



Issued August 2007

Cover photo: Gully erosion may be a significant source of sediment to the stream. Gullies may also form in the streambanks due to uncontrolled flows from the flood plain (valley trenches).

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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Purpose

This NEH654 TS describes the formation and control of gullies. The severity of gully development depends on a number of factors including soil type, vegetation, rainfall, concentrated flow, and human disturbances. Gullies can erode hillslopes and fill stream channels with sediment. Unchecked, they erode and deliver sediment through a variety of processes that cause loss in soil productivity, channel entrenchment, and headward expansion into the landscape. To best select a design alternative, the desired results of the landowner must be understood along with the character of the gully and its potential impacts.

Introduction

Gullies are entrenched channels extending into areas with previously undefined or weakly defined channels (Schumm, Harvey, and Watson 1984; Hansen 1995). They may occur in concentrated flow areas, such as those which can be identified on topographic maps, indicated by small contour crenulations (Hansen and Law 2004). Figures TS14P-1 and TS14P-2 are excerpts from the U.S. Geological Survey (USGS) Topographic Contour Map. Most gullies are located remotely with

aerial photos or reconnaissance and evaluated in the field for activity level. Many gullies are easily seen on aerial photos.

Gullies can be thought of as extensions of a watershed drainage system up into the landscape. Under extreme conditions, gullies can expand into hillslopes extending up to the topographic watershed divide. Active gullies are recognized by headcuts (primary nickpoints), where there is an abrupt drop in elevation (figs. TS14P-3 and TS14P-4). The channel below the headcut or nickpoint is enlarged by plunging flow and erosion. Secondary nickpoints may be located downstream, showing additional base-level adjustments. Several processes are involved in nickpoint migration including cavitation, plunge development, soil piping, bank failure, and freeze-thaw cycles.

Nickpoints travel upstream as gully systems enlarge and expand in response to rainfall, runoff, and changed cover conditions. Restrictive channel materials such as bedrock or tree roots can halt or slow nickpoint migration. As figure TS14P-5 shows nickpoint migration upstream was halted by the trees in this ephemeral channel. The pastureland in the background was probably farmed. If the farmer had cut these trees, channel entrenchment and nickpoint migration would have been likely.

Figure TS14P-1 Leeds, SC: lat. 34°44' N, long. 81°25' W. Contour interval on map is 10 feet. Arrow shows contour crenulations corresponding to gully (first order stream) (fig. TS14P-2).

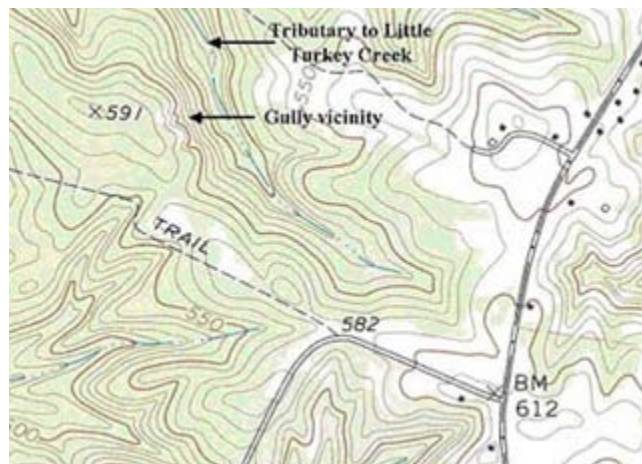


Figure TS14P-2 Aerial photo taken in 1974 highlights vicinity of gully marked in figure TS14P-1. The long gully (arrow) is about 0.25 acres and has delivered more than 53 tons of sediment over the last decade.



As the channel elevation decreases and approaches the ground water level, the length of the period of saturation or flow increases at the headcut and channel banks. The processes responsible for headcut migration vary somewhat with the position on the landscape and land use and cover conditions. Surface flow and plunge action exert pressure to undercut, widen, and

collapse the nickpoint. Saturated soil is susceptible to cavitation enlargement and slope failure, winter frost heaving, slope raveling. Storm runoff causes plunge enlargement and material removal. Soil piping in certain soils has also led to gully development (Heede 1976).

As gullies expand, storm runoff increases, with declines in infiltration, ground water, baseflow, and evapotranspiration. The increased drainage density, soil exposure, erosion, and sediment delivery cause adjustments to both the adjacent uplands and downstream bottomlands. In this process of channel entrenchment, ground water tables may be lowered, resulting in declining baseflows and conversion of perennial streams to intermittent or ephemeral flow. Lands adjacent to entrenched gullies have reduced moisture available for plant growth, as the water table is lowered. Aggraded channels in downstream valleys have reduced capacity for flow, resulting in more frequent and extensive flooding. When the capacity of the channel cannot efficiently move the sediment load, braided channels develop with multiple divisions and frequent shifts. Gullies not only alter and deplete the physical character and biological capability of the affected landscape, but their downstream effects can also be pronounced.

Figure TS14P-3 Gully erosion is episodic and characterized by the incision and widening of concentrated flow channels (upslope portion), headcutting, nickpoint migration, and widening (foreground)



Figure TS14P-4 Active gully headcut (nickpoint) is enlarged by concentrated flow and erosion



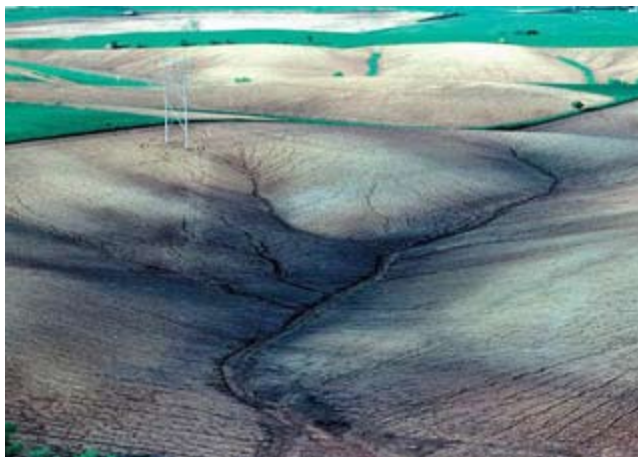
Figure TS14P-5 Headcut halted by tree roots in Union County, SC



Classical gullies and ephemeral gullies

The previous section of gullies focused primarily on what have been termed classical gullies by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). These are concentrated flow erosion features that are too large or deep for normal farming implements to cross and may occur on all land uses. As farming equipment grew larger and more powerful over time, the ability to farm through gullies was attained on cultivated fields. Cropped fields that would normally have developed classical gullies instead show concentrated flow features that lie in field drainageways or where opposing slopes occur. These are termed ephemeral gullies because their occurrence is ephemeral, depending on rainfall and runoff conditions, the soil's resistance to erosion, and land use and treatment. Normal farming practices may completely or partially fill in the small concentrated flow channels. Occasionally, these ephemeral gullies may recur in the same place later in the year. Figure TS14P-6 shows a cropped field with severe erosion in the foreground and some treatment of ephemeral gully erosion with grassed waterways in the background. Note that ephemeral gullies and severe sheet and rill erosion persist above some of the waterways.

Figure TS14P-6 Ephemeral gullies and severe sheet and rill erosion in unprotected northwestern IA field



Gullying processes in streams

Entrenched perennial channels may exhibit some of the same features and processes as gullies. For example, Isaacs Creek in Union County, South Carolina (fig. TS14P-7), is a small perennial gully channel (drainage area about 2.5 mi²), which has entrenched through sediments that were deposited from past hillslope gully erosion. The channel has eroded to a massive root system that was likely part of the original valley surface. Bank undercutting and widening are a result of the grade control provided by the root system. The humid climate with well-dispersed rainfall has helped to retain the riparian character on the abandoned terrace.

The channel evolution model, developed by Schumm, Harvey and Watson in 1981, has been used to describe the evolution of gullies. Rosgen (1992, 1994) also developed criteria for gully-type channels that include low width-to-depth ratio, high entrenchment, moderate slope, and low sinuosity. Gully channels are dominated by streamflow and internal channel dynamics, with no access to a flood plain during severe storm events. Channel degradation and the headward expansion of secondary nickpoints may occur, but are generally less obvious than gully headcuts into hillslopes.

Figure TS14P-7 Perennial gully channel



Under some conditions, perennial gully-type channels may develop slowly, dependent on wearing through a resistant layer at the channel nickpoint, eventually enlarging and entrenching as the underlying erodible materials are exposed by nickpoint failure. Gully development in alluvial valley channels may occur when there is a marked change in flow, bank vegetation, channel path, base level, and/or reduction in sediment loading, causing channel degradation.

Where surface drainage enters a stream in an uncontrolled fashion, concentrated flow erosion and gravitational collapse combine to form valley trenches or sidewall gullies and sometimes edge-of-field gullies. These may also form in response to changes in base level of the receiving stream due to incision (fig. TS14P-8). Controlling this type of erosion requires conveying the water safely from the higher elevation to the stream, without eroding. Treatments include the construction of rock chutes, diversions to a safer entry level and location, or construction of pipe drops, which capture the water from the higher elevation into a pipe, which conveys the runoff water safely through the bank and into the stream.

Valleys buried by sediments from severe erosional features may change in response to implementation of erosion control. TS14P-9 shows a valley buried

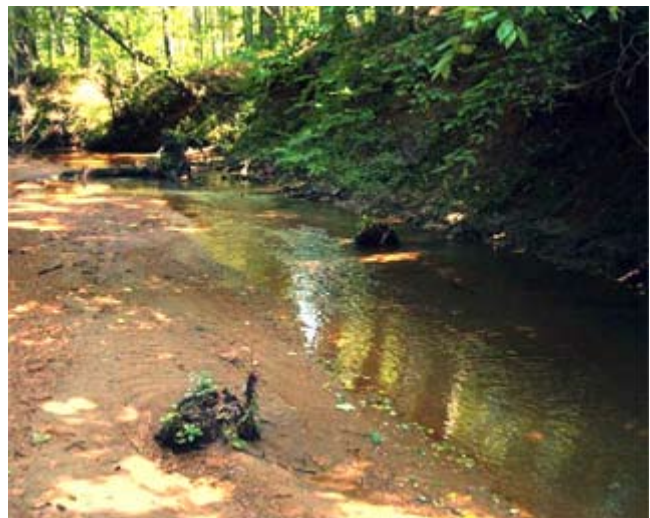
with 10 to 12 feet of sediments from gully erosion in the early 1900s. Since then, channel entrenchment has reached the original channel, and is marked by exposed tree stumps. Since then, channel widening into the erosive alluvial materials has widened this channel to 36 feet wide, with a bankfull depth of 2 feet (Rosgen F stream type). There are some signs that the channel is trying to build a narrow flood plain within this entrenched channel.

Channel evolution in aggrading valleys may eventually lead to braided channels (Rosgen D stream type). Channels aggrade when sediment supply is greater than the stream's ability to transport it, resulting in accumulating sediments, channel filling, shifts in channel location, and multiple channels. When sediment supply declines after channel filling periods, channel evolution may initially produce a sinuous, low-gradient channel (Rosgen E stream type). However, during bankfull and larger floods, the sinuous path may become unstable in the erosive, alluvial sediments, causing avulsions, meander cut-offs, bank failure, and development of an entrenched Rosgen G gully channel (Rosgen 1994). As temporary or permanent base levels are reached, lateral channel adjustments may occur, eventually increasing width through bank failure and sediment removal, developing into Rosgen F or C channels.

Figure TS14P-8 Gully formation adjacent to a degrading stream



Figure TS14P-9 Valley buried with sediments from gully erosion



Further adjustments in channel type may occur, and channel sections may undergo phases of aggradation, degradation, and quasi-stability (Schumm, Harvey, and Watson 1984). Channel gradient changes may signal the shifts from sediment accumulation to enlargement phases. The adjustment process of gully channels can be slow or fast, depending on factors such as storm severity and frequency, land use, soil erodibility, and vegetation.

Some of the periods of highest sediment yield in the Southwest coincide well with periods of drought, rather than periods of rainfall (Leopold and Rosgen 1992). The key difference in arid and semiarid terrain is the lack of vegetation during dry periods. Erosion is more severe than periods with higher rainfall and more vegetative cover.

Issues contributing to gully formation or enlargement

Some critical conditions (alone or in combination) could cause rejuvenation of gullies and channel forming processes with rapid erosion and expansion of the drainage network (Schumm, Harvey, and Watson 1984). Land use, soil, climate, rainfall, and hydrology are some of the leading considerations in evaluating gully processes and their control.

Warning signs of channel incision and degradation may include pistol butted trees, jack-strawed or heavily leaning trees, soil cracks, tree roots under tension, flow restricting geology near the surface, slopes with geologic dips nearly parallel, very steep side slopes, and/or colluvial materials (Hansen and Law 1996). Indicators of imminent channel bank collapse may or may not be present before actual failure.

Land use practices

Land use practices that alter cover, soil or hydrologic function can act as trigger mechanisms to gully formation and development. Practices that disturb and compact soils contribute to soil detachment and concentration of surface flow. Practices such as farming, road construction, grazing, mining, water transmission (ditches, trenches, terraces, or waterways), urbaniza-

tion, development, and impermeable surfaces have the potential to alter conditions by changing the balance of rainfall absorption, runoff, or flow capture from adjacent areas. Figure TS14P-10 shows a slope failure likely due to excessive road drainage. Soil properties altered by years of cultivation show major reductions in subsurface soil percolation and macropore space, resulting in increased surface flow (Hoover 1949). As illustrated in figure TS14P-11, early farming and other practices had a severe effect on many landscapes, reducing soil productivity from years of surface erosion. In many instances, the soil surface is gone, exposing subsoils to continued erosion.

Figure TS14P-10 Slope failure due to excessive runoff from a road



Figure TS14P-11 Early farming and other practices had a severe effect on many landscapes



Disturbed soils lose much of their structure and have increased risk for gullying, especially if left exposed or subjected to concentrated flow for extended periods. Loss of vegetation alters the balance of rainfall, infiltration, evapotranspiration, surface cover, root strength, and runoff.

Failure to use preventative practices or heed warning signs of rill entrenchment may allow gullies to form. Although gully formation and enlargement are typically episodic, they are not instantaneous. Careful observation and treatment in the initial phases can slow or halt development (Schumm, Harvey, and Watson 1984).

Soil properties

Certain soils and landforms are especially susceptible to gully formation. Soils with weak cementation, poor consolidation, and low cohesion (alluvium, colluvium, loess, ocean, or lake deposits) have more risk. Oxisols are susceptible to gully formation due to their high degree of physical and chemical weathering. Soils that are altered by physical, chemical or biological activity may develop weaknesses that increase their erodibility. Soils sorted by water or wind often form deposits in layers of uniform-sized materials, losing much of their natural cohesive forces and erosion resistance. Soil chemical imbalances, such as high sodium absorption ratios (SAR) or low dithionite extractable iron, are more prone to be highly erodible (Heede 1976; Singer et al. 1978).

Figure TS14P-12 shows soil-piping in road fill materials within the Alkali Creek, Colorado, drainage (Heede 1982). The outlet of this failure was about 100 feet downslope. Other soil pipes found in the field survey were associated with cattle trails that concentrated flow into areas with soil cracks, dispersive soils, or other weaknesses.

Micaceous, granitic, and saprolitic soils are susceptible to gully formation. Schumm, Harvey, and Watson (1984) show that gullies are more apt to develop in landforms with comparatively steep, narrow valleys on a unit area basis. Water accumulation on low-permeability soil or hard layers, such as a fragipan or bedrock, can contribute added flow to a gully headcut or stream channel.

Climate

Certain climate, soils, and bedrock types limit the abundance and permanence of plant cover, resulting in extended periods of soil exposure. Arid and semi-arid areas or nutrient deficient or depleted soils have increased risk for gully development because the presence of plants can be tentative and fragile. In these circumstances, understanding and maintaining the natural balance can be the key to gully prevention. Native plant cover needs to be protected. If native cover is gone, restoration, replacement or other stabilization measures may be needed to control exposed soil, erosion, and the erosion caused by concentrated flow. The ability to maintain quality plant cover, infiltration, and root support across drainage areas will often prevent severe erosion and gully formation. Even minor gullying can alter soil moisture conditions and contribute to poor plant cover. To restore arid climates, mechanical means may be needed to capture and collect rainfall for plant recovery (Cohen 1994; Fayang 2004).

Hydrologic and hydraulic controls

Hydrologic alterations that modify the normal flow patterns can occur naturally or be affected by land use and treatment. Geologic controls, such as faults, may affect channel dimensions, which may confine and focus flow energy within the channel, leading to en-

Figure TS14P-12 Soil-piping in road fill materials



trenchment. Roads along streams may also impinge on the natural ability to dissipate energy on a flood plain. Wildfires on erosive soils may reduce cover or develop nonwettable soil layers that contribute to gully development. Excessive traffic and hoof shear from wildlife or cattle can develop trails that concentrate flow, eventually leading to rill and gully formation. Stream capture as a result of erosion from an adjacent area can also generate severe erosion, gully formation, or channel entrenchment. Severe storms can cause erosion and sediment delivery even from relatively small gullied areas (Hansen and Law 2004). Figure TS14P-13 shows how erosion associated with 5 inches of rainfall in 1994 resulted in 5 tons of sediment from a small gully trapped in a filter fabric fence in Chester County, South Carolina.

Gully erosion control

Some of the earliest treatments began in the 1930s with the Civilian Conservation Corps. Adjustments in treatment methods have been made in response to past failures and to take advantage of new equipment or operation developments. This NEH654 TS illustrates gully treatments from a variety of different areas. However, many approaches are site specific. Adjustments may be needed for differences in soils, rainfall, and climate conditions.

The prescription for gully treatment needs to address the severity of conditions. It should also look for specific ways to take advantage of existing conditions to produce stability. Treatments that depend on vegetation for stability are easier in moist and humid climates with productive soils, but may be more difficult to establish, develop, and maintain in nutrient-deficient soils. Vegetative-based treatments are also problematic in arid or semiarid climates.

Control of concentrated flow on forested or vegetated hillslopes is a reasonable approach, but becomes more difficult for areas affected by impermeable surfaces and larger drainage areas prone to rainfall with high intensity and duration. To achieve reliable results in both the short and long term, several of the treatment options may be combined to achieve results and reduce risk of failure.

Treatment of classical gully erosion involves protecting the headcut from further erosion, diverting overland flows away from the gully, changing land use, grading and filling in the gully, stabilizing with trees and vegetation, or by constructing a small earthen dam to impound water in the gullied area.

Treatment of ephemeral gullies includes the use of grassed waterways, terraces, diversions, water and sediment control basins (WASCoBs), accompanied by reduced tillage methods. Figures TS14P-14 and

Figure TS14P-13 Erosion resulted in sediment from a small gully trapped in filter fabric fence



Figure TS14P-14 Ephemeral gullies on cropland treated with grassed waterways, northwestern IA



TS14P–15 show ephemeral gully erosion treatments, using grassed waterways, terraces, contour farming, and conservation tillage.

Treatment options

A variety of methods have been used to stabilize, rehabilitate, or restore the effects of gully erosion (Heede 1976; Hansen 1991, 1995; Wirtz et al. 1992; Hansen and Law 1996; Law and Hansen 2004; Liu and Li 2004). Stabilization halts expansion of erosion and gully networks, reducing sediment yield, and improving water quality. Rehabilitation not only stops the erosion expansion but also improves other resources such as timber, recreation, and wildlife. Restoration is a more comprehensive effort to return the affected land to an acceptable condition for hydrology, soil productivity, and biologic response. Although a complete reversal in history of gullied terrain may not be possible, restoration is intended to stop the gully-forming cycle and produce sustainable results.

Reforestation/revegetation

Since the 1930s, establishment of forests and woodlands have been successful in reducing surface runoff and erosion associated with abandoned, cultivated, and other abused lands in many areas. Many active

gully systems eventually healed themselves following replanting efforts by the Civilian Conservation Corps. This treatment was inexpensive, but the success was not immediate or assured. Issues can include a need for fertilization, mulching, and irrigation to get the plants established. Without the nutrients and moisture added by these treatments, a decade or more may be necessary for significant development of roots and litter.

Areas with less severe erosion and gully activity are more apt to successfully respond to reforestation as the primary treatment. Severely eroded sites depleted of nutrients produce only anemic forest or grass conditions. Evidence also suggests that some of the early failures may have been the result of poor planting practices, initial seedling health, lack of follow-up checks and maintenance. Even after forest recovery, gullies remain susceptible to reactivation if conditions change.

Vegetative techniques are key elements to reversing land uses or conditions that have artificially left watersheds barren. They improve soil cover, promote water absorption, root development, and soil stability. Selection of species and accompanying treatments depend on climate and soil conditions. Some adjustment from normal practices may also be necessary to develop and maintain vegetation health. Soils with a hardpan or fragipan may need to be ripped on the contour to break up the relatively impermeable layers. On saprolite or other nutrient imbalanced soils, fertilization with lime, nitrogen, phosphorus, and potassium has enabled plant response and recovery on many sites. When needed, ample mulch is also used to help retain the seed and moisture to improve generation success.

Treatments that disturb the ground often need rapid cover and revegetation, but drainage control and other treatments can buy time and stability. Seed mixtures generally include grasses with quick response, such as brown top millet or winter wheat. The goal is to provide cover that will help control erosion, but still allow the desired perennial plants to germinate and grow. When available and appropriate to the area of treatment, native grass, forb, shrub, and tree species should be selected to provide immediate cover, long-term erosion control, and soil productivity, requiring little maintenance. When rapid cover is unlikely or added insurance is needed, straw or other mulch is recommended to hold seed on the site until moisture

Figure TS14P–15 Terraces and filter strips on cropland in Shelby County, IA



and temperature conditions improve for germination. Drainage modifications may be needed to manage the flow of water into and across the site. When possible, vegetative treatments should benefit soil, water, and wildlife objectives and fit in with the natural system.

Gully plugs

A gully plug is a small earthen dam constructed at one or more locations along the gully. Branch packing and wattle check dams can also be used as gully plugs for small gullies. Information on these and other soil bioengineering applications of gully plugs is provided in NEH654 TS14I. Regardless of the size, the gully plug provides grade control and retains sediment. Larger structures will have a control structure providing overflow protection and dispensing flow to a more stable section of the gully channel (fig. TS14P-16). These structures are used to stabilize gullies with design similar to a road stream crossing with a culvert. The goal of these structures is to reduce the grade above the gully plug by storing sediment. Excess runoff is delivered to the downstream channel by a drop inlet structure typically made from a corrugated metal culvert with a spillway.

Gully plugs are normally successful when constructed below active gully networks with small drainages in gentle to moderately sloping terrain. Fill materials for gully plugs should be free of woody debris and have adequate moisture and clay components to be compacted, particularly around the drop inlet structure.

Debris dams

Debris dams were used on some of the early efforts to help stabilize gullies (fig. TS14P-17). Structures were often made of available materials such as small cedar trees piled between posts in the gully. Others consisted of chicken wire fences with cedar and other brush placed across small channels and barren lands. Straw bales with rebar support have been used with limited success. They work best when installed with the lowest areas of the installation emptying into the channel thalweg and when used as a gradient control to spread flow across a channel, rather than to act as a dam structure. If straw bales are not installed correctly, they can cause water to be diverted around them, which negates any benefit. Debris structures generally provide some short-term stability success by increasing roughness and slowing or dispersing concentrated water flow, which encourages sediment deposition. Debris dams break down after a few years and lose their effectiveness.

Figure TS14P-16 Active gully area reshaped with the flow from terraces going into a waterway, rather than adjacent gully areas



Figure TS14P-17 Early efforts to stabilize gully enlargement in the SC Piedmont used log check dams



Debris dams from rootwads or large trees provide for increased grade control and sediment retention, unless concentrated flow finds a path around or under the debris (fig. TS14P-18). Once the gully treatments are stabilized with vegetation, limited surface flows occur in these hillslope channels, and most of this sediment would be retained in place. Woody debris dams are sometimes used in gullies below land reshaping activities to remove debris from the treatment area and for added sediment retention, until erosion control measures become effective. Debris dams are not appropriate as a primary control measure on severe erosion problems. A series of small dams are more practical and stable than a few larger structures.

Commercial coir logs made from coconut fibers can provide many of the benefits of debris dams when they are installed in small gullies where flow velocities and volume are low (fig. TS14P-19). Water and finer particle sizes pass through the coir logs, but coarser materials are retained in the channel, as the flow velocities are reduced and spread across the channel surface. The limited height of these porous structures prevents plunge development.

Where sediment is stored behind them and revegetation occurs, they can be stable for extended periods. Where debris dams can be used to provide some temporary improvement, costs are usually reasonable. When used concurrently with other techniques, debris dams may provide the needed short-term stabiliza-

tion until other measures become effective. Regular maintenance checks are necessary after the first major storms after construction to ensure that they are functioning properly.

Living brush barriers or hedges have been used to stabilize gullies. They are effective in increasing roughness, reducing velocities, providing grade control and capturing sediments from gully channels of low to moderate gradient. Vetivergrass (*Vetiveria zizanioides*) and switchgrass (*Panicum virgatum*) hedges have proven useful in protecting slopes and small channels in many areas from entrenchment and in accumulating sediments (National Research Council 1993; Dabney et al. 2004).

Rock check dams

Rock check dams help stabilize eroding channels or waterways and can provide permanent channel protection (grade control); water detention, rather than retention; and allow for high water overflow. Guidance for these and other grade control structures is provided in NEH654 TS14G, Grade Stabilization Techniques. Costs, proper sizing of materials, downstream splash and plunge pool control, and the frequency or number of structures are the most critical considerations. Downstream structural controls at elevation drops are needed to dissipate flow energy and prevent plunge pool undercutting of the structure. The porous nature

Figure TS14P-18 Woody debris dam used for sediment retention in SC. Sediment was produced by a severe storm.



Figure TS14P-19 Coir logs used to complement surface stabilization and revegetation measures used in background gully channel



of the rock helps to delay flow without completely restricting, as is common with concrete or other impervious structures. This is why rock check dams function as water detention structures, as they temporarily store and attenuate the runoff water. Where materials are readily available and channel access is not a problem, costs of rock dam construction can be reasonable. Due to the extent that dams modify channel function, several small, frequent dams that act as gradient control or steps are preferable to a few larger structures. In reducing gully erosion, gradient control from these structures is probably more important than sediment storage. However, in arid locations, sediment storage and moisture retention are also important to treatment goals.

The gradient associated with stable channel conditions should be considered in the location and placement of structures. Information on calculating stable slopes is provided in NEH654.08. However, reducing grade in confined gully channels does not necessarily assure stability. In small intermittent gully channels, placing a series of low rock check dams with downstream splash aprons will allow the channel to dissipate the energy by spreading out the flow. Figure TS14P-20 shows a heavily grassed waterway where a series of loose rock check dams were used to reduce channel erosion. The rock checks provide frequent grade control and flow dispersal. The woody materials in the figure are the remains of failed log check dams that floated in onto the rocks.

Dam stability is inversely proportional to the height of the dam. The primary means to reduce gully expansion is to control the grade, provide flow dispersal at the dam, and velocity and grade loss below the dam. The next rock dam in the system should be placed just before flows concentrate, velocity accelerates, and channel degradation begins.

Numerous publications exist on rock dam construction in the West for gullies and entrenched channels (Heede 1976). Many include design and installation guidelines. When properly designed and installed, rock dams have proven effective in a variety of conditions and can withstand higher flows associated with larger channels. Their advantage in arid conditions is that they are helped by additional watershed improvements such as revegetation, but do not necessarily rely on them to be functional. Materials used in rock check

dams should be well graded. In small gullies, the loose rock fills appear more natural and effective in conforming to the channel dimensions. They are structurally limited in their stable height, so plunge effects from stormflow can be more easily mitigated. Natural or planted vegetation will often add to the structural integrity.

Figure TS14P-21 shows a loose rock check dam providing sediment retention and grade control in stabilized gully channel. Reducing grazing pressure helped to restore vegetation in this area.

Figure TS14P-20

A series of loose rock check dams used to reduce channel erosion, Union County, SC



Figure TS14P-21

Retention and grade control in stabilized gully channel, Alkali Creek, CO



All check dams need a control section and an energy dissipation section below it. They need to be spaced appropriately and have flanking protection as part of the design. In practice, most all are keyed into the bed and bank. Figure TS14P-22 illustrates an approach that is simple and small scale, but has at least partially failed because of the lack of a control section and energy dissipation. The result can be that the gully erodes around or underneath the structure(s). Figure TS14P-23 shows a check dam with a clearly defined

Figure TS14P-22 Gully control measure failed due to lack of control section and no energy dissipation



Figure TS14P-23 Gabion check dam provides sediment retention and grade control in stabilized gully channel, Afghanistan



control section, energy dissipation section, and appropriate bank key-in. This structure has succeeded in stopping and controlling gully formation.

Other materials are sometimes used for grade control dams when large rock materials are not available. These materials include soilcrete, aggregate-filled geotextiles, and gabions.

Rock and brush grade stabilization—Small dams constructed of alternating layers of rock and brush have been used extensively with good success in arid areas. These rock and brush structures usually are relatively short structures (less than 4 feet) and typically applied on drainage areas less than 200 acres. One of these structures under construction is shown in figure TS14P-24. As a type, rock and brush dams fall between the categories of rock dams and debris dams. Like these structures, rock and brush dams flatten the gradient and promote deposition. One of these structures that has been effectively working for some time is shown in figure TS14P-25. While relatively inexpensive, they do require design. NRCS-AZ has general design details available for the design of these structures (fig. 26).

Figure TS14P-24 Rock and brush dam under construction in AZ (Photo courtesy of Pete Bautista)



Soilcrete—This practice involves a mixture of approximately 50 percent soil and 50 percent concrete and is placed in cloth bags. The bags are stacked in layers across the channel, with some overlap. In figure TS14P-27, the soil and concrete were dry mixed with a cement mixer, placed in cloth bags, and eventually hardened from rain and flow. The bags are placed higher on the edges of the channel, and lower in the channel thalweg to allow for overflow. Some of these structures can remain in place in gully channels for decades, after successful revegetation controls surface flow. Higher flow rates and freeze-thaw eventually contribute to soilcrete wear and failure. Poor mixing of the materials can cause weak areas, cracking, and breakup.

Aggregate-filled geotextiles—Aggregate-filled geotextiles such as geoweb material can also be used where grade control is needed and where flows are not excessive. Some gradation in the materials is needed for proper compaction. These are best installed across the channel at the channel elevation, with no plunge downstream. They require some energy dispersal to prevent plunge development below the structure.

Figure TS14P-25 Rock and brush dam in AZ that has been working effectively (*Photo courtesy of Pete Bautista*)



Gabions—Gabions are welded wire or twisted wire baskets filled with rock. They can be used to form rock material into structural members (fig. TS14P-23). These can be very effective treatments especially in low precipitation areas. They can also be constructed relatively cheaply and can withstand high stresses. Drawbacks of gabions include that they often need extra care in installation. Settling of materials, plunge pool development, soil piping, and flow diversion around or under structures can also cause failure. NEH654 TS14K provides guidance for the design of gabion structures.

Grade control structure

A rock grade control structure can be used in channels or waterways to help disperse flow and provide grade control. Figure TS14P-28 shows a reshaped gully in Abbeville County, South Carolina, with a terrace failure that resulted in severe erosion within two waterways within a tributary of Curtail Creek. Flows from outside road and trails also contributed to the failure. The grade control structure is lined with filter cloth and filled with rock. It provides grade control and flow dissipation in each waterway, but no storage of sediment. Several of the structures were installed in each waterway. The rocked gully plug uses a culvert to protect against overflow. Filter cloth check dams were installed downstream to capture sediment. This structure was constructed with a 3-foot deep ditch across the channel lined with filter fabric and filled with materials that will not easily erode. A variety of materials can be used to construct grade control structures. These may include logs, concrete, bricks, and weathered asphalt waste.

Another example of a grade control structure is shown in figure TS14P-29. More information is available in, NRCS National Practice Standard 410, Grade Stabilization Structure. This standard applies to all types of grade stabilization structures, including a combination of earth embankments and mechanical spillways and full-flow or detention-type structures. This standard also applies to channel side-inlet structures installed to lower the water from a field elevation, a surface drain, or a waterway, to a deeper outlet channel.

Figure TS14P-26 Detail for rock and brush grade stabilization

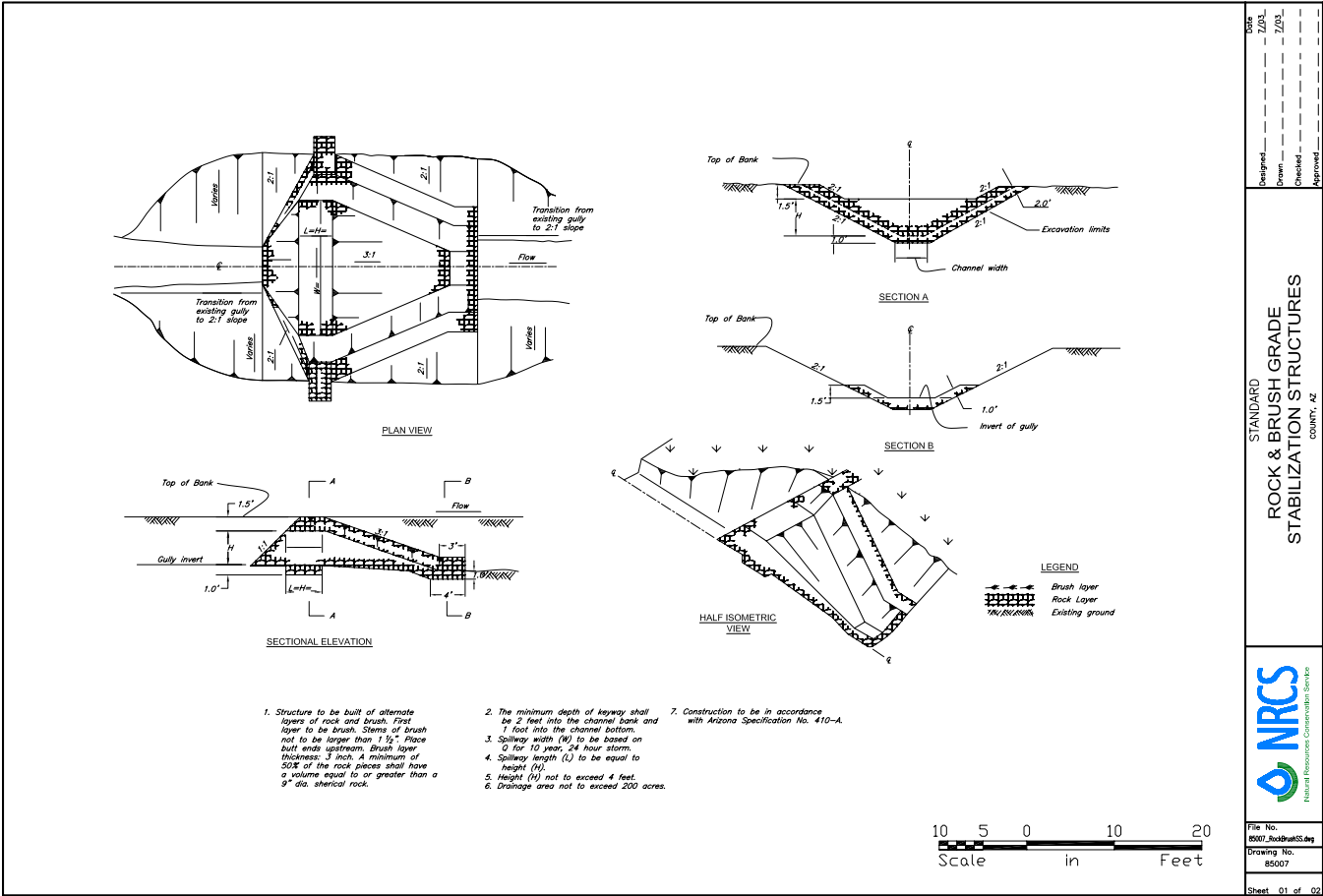


Figure TS14P-27 Soilcrete used to construct a small grade control structure



Figure TS14P-28 Reshaped gully with terrace failure, Abbeville County, SC



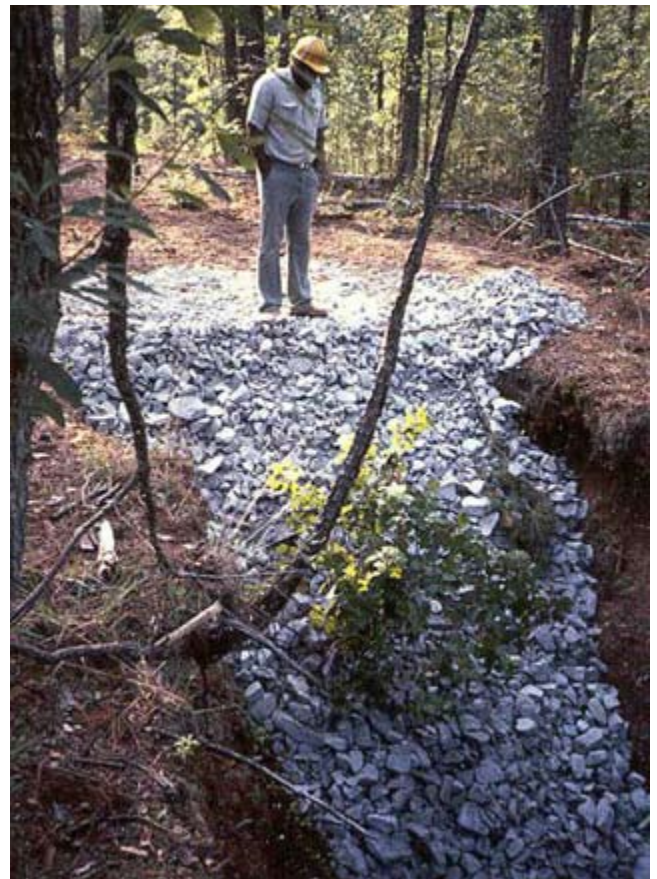
Figure TS14P-29 Grade stabilization structure



Rock treatments

Rock materials can effectively treat some of the moderate to severe gully erosion. Crushed rock and gravel and cobble-sized rock placed in gully nickpoints provides effective channel cover and erosion control, while allowing surface water flow to be dissipated (fig. TS14-30). The gravel allows water to disperse and lose energy as it moves past nickpoints, controlling erosion. This treatment is generally applicable to gullies with small drainage areas. Within a few months, the vegetation and other treatment measures will help control erosion and reduce the concentrated flow from the hillslopes. In humid climates, grass and tree

Figure TS14P-30 Gravel treatment in active gully head armors the surface and conveys stormflow from failed terrace and lowers it to the more stable main gully channel



growth will develop in 3 to 5 years to control runoff. Rock placement provides immediate benefits, but can be costly when materials are not readily available and where hand labor is required.

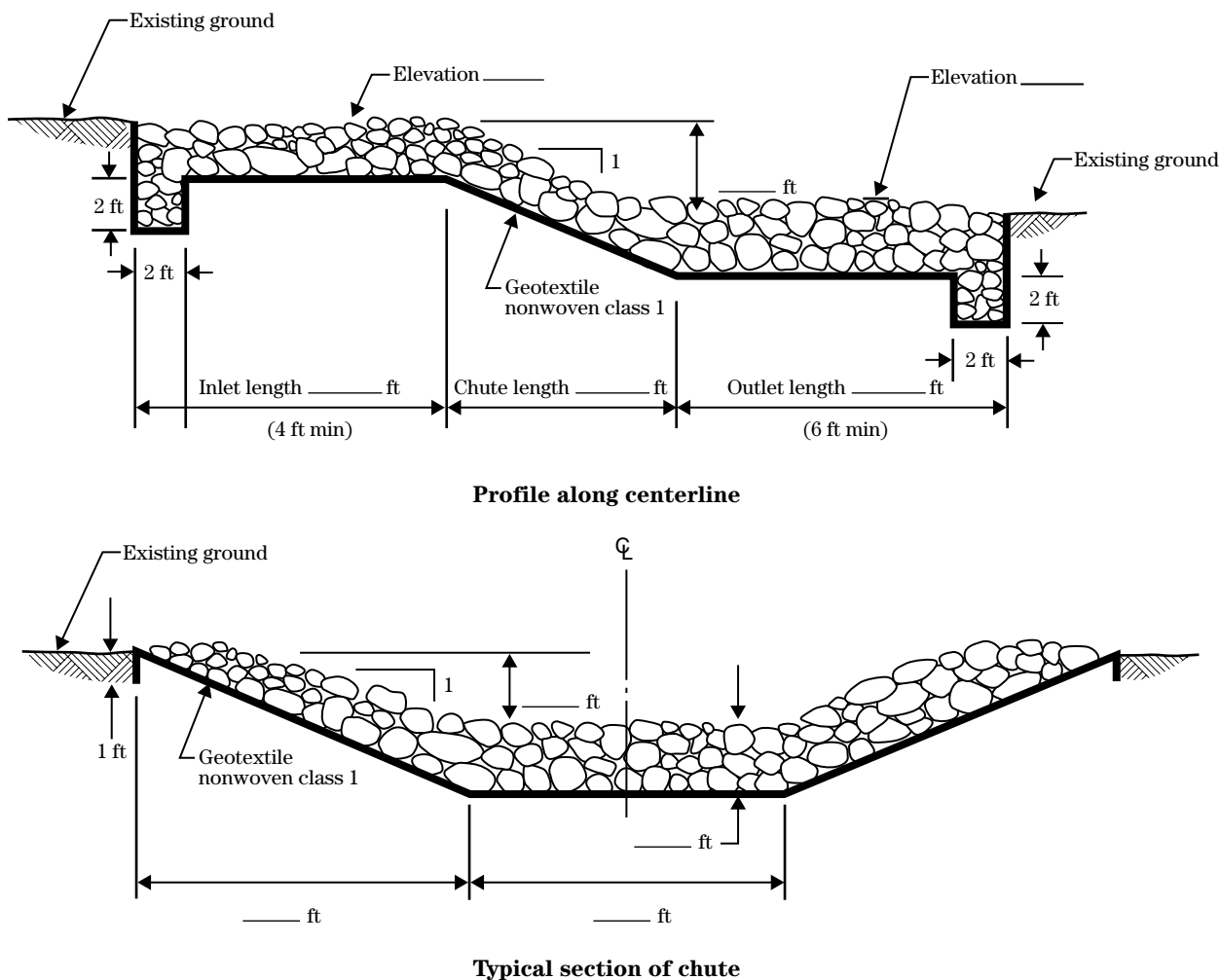
Rock chutes are grade control structures that are designed to reduce instream gradients or provide stable entry for surface water drainage to a stream. An example of a rock chute is shown in figure TS14P-31, and example design drawings for a rock chute are shown in figure TS14P-32 (NRCS-MI). Rock chutes are addressed in more detail in NEH654 TS14C.

Figure TS14P-31

Rock chute constructed to prevent gully erosion at surface water inlet to stream, SD



Figure TS14P-32 Design drawings for rock chute grade control structure



Prior to the establishment of vegetative cover, rock is occasionally used to stabilize gullies, waterways, terraces, contour trenches, or diversion ditches where excessive rainfall and erosion occur. While easily implemented, the approach shown in figure TS14P-33 may not be appropriate in an actively farmed field. In addition, it may not prove to be successful in the long term without land treatments.

Water diversion

Water diversions capture and transmit stormwater away from the gully. They are especially appropriate when roads, terraces, parking lots, urban and housing developments, or water transmission or other activities have captured or diverted flow into the gully channel. Removing other contributing flow sources can help stabilize active gullies and are used when there is a place to divert the water for dispersal and infiltration without accelerating erosion on an adjacent area. The larger the contributing drainage, the less likely this technique will be effective. Costs are generally low; however, the ability to divert water is often limited in severely gullied terrain. The diversion outlet should be on relatively flat to moderately sloping terrain with good cover and infiltration capability. Field review of soils, landforms, and bedrock will help prevent activating other types of mass erosion instability in the process of diverting flow. Stormwater storage of diverted waters in retention ponds may be appropriate for some applications.

Figure TS14P-33 Rock placed in gullies armors the flow path on steeper slopes to prevent gully advance



Terraces are a type of water diversion placed systematically along a slope to remove stormwater from a gully treatment area before surface erosion and severe rilling occur. Terraces need stable gradients (preferably 1.5% to 2%), so that runoff water will move effectively from the area without aggradation or degradation. However, gullies can be caused by abandoned or unmaintained farm terraces. Terraces and other water conveyance structures may eventually fill in, settle, or weaken from buried debris, plant roots, rodents, and other burrowing animals that can contribute to soil piping. For these reasons, hillslope terraces need periodic maintenance to function correctly. Increasing terrace size to an effective depth of 2 to 3 feet and adding some soil compaction from equipment are more costly, but will provide added insurance that minor settlement or sedimentation will not alter their function. Conversion of contributing areas to permanent forest and grasslands will often increase soil infiltration and plant transpiration to the extent that terraces are no longer needed, as surface flow is no longer present.

Waterways

Waterways are sometimes constructed to prevent gully erosion when water and associated erosive forces cannot be diverted, defused, or contained. Special treatments or designs are often necessary when dealing with highly erosive soils to ensure rapid stability through vegetation, channel armor (gravel, rock placement, erosion blankets, and hedges), geotechnical, or soil bioengineering materials. Surface water energy is dissipated through a channel-type system. Incorporating channel features consistent with other stable streams in the vicinity with similar watershed size and conditions would approach restoration goals. More information on the design of a waterway is provided in NEH654.07, in the design of threshold channels.

Rock treatments have been used in small gullies to facilitate immediate repair. Figure TS14P-34 shows a reshaped gully with rock-filled concentrated flow channel. Stormflow from the contributing 40-acre drainage area above the treatment area resulted in severe erosion of the waterway before erosion control measures were established. Soilcrete check dams were used for immediate stabilization, but the severity of the erosion made long-term stability a major concern. However, the erosion resulted in a relatively natural looking channel that entrenched several feet

into the landscape. Filling much of the storm channel with the crushed rock provided the desired immediate stability and a waterway with some sinuosity and natural function.

Geotechnical materials, fiber logs, and erosion mats may provide waterway protection and aid vegetative recovery, but costs can be excessive on large project areas. Careful attention to manufacturers' recommendations is needed when using prefabricated materials, and to ensure that the materials' performance criteria meet the needs of the application. Grass sod may be useful when placed at frequent intervals across the waterway, to cover much of the waterway to provide an immediate increase in flow resistance and channel stability. Vetivergrass and switchgrass hedges and plantings have also been reported to protect and stabilize the soil on steep banks and in concentrated flow channels (National Research Council 1993; Dabney et al. 2004). On larger channels, soil bioengineering or similar channel design techniques as described elsewhere in this handbook can help supply short and long-term stability needs.

Fertilization

The application of fertilizer to treat gullies can be an effective method to increase plant diversity and density (McKee and Law 1985; McKee, Gartner, and Law 1995). Soil nutrient testing should be conducted to

verify nutrient needs. For example, in the South Carolina Piedmont, nitrogen and phosphorus have been depleted on severely eroded sites, and applications of 400 pounds per acre of pelletized 35-17-0 (%N-%P-%K) have proven invaluable to increase survival, growth, and enhancement of vegetation. Where gully and watershed conditions are beginning to stabilize, fertilization may be the only treatment needed to accelerate recovery. Marked benefits in plant growth and density have been documented for more than 5 years from a single application of slow-release fertilizer onto problem soils in the South Carolina piedmont. Other soil conditions may benefit from fertilizer application; however, the type of nutrient needs will dictate the amount and type of fertilizer used.

Land reshaping

Land smoothing or reshaping has been a useful approach for active complex gully systems, but this method provides the best long-term rehabilitation or restoration, when all resources and benefits are considered. Land reshaping to smooth the surface to less than 25 percent slope is typically done with dozers, but a pan scraper with one or more dozers can efficiently move soil on larger treatment areas. Reshaped gully slopes over 25 percent are extremely difficult to stabilize with standard erosion control practices. Soil from adjacent areas is typically borrowed for use to fill in and reshape the treatment area. Adjacent soils may be highly erodible, and intensive erosion control measures may be needed to prevent gully formation.

Practices associated with land reshaping may include diversion ditches, waterways, contour trenches, subsoiling or ripping the soil (18 to 24 in deep and sometimes in two directions), liming, fertilizing, mulching, seeding, planting trees, and several years of maintenance. Primary costs are for equipment use. This method relies on several interdependent steps and timing for success. Land reshaping and smoothing may be questionable where conditions will not favor vegetative regrowth needed for erosion control. Land reshaping should not be attempted without aggressive erosion control to address the exposed soils and concentrated flow issues.

Figure TS14P-34 Reshaped gully with rock-filled concentrated flow channel, Union County, SC, 1987



Examples of using another type of land reshaping in arid areas on a smaller scale provides individual tree catchments or scallops in the surface by digging small contour trenches, potholes, or pits for each tree (Cohen 1994; Fayang 2004). The catchments intercept much of the sparse rainfall/runoff, capturing the rainwater for each tree. As the trees develop and flourish, leaf fall and other vegetation begin to develop a soil cover. With time, infiltration improves, runoff declines, and nutrients recycle. Gradually, additional benefits accrue in enhanced water tables, reduced flooding, and increased baseflow. This treatment has also been used in the American Southwest (Schmidt 1994).

Example: Gully erosion control guidelines

Reshaping gullies can be a wasteful and ineffective experience if the measures and operations are not designed, implemented, checked, and maintained until they are stable. The following are suggestions or guidelines that have produced benefits from humid South Carolina conditions (Hansen 1995). The user is cautioned that modifications to these guidelines may be needed to account for conditions in different areas. However, many of these recommendations are broadly applicable.

- Avoid land reshaping during dry periods (hardened soils) to reduce costs.
- Treat active rill or gully erosion before it erodes into the saprolite (or other extremely erodible material) to avoid gully expansion and added costs.
- Avoid exposing or using saprolite as fill material, when possible.
- When moving large amounts of soil on relatively flat or moderate slopes, a pan earthmover is almost twice as effective as a dozer, resulting in reduced costs.
- Design drainage terraces with uniform slope gradients of 1.5 to 2 percent.
- Space terraces to control erosion and disperse surface flow into filter areas.
- Compact fill materials when needed to avoid settling or failure.
- Plant trees in soil rips to capture and retain moisture to improve survival.

- Construct terraces (about 3 ft deep) to minimize maintenance and prevent failure due to settling of soil.
- Tree survival and growth increase when planted the same year as the grasses.
- Inoculating seedlings with mycorrhizae may improve survival and growth.
- Maintain the investment by checking after major storms or other disturbances.
- Without project design and contract, equipment with operator rental may pose less risk resulting in lower cost, but with higher technical administration fees.
- Maintain access for equipment until the area is fully stabilized.
- Check terrace outlets, waterways, structures, channels, and other flow conveyances for stability, especially after major events.

Example: Conceptual treatment design—rock check dam

The following describes the site assessment and concept design for gully control at a site in Sumter National Forest of South Carolina.

Site selection—From problem site visits, gully channels with 2 percent or less gradient are generally not actively entrenching and expanding into the surrounding area. A gully section with a 6 percent gradient is actively eroding and expanding. Old agricultural terraces and uncontrolled road drainage may be adding flow to the gully, and continued nickpoint migration upstream will cause further channel instability and sediment effects.

Treatment selection—Grade control and some sediment storage with rock check dams are needed, but major plunge development in the highly erodible soils must be avoided.

Treatment concept design—Dam height is limited to 2 feet with some rock dissipation below each one. The initial grade minus the desired gradient is 4 percent. Therefore, over each 100-foot length of the gully channel, a 4-foot loss in elevation must be achieved so that the effective gradient between the check dams becomes 2 percent. For each 100-foot spacing, two 2-foot check dams will reduce the gradient by 4 percent (4 ft/100 ft), so the spacing should be at 50-foot intervals.

Conclusion

Gullies can have serious negative impacts. These impacts can range from loss of agricultural production to impacts on water supply and channel conveyance to destruction of downstream habitat. However, there are numerous land management and treatment practices that have proven effective in stopping gully formation.