recheck Elevations. While construction equipment is still present on site, check all measurements, especially the elevation of the brim and berm for adequate freeboard. Adjust brim elevations by adding or removing soil and by compacting as necessary to achieve uniform elevations across the length of the brim.



Downstream structure in the same complex as previous photos. **Spread zone** comprises tan-colored grassy vegetation in the mid-ground and occupies formerly hydric soils.


Equipment used on a project in Colorado includes a mini-excavator, skid steer, bulldozer and water truck. Water truck is being used to wet down fill material.

CHAPTER 6
MONITOR–MAINTAIN–MODIFY

Timely monitoring, followed by prompt maintenance or modification of structures, can help to ensure that:

1. Structures function as intended,
2. Water is dispersed widely across the spread zone,
3. Any leaks are repaired while still minor,
4. Desirable vegetation becomes established, and
5. Unintended consequences, such as headcutting and rill formations, are corrected.

Monitor. The project area should be monitored after the first flow event following construction and subsequently as long as necessary to determine if structures are performing as planned. Monitoring can be as simple as a careful walk-through and repeat photography. Or, it can include the use of groundwater monitoring wells or vegetation transects. Results can be highly variable depending on the timing and magnitude of runoff events, the amount of snowpack or the intensity of monsoon storm events. Results can also vary based on the sediment supply and amount and the location of sediment deposition and whether sediment is sand, gravel, silt, clay, or organic debris. Structures built within drainages carrying heavy sediment loads can rapidly silt in, filling the bay with mud, but sheetflows should continue to spill across the spread zone (Figure 31).

Results may also vary depending upon the occurrence and location of subsurface flows and their point of emergence within the spread zone or the abandoned gully. For example, flows may seep underground within the bed or banks of the ponded area above the plug and emerge in the form of a spring or spring seep further down valley, prolonging flow in the gully bottom.

Examine the spread zone downstream of each structure. The following issues may be evident and should be corrected.

- Water is not spreading as widely as intended.
- Rills or shallow gullies are beginning to develop on the land surface (as made apparent by small headcuts). The steeper the valley slope, the greater the risk of developing rills and gullies on the spread zone surface.
- Water is spilling back into the original gully sooner than expected (further up valley).
- Hillslope runoff or water from a minor tributary is eroding the surface of the bay or the margins of the spread zone.
- Wetland surface is not revegetating as expected (species composition, plant height or density).
- Water is spreading too widely and damaging fences, roads, stock tanks or other infrastructure outside of the intended spread zone.
- The solution may include a simple direct treatment or multiple integrated treatments.

Plant species diversity and composition may change over time with prolonged saturation of the spread zone. For example, in the Southwest, smooth brome may be replaced by western wheatgrass, Kentucky bluegrass by sedges, and bare soil by vine mesquite grass. Ponded portions of the gully, bay and backfilled areas may become dominated by willows, cattails, bulrushes, rushes or sedges. This will depend on water depth, season and duration of flooding. Colonization by obligate wetland species adds habitat niches for wildlife and highly palatable forage if the unit is grazed during the growing season. Sedge plugs can be planted anytime the soil is not frozen. Willow cuttings are best planted during spring or early summer.

It is important to remember that in headwater wetlands, water levels are never stable for long, and are either rising or falling. Native vegetation is adapted to changing soil moisture conditions and will persist unless the absence of water holds constant for a long period of time. Expect species composition within the spread zone and ponded areas to change rapidly during the first three to five years after treatment. As a result, there may be notable differences in plant species composition between different ponds or spread zones within the Plug and Spread complex. Upland species such as sagebrush or rabbitbrush may die out but not necessarily in the first year.

Permanent vegetation transects installed prior to construction can provide valuable information over time regarding the restoration effort.

Problem Indicators - Cause for Concern	Success Indicators - Cause for Celebration
Damage to plug or berm	Debris along the edges of the spread zone, indicating the depth and extent of sheetflow
Evolving rills, gullies, or bare soil in the spread zone	Thin layers or deposits of fine-grained soil (silt and clay) on the surface of spread zone
New headcuts at flow return location	Increase in number of desirable plant species, plant vigor, growth, or density
New trailing patterns on spread zone	Loss of upland plant species
New exotic plants or weed species on plug or berm	Newly evolving springs or spring seeps emerging along walls of the old gully or on the spread zone

Figure 31. Interpreting results of monitoring.

Maintain. Any corrections should be made as soon as possible, hopefully in advance of the next flood. When inspecting the structures, pay special attention to the following:

- **Berm:** Look for evidence of slumping or piping through the plug or around it. Check for adequate freeboard. If the berm has been overtopped, the four possible solutions are to: 1) increase the height of the berm to add more freeboard, 2) lower the elevation of the brim to add more freeboard, 3) increase the width of the bay to increase the cross sectional area of the outlet, or 4) add rock rip-rap to the top and tips of the berm to resist erosion.
- **Brim:** If the brim is eroding or downcutting, this may be due to the concentration and acceleration of flows at some point along the surface of the brim. Look for bare soil and/or rills and correct by adding rock or sod to the eroded surface and building the brim back to a uniform elevation, resistant to scour. It may be necessary to flatten any high points along the surface of the brim.
- **Stable Return Site:** Check the return site for evidence of headcutting, erosion, rills, missing rock or other damage. Repair the site as quickly as possible, before the next flood event. If water is entering the gully at other locations, these will need to be stabilized by adding additional structures such as Zuni bowls, rock rundowns, rock lay-backs or short levees.

Modify. Be prepared to trouble shoot for unanticipated problems including the following:

Cross sectional area of the bay too small to accommodate large floods.

SOLUTIONS:

- If the landform permits, widen the bay and brim.
- Raise the height of the berm to create additional freeboard.
- Move the brim down valley which will lower the elevation of the brim, and thus create more freeboard without raising the berm elevation.

Increased surface roughness has reduced flow velocity, causing water to deepen and overtop the berm.

SOLUTIONS:

- Allow more freeboard or increase the length of the brim.
- Place a layer of coarse rock on the top and tips of the berm to resist erosion if it is overtopped.
- Revegetate the berm with vigorous grasses as quickly as possible.

More ponding capacity than total runoff has caused water to infiltrate too quickly and not spread across the spread zone.

SOLUTIONS:

- If the bay(s) is excavated from a sandy or gravelly stratum, cap it with clay or wait for silt deposition to seal it naturally over time.
- If the bay(s) is excavated from a clay stratum, ignore the issue and wait for a larger storm event to fill the bay as planned.

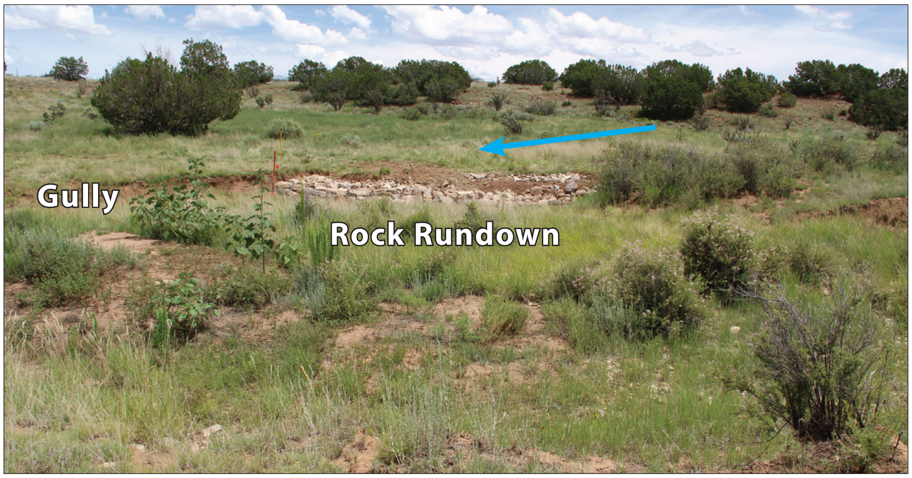


Figure 32. A rock rundown as a stable return site. Spreading stockpiled topsoil on the berm.

Where flow returns to the channel a headcut is developing; the return site is not stable.

SOLUTIONS:

- Install an additional plug and move the spread zone to access the gully at a more stable return site.
- Install an appropriate grade control structure such as a Zuni bowl or rock rundown at the return site (Figure 23, page 16 and Figure 32).
- Revegetate with willows or other erosion resistant species.
- All of the above.

Damage to Improvements. If the water is spreading too widely and threatens infrastructure, a site-specific mitigation treatment will be in order. In planning the mitigation measure, it may be desirable to relocate or realign a fence, road or affected infrastructure in order to maximize benefits to soil, vegetation, subsurface water storage or other values related to the Plug and Spread treatment. It may be necessary to protect the feature by building a protective levee or drainage structure.

Levees. If water is spilling back into the original gully further up valley than expected, it may be possible to install a short levee or dike to keep the water within the intended spread zone. Many gullies flanked by willows or other woody vegetation have natural levees along their banks built over time by sediments deposited during previous flood events. Where these have been breached, it may be feasible to plug the gaps with short, constructed levees.

Gully Treatments Between Plug and Spread Structures. Routing runoff events across the spread zone may greatly diminish or eliminate flow within the gully itself. The gully between structures may be sediment starved and may not aggrade, especially for structures lower down the valley. However, depending on the nature of sub-surface flow through the valley alluvium, seepage may emerge to create new pools within the bypassed gully. These evolving pools may quickly revegetate and have high value as seasonal habitat for wildlife, especially migratory birds, reptiles, amphibians, and small mammals. Building accessory structures such as one rock dams in the gully between structures in the complex may or may not be desirable or necessary. The portion of the gully upstream from the uppermost structure will fill most quickly with sediment and will tend to revegetate with wetland-dependent species.

Other Modifications

- Bare soil resulting from construction activities along with the establishment of unwanted invasive plant species (various thistles, tamarisk and smooth brome for example) may be unavoidable. If so, appropriate treatment should be undertaken as soon as possible. Some invasive plants (such as Kentucky bluegrass, timothy or dandelions) may invade initially, but may be crowded out as native species become established.
- Add rock to berm tips and the surface of the berm, if these are being eroded by flooding.
- It is important to install corrective treatments as soon as possible. Heed Ben Franklin's advice! "A stitch in time, saves nine."

CHAPTER 7
CONCLUSION

The Plug and Spread treatment can be a powerful tool for moist soil restoration on suitable sites. Proper application, including the careful evaluation of landforms likely to be affected, can yield significant economic and environmental returns.

The purpose of a Plug and Spread project is to reconnect channelized flow, currently captured by an incising gully, with the natural floodplain or alluvial fan surface that was accessed by flood flows before the gully evolved. The intent is to restore moist soil conditions to historic valley bottom sites, not to artificially irrigate upland areas.

The supply of water is finite. This is especially true for small headwater watersheds a few hundred to a few thousand acres in size which support ephemeral and intermittent channels. Carefully select between candidate sites, giving preference to those most easily wetted by lesser, but more frequent storms. Remember, we can expect perhaps only one event per year of sufficient magnitude to "flood" all sites. If a series of sites will be treated, the top or first one in the series should be the site with the most restoration potential. It may be desirable to postpone treatment of sites elsewhere in the same watershed until more experience is gained from the first sites restored.

Where water supply is limited, be aware that existing stock ponds may be adversely affected by treatments installed higher in the watershed. Lower elevation structures could go dry sooner or more often than before. Where Plug and Spread treatments increase shallow ground water (alluvial) storage, more prolonged base flow will serve to sustain storage in stock ponds and raise ground water levels in affected wetlands. Both extremes have been experienced across the range of areas treated to date.

A variety of Connect and Spread treatments offers a means for preparing for climate change in a small but significant way on suitable sites and landforms. Connect and Spread (Plug and Spread, Plug and Pond, and road treatments) is one way to build resiliency separately or in combination with other climate adaptive measures. Predictions are for less precipitation in total and significant change in storm patterns—annual rainfall all in one storm, or multiple large events back to back. Longer, hotter, more severe droughts interspersed with more intense storms, less snowpack and earlier snowmelt are also predicted (National Climate Assessment, 2014).

Plug and Spread treatments are one way to store water in the soil and build resilience in the face of climate change. Keeping the soil covered with vegetation will slow runoff, increase infiltration, increase soil organic matter, increase the soil's capacity to store water and thereby increase vegetation diversity and overall total biomass.

Proper and timely application of the Plug and Spread treatment can yield significant returns, but may not be appropriate to many areas and only marginally so in others. Land managers interested in trying the methods described in this publication should carefully assess potential sites using information presented in Chapter 3.

Other Considerations

- Cost-sharing and planning assistance may be available through various federal, state and private organizations.
- Prompt maintenance and modification of structures following the first runoff event is highly recommended.
- Before implementing any project, determine any water rights implications.
- Secure necessary Clean Water Act and other permits. It may be necessary to discuss expected benefits with the regulator in charge of issuing the needed permits. Not all regulators are familiar with this method of land restoration.
- Synchronize grazing activity, timing and intensity with season of use to optimize stubble height on the spread zone during the period when flows are normally expected.
- Tell your neighbor. Coordinating Plug and Spread treatments across the boundary fence may benefit all concerned.
- Look into using other Connect and Spread structures and treatments.

- Consider the long-term vision for your project. What changes in vegetation, ecology, hydrology and geomorphology would you expect to see? How would sediment build-up in the gully affect flow amounts and velocity? Would there need to be additional treatments to adjust for these changes?
- For best results, attend a workshop or training where the Plug and Spread method is being demonstrated. Discuss this method with those who have already applied the treatment.

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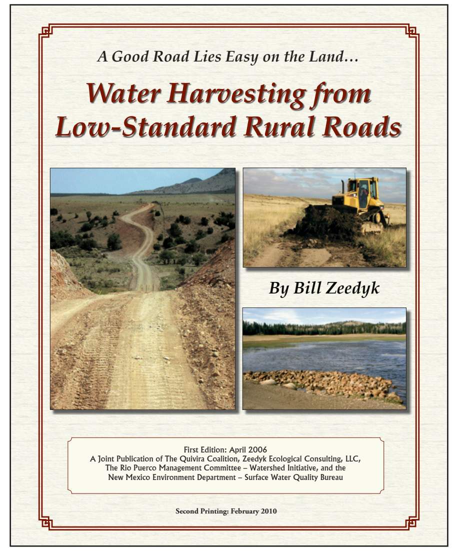

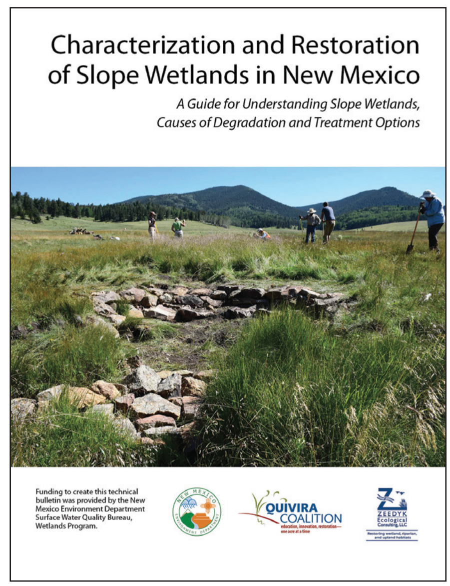

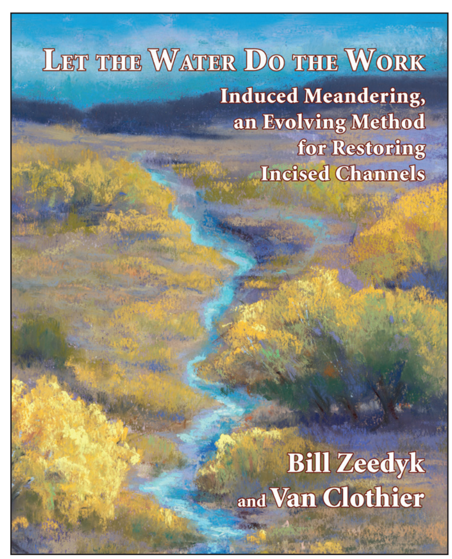

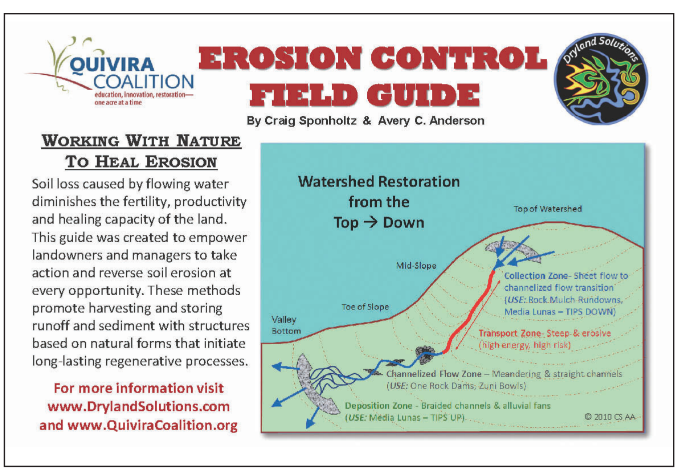

Notes

"The Reineke Construction team is honored and excited to be part of the "wave of innovation" in restoration techniques. The combination of engineering, art, science, and watershed interpretation inspired by Bill Zeedyk makes the Plug and Spread treatment a favorite construction project for us. We hope all land stewards will explore this treatment option."
— Mark and Margie, owners, Reineke Construction

"The Plug and Spread treatment is an important resource for land managers and ranchers looking for innovative and cost-effective ways to restore and build resilience of wet meadows and wetlands. Bill Zeedyk recently designed a series of Plug and Spread structures in wet meadows in the Gunnison Basin, Colorado. The structures are already storing water and improving habitat for wildlife and livestock!"
— Betsy Neely, The Nature Conservancy and the Gunnison Climate Working Group

"Over the last 10 years we have installed a number of Zeedyk-designed structures for erosion control and riparian restoration—including Plug and Spread structures—and as a result we have many acres with increased forage production and diversity. The investment has really paid off in terms of ranching and wildlife habitat and the continued health of our little part of the planet."
— Joan Bybee, Mesteño Draw Ranch

"The Plug and Spread treatment is very unique and unconventional in the sense that the water is redirected and not captured; therefore, using the water as a tool to re-saturate land that was historically saturated."
— Chase Currie, PhD, Natural Resource Manager, San Pedro Ranch

ABOUT THE AUTHOR


Bill Zeedyk

Bill Zeedyk, a retired Forest Service wildlife biologist, has devoted the past twenty years to developing and implementing new methods for stabilizing eroding stream channels and restoring gullied wetlands. His projects have been installed on both public and private lands throughout the American Southwest. Growing public concern for the devastating effects of a changing climate on watershed health has convinced Bill of the need for new, more innovative restoration techniques. His Plug and Spread treatment promises to produce both economic and environmental benefits even in the face of climate change.

Zeedyk enjoys working with private land owners, ranchers, public land managers, non-profit organizations, dedicated volunteers, practitioners, students and others—all those who share a common interest in wetland restoration for whatever reason. Bill and his wife, Mary Maulsby, own and operate Zeedyk Ecological Consulting, LLC. They enjoy working together on their very own wetland while at home in northern New Mexico.

To purchase additional copies of this book, contact the Quivira Coalition
505-820-2544 ext. *# or online, *www.quiviracoalition.org*