Case Study 11 Streambank Stabilization in the Red River Basin, North Dakota

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Cover photo: Treated section of Cole Creek in the Red River Basin in North Dakota

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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Introduction

Geologic and geographic features of the Red River Valley in North Dakota, Minnesota, and southern Manitoba create unique geotechnical challenges for slope and streambank stabilization efforts (fig. CS11–1 (University of North Dakota (UND) Energy and Environmental Research Center). The extremely low-gradient landscape (0.2 to 1.5 ft/mi) formed less than 10,000 years ago by the retreat of Glacial Lake Agassiz and is frequently subjected to overland and out-of-bank flooding from the Red River and its tributaries. The relatively young river network of the valley cuts sinuous channels through glacial lacustrine sediments that have been developed into some of the richest agricultural land in the world. Beneath the rivers and agricultural lands are layers of highly plastic clays deposited in the ancient lakebed. The clays shrink and swell in reaction to the region's extreme seasonal climatic swings and are subject to slope failure where they are unconfined along the river meanders.

Figure CS11–1 Boundaries and shaded relief of the Red River Basin

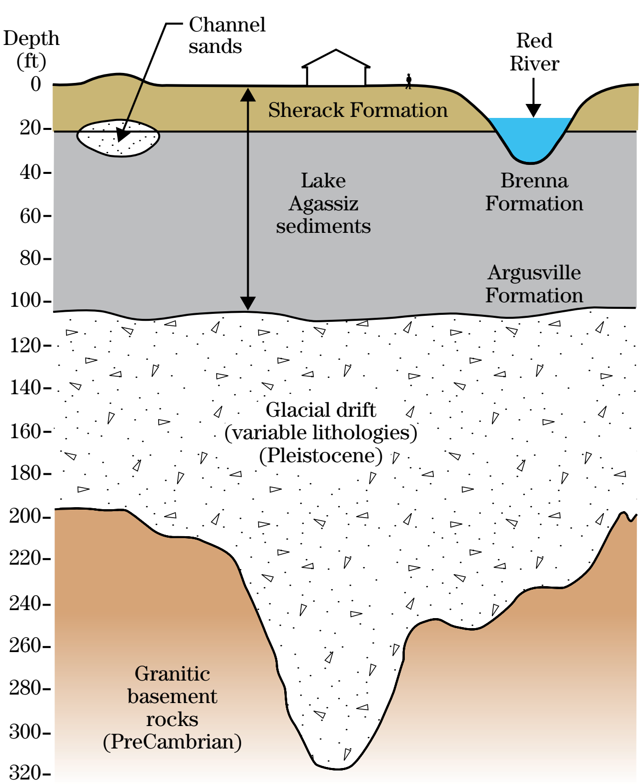
Project planning

For the past 8 years, the Red River Basin riparian project staff have been working to restore riparian zones and stabilize stream channels and banks in the Red River Valley. The project, funded through the U.S. Environmental Protection Agency's (EPA) Clean Water Act Section 319 program, seeks to improve water quality throughout the watershed. Expertise from a variety of Federal, state, and local agencies is provided to the project through subcontracts and cooperative agreements. Project cooperators include the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), North Dakota Forest Service, North Dakota State Water Commission, University of North Dakota (UND), and local soil conservation districts. The project's involvement in several slope-failure stabilization efforts within the valley has ranged from providing geotechnical information to design and implement engineering and soil bioengineering solutions. The project staff are frequently contacted for assistance with a failed riverbank where the riparian vegetation has been removed or altered and the hydrology has been changed. Although the main goal of the project is to restore a functioning riparian forest to act as a filter between urban or agricultural land use and the river, stabilization of active slope failures is frequently necessary before riparian restoration can be implemented.

Geologic history and geomorphology

Project staff and cooperators recognized at the project's onset that understanding the causes of slope failure was essential to identify riverbank stabilization solutions. The main source of the riverbank instability is the thick highly plastic smectitic clays and silty-clays formed by eroded Cretaceous shales and glacial tills (Schwert 2003). These suspended sediments were deposited over the glacial lakebed in thicknesses of 100 feet or more. The Sherack Formation (fig. CS11–2 (Schwert 2003)) comprises the upper 20 to 30 feet and consists of light colored, silty, laminated clays that were deposited in shallow water of the glacial lake (Harris, Moran, and Clayton 1974). Beneath this are the dark, highly plastic clays of the Brenna/Argusville formations (fig. CS11–2) that were deposited in deep water during higher lake levels (Harris, Moran, and Clayton 1974). Soil tests of the two formations yield high plasticity index values and liquid limit results and consistencies that range from very soft to rather stiff.

Figure CS11–2 Typical cross section of Red River Valley near Fargo, ND



Hydrologic effects and slope failures

These clay soils cause significant geotechnical problems, especially where they are unconfined. Because of the low-gradient and underfit nature of rivers in the valley, sinuosities are very high (>1.5), creating meanders with a very low radius of curvature. In tight meanders, higher velocity flows are forced against the outside of the channel, eroding the slope toe and steepening the bank. This natural process leads to frequent slope failures along the Red River and its tributaries. The two most common types of slope failure are rotational slumps and flow slumps (fig. CS11–3), with creep and earth flows occurring to a lesser extent.

Although these slope failures naturally occur in the Red River Valley, their frequency and severity has been exacerbated by clearing of riparian vegetation, development of riverside land, and changes in basinwide hydrology. Since the settlement of the Red River Valley in the mid- to late 1800s, the riparian galley forests have been cleared to make use of the rich soils and provide lumber for construction and fuel for steamboats. In recent years, expansion of the valley's urban centers for residential and commercial development has led to the removal of some of the remaining band of forest and native vegetation. Developers and homeowners will often remove or thin the riverbank vegetation for a clearer view or easier access to the river.

Enhanced soil moisture, a critical factor of slope stability, is frequently the result of development. Removal of the moisture-loving native plants and trees, installation of lawn sprinkler systems, and septic drain fields may double or triple the amount of moisture these soils typically receive annually. Local hydrology is altered as homeowners seek to move water away from their houses and, logically, toward the river. However, water from gutters, sumps, and yard drains only helps to saturate the already wet slopes (fig. CS11–4 (UND Energy and Environmental Research Center)).

Regional hydrologic changes may be contributing to the problem, as well. Increased drainage of agricultural land during the last 50 years and record precipitation during the past decade have led to frequent and significant flooding in the valley. The precipitation

Figure CS11–3 Types of slope failures

(a) Rotational failure near Reynolds, ND

(b) Flow slump failure near Wild Rice, ND

Figure CS11–4 Slump flows caused by septic drain fields near Fargo, ND

and flooding, especially during frost-free months, has drastically increased ground water levels and soil moisture. These changes in discharge and flooding have caused river channels to downcut and widen as they adjust to new flow regimes. The combined effect of the factors described above has been a rapid increase in the number of slope failures across the Red River Valley.

Project area: Grand Forks Country Club restoration site

Efforts to stabilize a rotational failure along Cole Creek in Grand Forks County, North Dakota, make a good case study of the difficulties posed by soils and hydrology in the Red River Valley. Project staff and cooperators worked with the Grand Forks Country Club (GFCC) Board of Directors, Club Manager, Golf Course Manager; two engineers; and three contractors to address a 2-acre slump that had damaged one of the club's golf cart bridges over the small creek. Two attempts using a variety of techniques were made during a 3-year period to stabilize the failure, some working better than others. Throughout the process, the goal of the GFCC was to find an effective, relatively inexpensive, and aesthetically pleasing way to stabilize the slope failure and protect a new cart bridge. The project entered the effort with the main goal of influencing riparian management along Cole Creek to improve water quality. Project staff and cooperators felt that the stabilization site provided an opportunity to demonstrate soil bioengineering and riparian restoration techniques to club members and residents of the greater Grand Forks area.

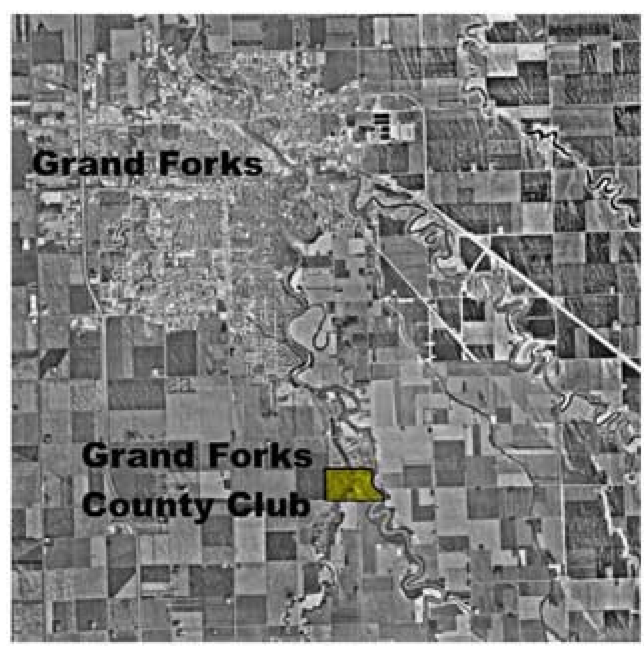
Watershed conditions

GFCC is located approximately 2 miles south of Grand Forks, North Dakota, where Cole Creek confluences with the Red River (fig. CS11–5). Cole Creek is a small stream draining nearly 300 square miles of agricultural land. The stream is intermittent in its headwaters, to perennial at its mouth, flowing regularly in the spring and during summer rainfall events. It is impaired along much of its length by a high sediment load, lack of riparian vegetation, low flows, and extreme summer water temperatures. When the golf course was built in 1963, trees, shrubs, and native vegetation were removed from what was previously a cattle pasture to create fairways and rough. In addition to vegetation and land use changes, Cole Creek has been adjusting to increased discharge from a legal county drain that expanded the watershed by nearly a third. This change in hydrology caused the channel to downcut and become incised throughout most of the GFCC. Wet weather and backwater from Red River flooding in the 1990s saturated the unstable soils adjacent to the entrenched channel and triggered slope failures throughout the course.

Stream problems

Evidence of the slumping that had damaged the golf cart bridge was visible in aerial photographs as early as 1997 (fig. CS11–6). As the 330-foot-long rotational failure settled toward Cole Creek, it unearthed the wooden bridge pilings, narrowed the creek channel, and raised the channel bottom (fig. CS11–7).

Figure CS11–5 Location of GFCC site in proximity to Grand Forks, ND



The narrowing of the channel at this point increased flow velocities, causing accelerated bank and channel scouring downstream (fig. CS11–8). A survey of the slump area showed the channel banks to be as steep as 2H:1V or greater and the slope grade to average 5H:1V (fig. CS11–9). A geotechnical report produced for the design for the new golf cart bridge suggested that the rotational failure could be 100 feet wide and 45 feet deep (CPS 2000).

Figure CS11–6 1997 aerial photo of Grand Forks Country Club slump, marked by arrow

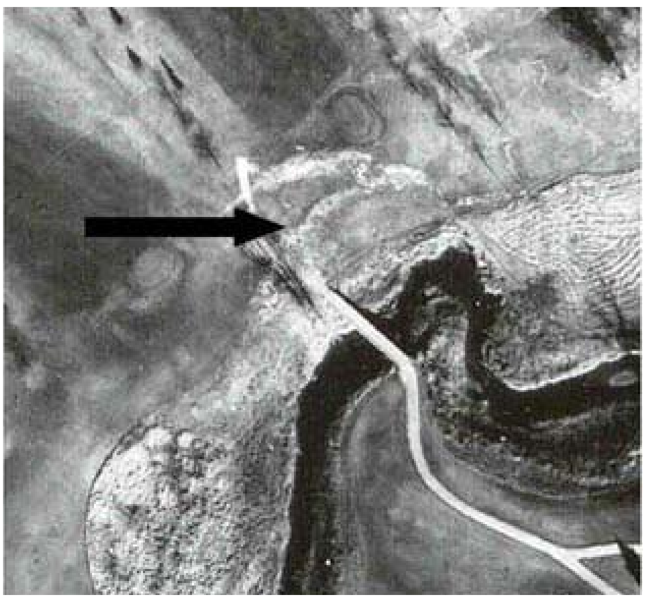
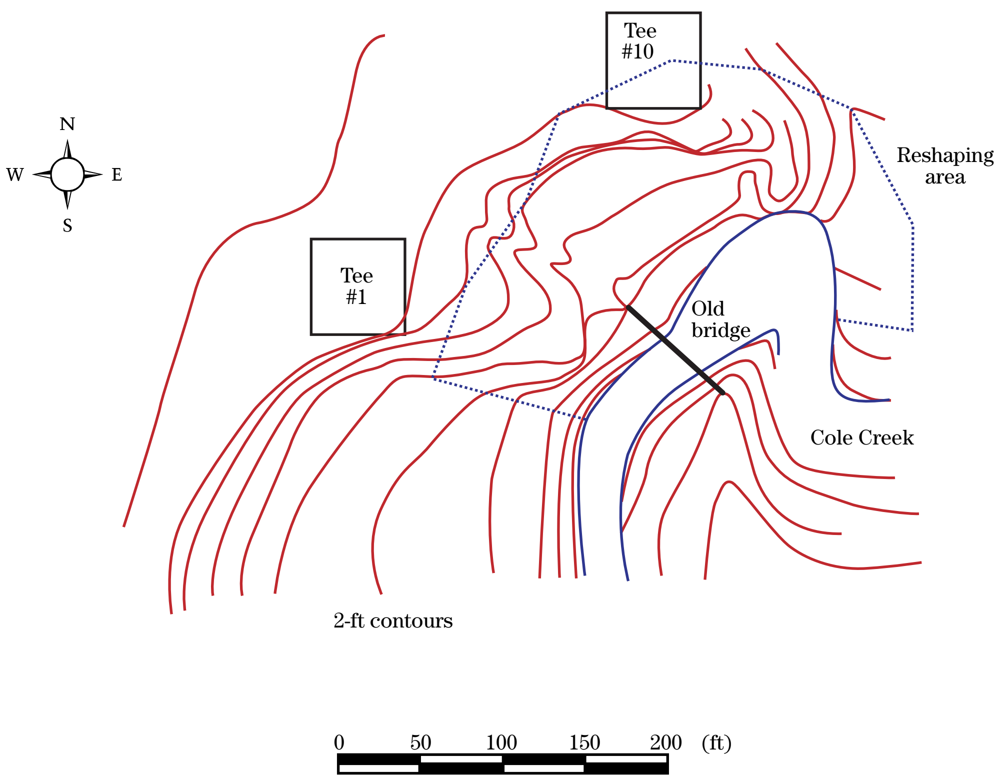


Figure CS11–7 Looking upstream on Cole Creek at the GFCC Cart Bridge (old)

Figure CS11–8 Looking downstream on Cole Creek at the scour erosion caused by the narrowed channel

Figure CS11–9 Topographic map of the slope failure prior to restoration



Planning and design for solutions

Typical efforts to stabilize this type of failure may call for keying significant quantities of rock riprap into the slope toe and channel bottom, balancing the forces causing the rotation. This method has been effective, but can be expensive, not as aesthetically pleasing, and may exacerbate downstream erosion problems. To address these concerns and balance the slump block, the project engineer called for reshaping the existing slope to a 7H:1V or 8H:1V grade and removing an estimated 10,000 cubic yards of soil from the top of the slump, reducing the loading weight. See the grading and restoration plan in figure CS11–10 and also the soil bioengineering and planting plan in figure CS11–11. Toe protection was also an essential aspect of keeping the reshaped slope in place. Rootwads were selected to be installed within a band of rock armor (105 yd^3).

It was expected that the rootwads would deflect energy away from the bank and that the rock would add weight and protect the toe during above-bankfull flows.

Moisture management was another factor that was considered as a solution to stop the slumping. Both natural and human sources were supplying water to the slope. Floodwaters, record precipitation during the last decade, and irrigation for the tee box and fairway above the slope combined to saturate the soils, add weight, and lubricate the slickensides in the clay soils. The project sought to solve this issue through irrigation management and the installation of deep-rooted, moisture-wicking vegetation. The plan developed by a North Dakota Forest Service riparian forester called for 2,400 dormant live sandbar willow stakes to be installed over a 7,200-square-foot area (fig. CS11–11).

Figure CS11–10 Design contours for grading and stabilizing slope failure

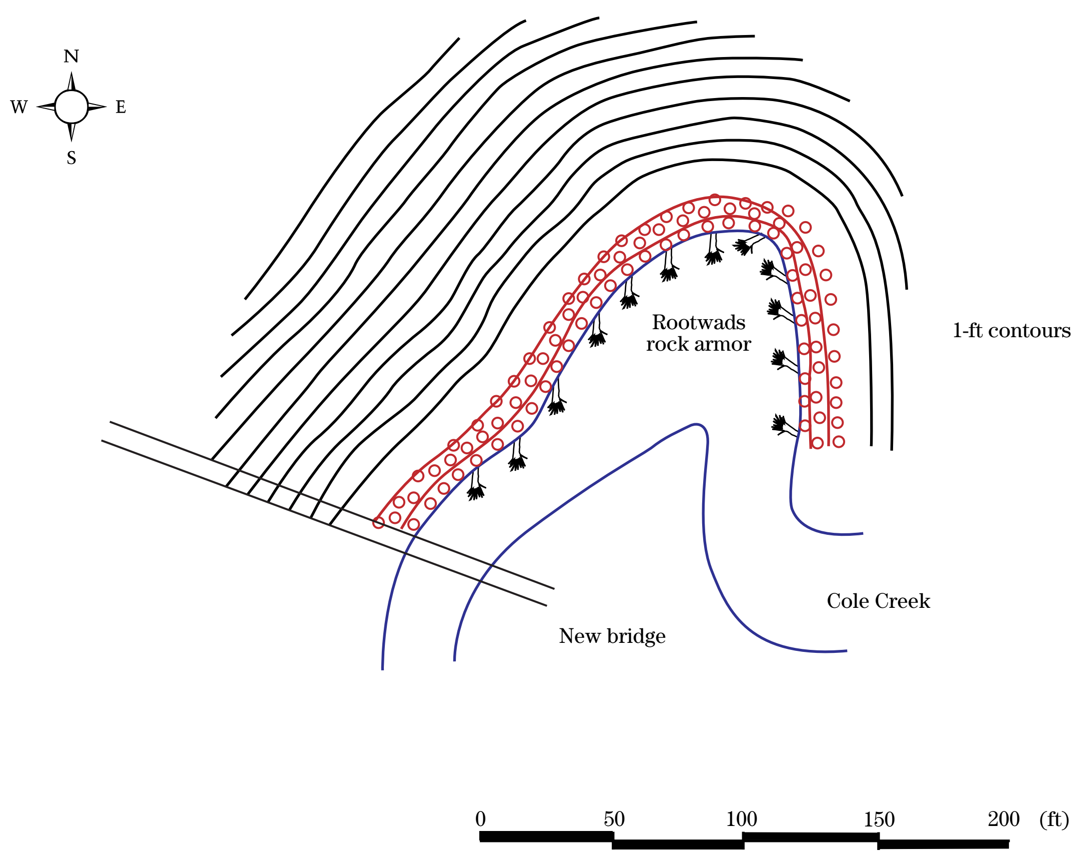
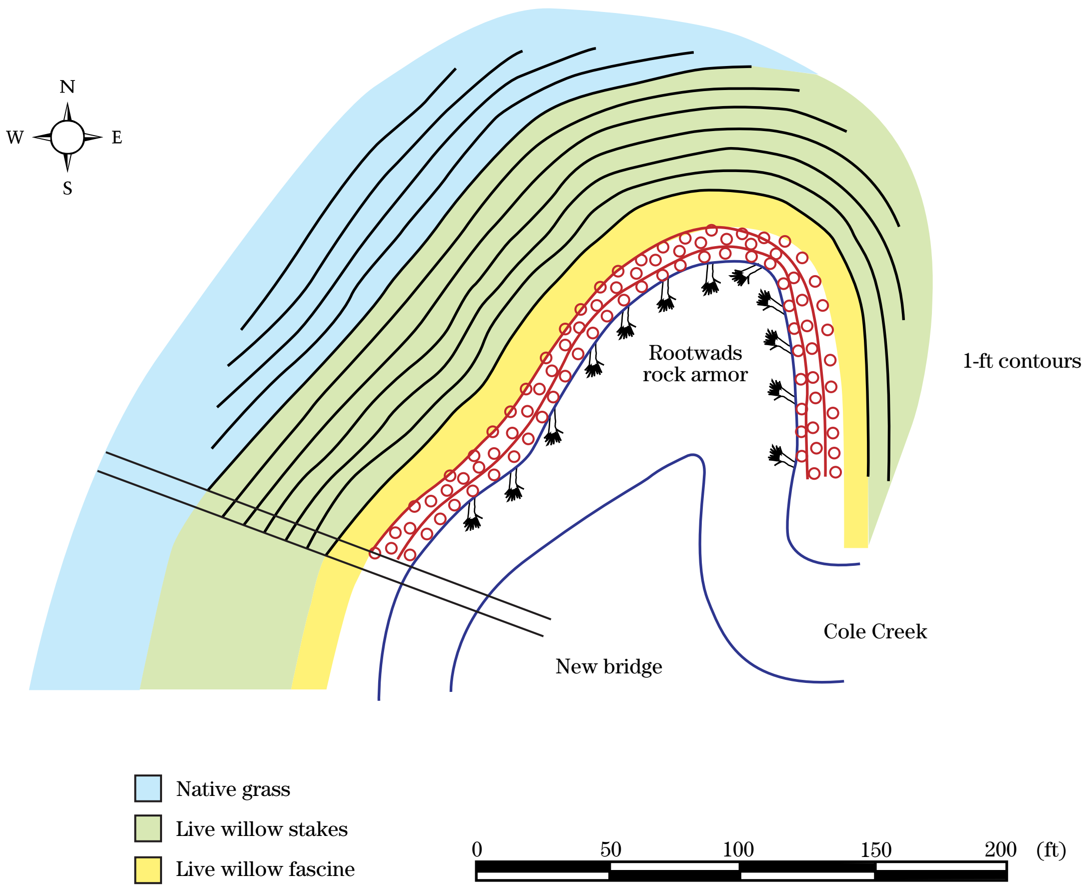


Figure CS11–11 Soil bioengineering and planting plan



Below the willow stakes, 450 feet of live willow fascine would be installed for additional root mass and flow energy deflection from the slope toe. To maintain access to the fairway, the top of the slope was to be planted with a mix of deep-rooted native grasses, including switchgrass, buffalograss, and big and little bluestem grasses. These grasses would take up more soil moisture with their larger and deeper root network and require little to no additional watering.

The design was not immediately accepted when presented to the GFCC Board of Directors. Both the earthmoving and revegetation plans indicated that a portion of a tee box would need to be removed. After negotiations, it was agreed that the tee box could stay, but that the final slope grading below the tee would be closer to 5H:1V and, therefore, would be less stable. It was explained to the GFCC Board that careful irrigation management or ceasing irrigation at the tee would be critical to success of the project, given the steeper final slope.

Restoration solutions: Construction and storm repairs

In March of 2001, the slope reshaping and rock and rootwad installation had been completed during the construction of the new golf cart bridge (fig. CS11–12). The plant materials were installed in June and by August were growing vigorously (fig. CS11–13). Total cost for the work was $33,400, with the excavation accounting for over half of the expense. With the exception of the native grasses being replaced with Kentucky bluegrass and irrigation continuing as before, the stabilization appeared to be holding.

However, by late fall, some minor slumping had occurred adjacent to the bridge where fairway drainage had not been diverted from the slope. The project engineer recommended repairs in the winter of 2002 that included stopping irrigation above the slope, diverting all drainage away, and replacing the Kentucky bluegrass with deep-rooted vegetation such as alfalfa. The project engineer also recommended that rock or fill be placed at the toe of the recent slumping to balance the downward forces and that additional rock be placed along the toe of the entire repaired reach. The weather during summer 2002 prevented the repairs from being completed.

Frequent widespread, severe storms between May and August 2002 brought torrential downpours and summer flooding not seen in the past 50 years. The Cole Creek Watershed was struck by two storms that dumped over 10 inches of rain in each event. The torrents that flushed through the creek were followed by backwater flooding from the Red River. At four times during the summer, the repaired slump was inundated to the bridge deck. Complete sections of the rock toe

Figure CS11–12 Downstream view of Cole Creek, May 2002, prior to planting

Figure CS11–13 Downstream view of Cole Creek, August 2002, after planting

had been washed away or slipped into the channel (fig. CS11–14). Portions of the fascine and entire rootwads had been pulled from the bank. Without toe protection and sufficient counter-balancing weight, the saturated slope began to move, rotating 2 feet and narrowing the channel by 4 feet. The force of the rotation had even bent the bridge piers that were set 80 feet into the clay.

Restoration attempt number 2

Project staff and the project engineer met with the GFCC Board that winter to discuss new alternatives to stabilize the failure. The engineer recommended that the slope be graded to at least 8H:1V and possibly 10H:1V, based on stable grades observed up and downstream of the site. It was also recommended that 325 cubic yards of rock riprap be placed over geotextile along the entire reach (fig. CS11–15). The rock was to have a D_{50} of 10 inches and would be keyed into the toe, extending 12 to 15 feet up the slope. The wedge of rock would protect the toe to bankfull events and above and add counter-balancing weight.

An aggressive revegetation and soil bioengineering plan was also developed for the site (fig. CS11–11). To deflect energy from flood flows, increase the root mass at the toe, and improve the aesthetics, a live wil-

Figure CS11–14 Views of Cole Creek looking downstream from the new cart bridge

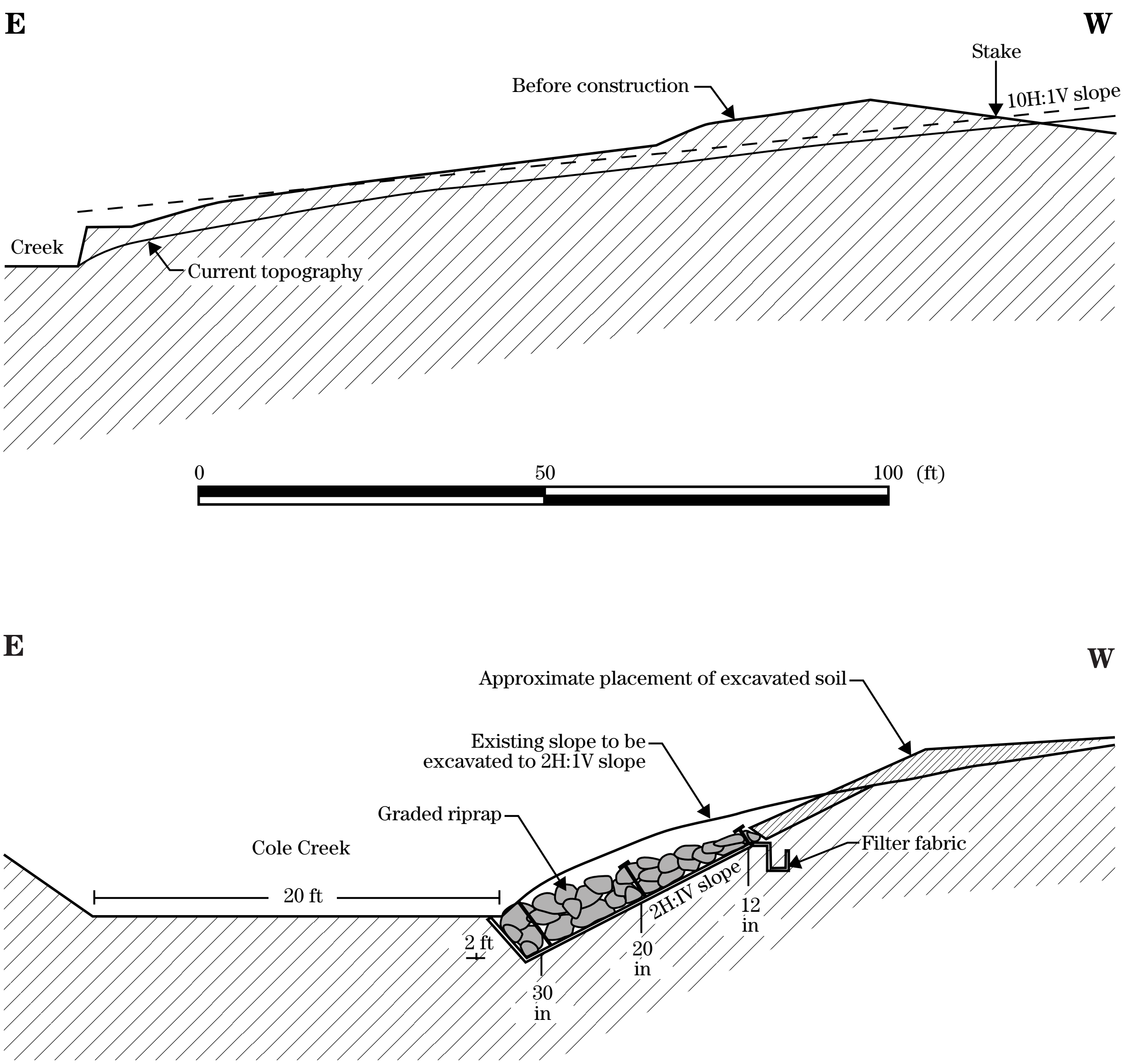
(a) Arrows indicate the same rocks in the stream

(b) Views of Cole Creek looking back upstream towards the bridge

low brush layer installed within the rock was planned for the section between the bridge and the meander. Excess moisture within the slump was addressed by installing three live willow pole drains among a dense planting of live willow stakes, rooted sandbar willow, and false indigo conservation stock. It was expected that the willow drains would intercept surface and shallow through-flows and direct them away from the slump, while the deep-rooted shrubs and trees would pull moisture from the clays. The plan again called for the upper portions of the slope to be planted with a deep-rooted grass and forb mixture to include prairie cordgrass, Canada wildrye, and switchgrass. All species planned for the site were flood tolerant, given the expectation of future flooding events.

The GFCC Board agreed to the plan, even though it required the removal of a tee box to achieve a 10H:1V slope. In fact, the club carried the plan a step further by planning the installation of a 6-foot-deep French

Figure CS11–15 Cross section of the slope showing the slope grade before construction and during repairs. The planned 10H:1V grade is shown for reference. Note that fill from the excavation will be placed directly above the rock.



drain that would divert surface and subsurface water from the fairway to either side of the slope failure.

Construction began in early June 2003 and was completed within 10 days (figs. CS11–16 through CS11–18). A nearly 10H:1V grade was achieved by removing material from the top of the slope, as well as placing fill above the rock toe. Total cost for the repairs was nearly $26,000, bringing the grand total for the site to $59,400. Table CS11–1 shows a breakdown of the costs. Repairs to the bridge pier had been completed earlier by installing four 16-inch, concrete-filled steel pipes 100 feet into the clay. Construction of the French drain and the native grass seeding was completed during drier weather in August 2003.

Repairs to the site appear to be functioning well; the vegetation is flourishing, channel erosion is limited, and the rotational slope failure is stable (fig. CS11–19).

Figure CS11–16 Aerial view of slope grading and earthwork to place rock toe

Figure CS11–17 Rock toe being placed over geotextile. A layer of live willow branches is visible within the rock toe.

Table CS11–1 Costs of the slope failure repairs by practice

Practice description	Cost
Earthwork for slope grading	$ 5,265
Installation of rock riprap at slope toe	$14,400
Live willow brush packing	$ 1,250
Installation of willow stakes and rooted tree and shrub stock	$ 3,464
Installation of live willow pole drains	$ 1,200
Native grass seeding	$ 240
Total cost	$25,819

Figure CS11–18 Completed stabilization

(a) Looking upstream toward the cart bridge

(b) Looking downstream from the cart bridge

Figure CS11–19 Slope stabilization and soil bioengineering project in May of 2004

(a) Looking downstream into the meander

(b) Looking upstream toward the new golf cart bridge