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16. Abstract

The Texas Department of Transportation (TxDOT) has commonly utilized concrete and other non-biodegradable measures to stabilize stream channels throughout Texas. This research project investigated an alternative stabilization method specifically geared toward the warm regions of Texas, which utilizes live plant materials combined with inert materials such as geosynthetics and rocks to provide protection of streambanks or slopes. In this project, researchers designed five demonstration projects and conducted plant dormancy extension experiments on black willow (Salix nigra). Two of five designed projects were let, and only one project was built. Researchers found that in biotechnical engineering, live plant cuttings are harvested and planted in the dormant period. Texas's short dormant periods make biotechnical construction scheduling very difficult. Following the definition of short dormant period in Texas, researchers conducted the dormancy extension research, which investigated the possibility of extending the dormancy window of live cuttings for construction of biotechnical techniques. The result of the dormancy extension research indicates that black willow cuttings may be able to be artificially cooled in a refrigerator to extend the dormant period for up to approximately 90 days.

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INVESTIGATING THE APPLICABILITY OF BIOTECHNICAL STREAMBANK STABILIZATION IN TEXAS

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Research Project Title: Regional Applications for Biotechnical Methods of Streambank Stabilization in Texas

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The researcher in charge was Harlow C. Landphair, Registered Landscape Architects, State of Texas, License Number 651.

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INTRODUCTION

The Texas Department of Transportation (TxDOT) has commonly utilized concrete and other non-biodegradable measures to stabilize stream channels throughout Texas. While these practices have temporarily solved problems incurred by streambank erosion, evidence indicates a secondary effect can occur downstream and/or upstream of the structure, which might be the cause of some structure failures. This not only leads to continual maintenance of the sites, but it could also lead to the retrofitting or eventual replacement of structures. Due to the large amount of funding spent on maintenance of streambanks and replacement of bridge structures, TxDOT is in need of effective streambank stabilization measures.

Biotechnical engineering utilizes live plant materials combined with inert materials such as geosynthetics and rocks to provide protection of streambank or slopes. Live plant cuttings are harvested and planted in the dormant period. This technique has been successfully applied in the United States (e.g., Gray and Sotir, 1996); however, its use in Texas is still very rare. Report number 1836-3 (Landphair and Li, 2001) documents a complete literature review of biotechnical engineering for this research project. The report provides an overview of biotechnical streambank stabilization and lists techniques that have been used successfully, with potential application in Texas. Using these successes as a foundation, researchers further investigated the applicability of biotechnical streambank stabilization techniques to Texas, including designing demonstration projects and conducting dormancy extension experiments. The objectives of the research project include:

- identifying applicable biotechnical streambank stabilization techniques for use in Texas;
- designing and building a streambank stabilization project coordinated by TxDOT local offices for the demonstration purpose;
- developing and drafting reference/guideline materials; and
- developing detail drawings and specifications.

One important task of this research project was to design and build streambank stabilization projects using biotechnical techniques for demonstration purposes. With TxDOT's help in contacting districts and area offices, the Texas Transportation Institute's (TTI) research team visited and evaluated TxDOT's candidate sites with stream erosion problems. During the demonstration project evaluation and design process, researchers defined five unexpected challenges, including:

- construction schedule conflicts;
- short, rainy winters in Texas;
- short plant dormancy period;
- shortage of qualified contractors; and
- insufficient technical guidance.

While struggling with these five challenges, TTI visited nine TxDOT districts, assessed 21 sites, and designed five streambank stabilization projects. Two of five designed projects were finally let, and only one project was built. The built project, located in Hutchins, Texas, was an off-system project coordinated by TxDOT. Researchers will use the monitoring results of the project to provide recommendations for future applications. Techniques with great potential for Texas application, which researchers determined from the literature review and the demonstration project process, were further drafted in nine recommended special specifications and illustrated in CAD files, all presented in Appendices A and B. These special specifications and detail drawings are intended for design engineers to modify for their design project sites.

During the process of the demonstration project from 1998 to 2001, it was clear that the climate was the main deterrent to the success of biotechnical technology. Most of Texas, even in the western parts of the state, is characterized by very short, wet winters. This represents two obstacles to successful use of biotechnical methods. First, wet winters make access to the stream bottoms difficult. Many of the biotechnical techniques require access to the toe of the slope. Second, live cuttings must be harvested and installed in the dormant period. With the short winters in Texas, the harvest and installation window is limited to about three months, from December 15 to March 15. The difficulty of document preparation in the letting cycle, normal Texas weather, and any delays in construction seriously limits the use of biotechnical methods. For these reasons, researchers investigated dormancy extension for use of biotechnical streambank stabilization in warm regions.

The dormancy extension study investigated the possibility of extending the dormancy window of live cuttings for construction of biotechnical techniques. Researchers used black willow (*Salix nigra*) cuttings that are widely available in Texas. Three storage methods were developed and tested, including cold storage at 40 ^{o}F (4.4 ^{o}C), onsite storage in compost, and onsite storage in water. These methods were intended to be economical and practical for contractors to apply once these techniques were proven to be effective.

This report contains four major chapters. "Biotechnical Streambank Stabilization" briefly introduces the biotechnical engineering application and lists potentially applicable biotechnical techniques for use in Texas. Details of these techniques were published in 2000 and can be found in "Regional Applications for Biotechnical Methods of Streambank Stabilization in Texas: A Literature Review," which is a preliminary report (Report Number 1836-3) of this research project. "Demonstration Project" describes the history and process of searching, assessing, designing, building, and monitoring demonstration projects. "Dormancy Extension Study" explains the experimental design of the study, analysis, and results. "Biotechnical Technology Reference/Guideline" presents suggestions of how to consider using biotechnical streambank stabilization in Texas. Due to the limited number of demonstration projects, comprehensive guidelines cannot be developed. As such, because streambank stabilization projects are always site-specific, applying universal guidelines for this type of work may be inappropriate and can even be dangerous.

BIOTECHNICAL STREAMBANK STABILIZATION

INTRODUCTION

Traditional practices for streambank stabilization in the United States, which were developed from years of research and engineering experiments, have provided successful solutions when judged from a purely engineering perspective. Through the armoring of a streambank with high-strength reinforced concrete and significant modification of channels, streams have been straightened, deepened, widened, lined, reshaped, relocated, and routed through pipes, tunnels, and other diversions for half a century (Landphair and Li, 2001). These methods, while successful, are being reevaluated due to environmental impacts and adverse public opinion of environmental issues. Increasing failures of traditional armoring and channelization methods are also being questioned as to whether the traditional practices were appropriate in every setting. When concern about traditional methods increased in the 1970s, the interest in a natural technique was raised, and the benefits and advantages of biotechnical engineering were gradually rediscovered (Riley, 1998).

Biotechnical methods integrate inert and live plant materials and landform modifications in order to stabilize slopes and streambanks (Schiechtl and Stern, 1997). The potential long-term benefits from the vegetative component and holistic approach of biotechnical engineering have promoted these applications among governmental agencies in recent years (e.g., National Research Council, 1992; USDA/SCS, 1992; USDA/NRCS, 1996; Allen and Leech, 1997; FISRWG, 1998; Fischenich and Allen, 2000).

Historically, the use of vegetation for slope or streambank stabilization can be traced back many centuries. Although these techniques have been utilized for a long time, the knowledge level of biotechnical engineering is still immature in terms of plant engineering properties, harvesting, handling, and planting techniques. This knowledge is essential to the success of biotechnical projects and is only briefly documented in the literature. These weaknesses have made technology transfer difficult because of a lack of scientific evidence.

Terminology: Biotechnical Engineering and Soil Bioengineering

The literature in the biotechnical engineering related field provided various terms in describing the same practices, including “bioengineering,” “soil bioengineering,” and “biotechnical engineering.” However, there is no consensus in the literature in describing these terms (Landphair and Li, 2001).

The term “bioengineering” is an English translation from a German title “ingenieurbiologie,” a recognized term for the discipline in German-speaking countries, meaning engineering biology (Stiles, 1991). According to Stiles (1991) and Lewis (2000), the term, bioengineering, is a mistranslation. It has caused some confusion with an area of medical research in the United States (Lewis, 2000).

“Soil bioengineering” is currently the official term used by United States Department of Agriculture, Natural Resources Conservation Service (USDA/NRCS), and refers to a design that employs brushy vegetation either alone or in combination with structures (USDA/NRCS, 1996, pp.16-1). In contrast, Gray and Sotir (1996) regarded “soil bioengineering” as a specialized area where plant parts were applied alone and were the main structural components in a stabilization system. They classified soil bioengineering as a subset of biotechnical engineering.

As for the term “biotechnical engineering,” Brosius (1985, pp.21) defined it as “using living plants in conjunction with inanimate natural or artificial structures.” Similarly, Gray and Sotir (1996, pp.1) described biotechnical stabilization as utilizing “mechanical elements (or structures) in combination with biological elements (or plants) to arrest and prevent slope failures and erosion.” Despite both Brosius’s (1985) and Gray and Sotir’s (1996) definitions of biotechnical engineering being recognized by the biotechnical engineering field, one important aspect, the landform modification, is not included. Therefore, this report defines biotechnical engineering as “stabilization methods that integrate inert and live plant materials, and/or landform modifications to stabilize slopes and streambanks.”

Biotechnical Engineering – An Ancient Slope and Streambank Stabilization Technique

Because of a large number of biotechnical engineering publications in the 1980s and 1990s, the origin and history of biotechnical engineering have been thoroughly documented (Schiechtl, 1980; Brosius, 1985; Lee, 1985; Greenway, 1987; Stiles, 1991; Finney, 1993; Turrini-Smith, 1994; Gray and Sotir, 1996; Riley, 1998; Lewis, 2000). This section focuses on a brief history of biotechnical engineering and emphasizes the European influence on United States practice.

The use of vegetative plants to control erosion, stabilize landslides and add aesthetic amenity has appeared in many ancient civilizations. As far back as 3500 B.C. in the Euphrates Valley and the Nile River Valley, trees were integrated into landscapes to modify microclimate, provide visual attractions, and restore environments (Riley, 1998). Lewis (2000) described that in East Asia, as early as 28 B.C., the use of biotechnical engineering for dike repair was recorded in Chinese literature. Lee (1985) reported that a Chinese engineer, Pan, utilized willow plantings to stabilize embankments during the Ming Dynasty of China. In Europe, planting riparian vegetation to protect streambanks can be traced back to the 16th century (Brosius, 1985). More details of biotechnical engineering development in Europe were described by Schiechtl (1980), Záruba and Mencl (1982), and Brosius (1985). All of these examples indicate that humans have been using plants to enhance safety and quality of life for a long time. The technique of using plants was continued by descendants and carried with human settlements migrating from Mesopotamia to Europe and then to North America, including Canada and the United States (Riley, 1998).

The biotechnical engineering tradition brought from Europe to the United States was almost abandoned with the onset of the Industrial Revolution in the 19th century, due to the low cost of energy, relatively high labor cost, and easily available raw construction materials such as steel and concrete (Gray and Sotir, 1996). Around 1930, biotechnical engineering was revived in Europe and the United States. In the United States, the earliest documented biotechnical work occurred in California (Kraebel, 1936), and gradually, more biotechnical engineering related works appeared because of the success in Europe (Schiechtl, 1980). Federal agencies, such as USDA and US Army Corp of Engineers (USACE), became proponents of this practice during the 1970s (Riley, 1998).

From the historical perspective, it is clear that the United States biotechnical practice has strong ties to the European tradition. In fact, one European practitioner, Hugo Schiechtl, authored one of the most influential references in United States contemporary biotechnical practice, *Bioengineering for Land Reclamation and Conservation* (1980). Almost all American biotechnical literature after 1980 was directly or partially based on the foundation built by Hugo Schiechtl, most of which cited Schiechtl's works, including Brosius (1985), Greenway (1987), Stiles (1991), Turrini-Smith (1994), Gray and Sotir (1996), Riley (1998) and Lewis (2000).

The Use of Live Plant Materials in Biotechnical Streambank Stabilization Techniques

Biotechnical streambank stabilization techniques described in the literature can be summarized into 12 major types: (1) live stakes, (2) live fascines, (3) brushlayering, (4) branchpacking, (5) vegetated geogrids, (6) live cribwall, (7) joint planting, (8) brushmattress, (9) tree revetment, (10) log and rootwad revetment, (11) dormant post plantings, and (12) coconut fiber rolls (Gray and Sotir, 1996; USDA/NRCS, 1996; Schiechtl and Stern, 1997; Bentrup and Hoag, 1998). Appendix C contains an illustration adapted from Li and Eddleman (2002) and descriptions modified from Landphair and Li (2001) for each type.

Of the 12 techniques, nine require the use of live cuttings or live posts. These nine techniques may have great potential for use in Texas because of the availability of some suitable plants such as black willow (*Salix nigra*). Recommended special specifications of these nine techniques and their corresponding detail drawings are included in Appendices A and B. Techniques such as tree revetment and rootwad revetment tend to be used for large streams so that some part of the revetment can be permanently submerged. As such, they are better for providing fish habitats. As for coconut fiber rolls, the materials are mostly imported from other countries and may be proprietary. For this reason, the authors cannot recommend this product.

Recognizing that the success of a biotechnical streambank stabilization project is strongly related to the survival of live cuttings, and cutting survival is significantly correlated to the timing of harvest and installation of the cuttings, the literature emphasizes that cuttings should be harvested and planted during the dormant period (Crowder, 1995; Hoag, 1995; Gray and Sotir, 1996; Allen and Leech, 1997; Schiechtl and Stern, 1997). However, the critical dormancy for biotechnical operations seriously affects its application in Texas because of Texas's warm, rainy winters. Detailed challenges of applying biotechnical methods in warm regions and a possible solution to extend plant dormancy are described in later chapters.

Despite the importance of harvest and installation timing, information provided in the literature on plant dormancy, handling methods, and timing is limited. This is probably because:

- Yearly climates can vary dramatically so that plant dormancy shifts annually. Hence, specifying exact dates for harvest and installation is not easy.
- Biotechnical engineering was developed in Europe and later introduced to Canada and the northern United States (Brosius, 1985; Finney, 1993; Donat, 1995), which generally have long, cold winters. Long winters allow more flexibility in scheduling biotechnical works, and therefore, the plant dormancy period was of less concern to cold regions.
- Biotechnical engineering was primarily developed by trial and error (Schiechtl, 1980). Such a practice attitude may have affected documentation that should have been more systematic.

Biotechnical technique tends to be region-specific and difficult to transfer to regions with completely different climates and soils. Most literature and documentation is for cold, dry climates. Therefore, more research is needed to effectively apply biotechnical engineering in warm regions such as Texas.

DEMONSTRATION PROJECT

INTRODUCTION

One important task of this research project was to design and build a streambank stabilization project using biotechnical techniques. The demonstration project tested the applicability of biotechnical techniques for streambank stabilization in Texas, provided examples of streambank stabilization alternatives for TxDOT design engineers, and collected plant growth and hydraulic data from post-project monitoring.

The search for candidate sites began in 1998 and ended in 2000. With TxDOT's help, TTI was able to contact all 25 districts, visited nine districts, and assessed 21 problem sites. From the 21 sites assessed, TTI used the following criteria to select candidate projects for design:

- Project schedule. If a project could not be scheduled for construction in dormant periods, the project would not be selected.
- Scale of the project. Because TxDOT had not used biotechnical techniques before, rivers were not considered for demonstration. Streams with perennial flows were not preferred. Streams with intermittent flow were good candidates.
- Support from local TxDOT offices. Biotechnical applications are site-specific. Support from local TxDOT offices to provide stream survey, soil boring data, right-of-way limit, and hydraulic study was considered very important.

Using these criteria, researchers selected a total of five projects for design. Two were finally let, and only one project was built. This chapter documents the design and construction processes of the demonstration project and explains the challenges in the process.

SELECTED CANDIDATE SITES

Five stream erosion sites were identified for design. The observed problems and site conditions are briefly described as follows.

Cottonwood Creek/Goode Road Project, Hutchins, Texas

Goode Road was closed from the public in 1996 because severe erosion occurred at the abutment of the bridge and on the north side of the road embankment. TxDOT was considering replacing the old wooden bridge and rebuilding the eroded road embankment. Problems observed on-site were:

- a large wrought iron pipe crossing the creek was likely to catch large debris and cause uncertain currents downstream;
- sharp turns on the north side of Goode Road had serious erosion; and
- a very steep slope occurs on the north side of the embankment. The elevation change between the road surface and the creek bed is about 20 to 25 feet.

Bollinger Creek/Steven F. Austin State Park Project, Sealy, Texas

The site is located in the Stephen F. Austin State Park, near the first bridge next to the park headquarters building. The bridge crosses Bollinger Creek, one tributary of the Brazos River, and is the only access to the golf course and campground. Under the bridge, the creek bottom was severely eroded, which exposed the foundation of the bridge columns. The bridge abutment was also eroded. To prevent the abutment failure, temporary sheet piles and concrete block fill material had been placed. The area around a 36 inch pipe on the south creek bank had been scoured by the water flow as well.

Nolan Creek/Belton City Park Project, Belton, Texas

The site is inside a city park along Nolan Creek under the FM 93 bridge. The site's major problem was the soil loss on the west bank of Nolan creek under the bridge, which endangers bridge piers as well as one sewer line operated by the City of Belton. According to TxDOT and city personnel's description, the site was within a floodplain, and some floods occurred in the past. Full-bank flow was observed approximately once or twice per month. The site was well covered by trees and grasses except the area around the bridge. The creek bottom was composed of bedrocks.

Little Walnut Creek Project, Austin, Texas.

US 183 crosses Walnut Creek at an approximately 45-degree angle. The creek on the upstream side of the bridge meandered and migrated toward the bridge abutment, which quickly caused failure on the concrete riprap. The upstream streambank was also seriously eroded, in which the bank slope was almost 90 degrees to the bottom. The creek was lined by a shale-type of clay at the bottom and had loamy soils on the side slopes. The failure of the concrete riprap resulted from toe scour. Some bridge pier foundations were also exposed to about 5 feet deep.

Boggy Creek Project, Austin, Texas

This site is about 2.5 miles south of the Little Walnut Creek Project on US 183. The most distinct structure observed at this site was an abandoned concrete sewer line laid across Boggy Creek near the bridge abutment. The abutment broke and fell into the creek due to scour at its toe area. According to TxDOT, both sites need immediate treatment to stabilize the surrounding area of the bridges. TxDOT was in the early stage of redesigning both bridges and proposes to build new bridges in about five years. TxDOT expects that the stabilization should at least control erosion for the next five years.

CHALLENGES OF WARM REGION APPLICATION

The major challenge of applying biotechnical methods in Texas is the short dormant period in the warm Texas climate. Modern biotechnical techniques and documents were developed in Europe and later adopted into North American practice (Brosius, 1985; Donat, 1995); little information can be found about biotechnical uses and their effectiveness in warm regions. In the literature, the most cited biotechnical technique is the planting of live stakes and cuttings, i.e., the live cutting technique (Gray and Sotir, 1996; Schiechtl and Stern, 1997). To be effective, live stakes and cuttings must be harvested and preferably installed during the dormant period. While the dormancy requirement in using live cuttings is well adopted in cold regions, it is a challenge to warm regions with short, rainy winters.

Construction Schedule Conflicts

Many TxDOT bridges that need repair or replacement are off-system and are often maintained and used by local governments, such as cities and counties. It is typical that more than one government agency is involved in a bridge repair or replacement project. Therefore, a project schedule can be easily delayed by local government agreements, right-of-way purchases, and other coordination. Further, TxDOT has a complicated system in scheduling projects, which makes the scheduling inflexible. Scheduling construction projects utilizing biotechnical methods can be very difficult and becomes further complicated with the short dormancy issue.

Climatic Constraints: Short, Rainy Winters in Texas

Stabilizing streambanks requires access to the bottom of a stream. A flowing stream makes the construction of streambank protection very difficult. Unless flow diversion devices are used, the probability is very high of missing the dormant period ideal for biotechnical construction. If a flow diversion is proposed, the construction will not only be more expensive but also involve severe disturbance of a stream channel. In the United States, construction activities that disturb a stream channel are strictly regulated and require a slow and complicated permitting process. Consequently, using flow diversions in streambank stabilization projects is not preferred under any circumstances. The construction becomes difficult when the stream is flowing and is very expensive if any flow diversion measure, such as sheet piles, is imposed.

Texas has very warm and relatively cold areas. The January daily mean minimum temperature ranges approximately from 50 ^{o}F in Brownsville to 15 ^{o}F in Dalhart (data from NOAA-CIRES Climate Diagnostics Center). However, most TxDOT streambank erosion problems occur primarily in the southeast region and most metropolitan areas, such as Austin, Dallas/Fort Worth, Houston, etc., where there are many bridge crossings. These areas have warm and rainy winters, resulting in frequent flowing water in many intermittent streams. Therefore, constructing streambanks in the wintertime (the dormant period) is very difficult.

Plant Physiological Limitations: Short Plant Dormancy Period

A plant becomes dormant because of changes in environments (Lang et al., 1985) normally decreasing temperature and day-length (Wareing, 1969). Plant dormancy is important to biotechnical techniques because to be effective, stakes must be harvested and planted immediately during the dormant period (Hoag, 1995; Gray and Sotir, 1996; Allen and Leech, 1997; Schiechtl and Stern, 1997). This is challenging in the warm areas of Texas. In general, plants in Texas become completely dormant in January and break dormancy from February to early March depending on the latitude. This short dormant period in Texas coupled with the rainy winters makes the application of live cutting techniques very difficult.

Insufficient Technical Guidance

Although a high number of published biotechnical materials are available for review, these publications offer little more than an introductory description of each biotechnical technique's application and effectiveness. The information is inadequate for definitive selection criteria and guidelines, as well as innovations in practice or research. This is because of insufficient understanding of plant properties in streambank applications.

Further study of the literature also shows that almost all of the design and selection information for non-structural streambank and channel protection is developed from a few literature sources and case studies, with little numerical or laboratory underpinning. This limited knowledge and information level of vegetation's engineering properties has created an obstacle in biotechnical uses.

Shortage of Qualified Contractors

A survey of erosion control contractors was conducted in 1999. Researchers found that very few contractors in Texas had experience with biotechnical applications.

GOODE ROAD STREAMBANK STABILIZATION PROJECT

The old bridge replacement and streambank stabilization project in Hutchins, Texas, was TxDOT's first designed-and-built project using biotechnical engineering. Beginning in 1996, the existing bridge on Goode Road in Hutchins (southeast of Dallas), Texas, was closed due to severe erosion on its abutment and a roadway embankment failure (see Figures 1 and 2).

Figure 1. Failure Near Abutment Area.

Figure 2. Failure on Roadway Embankment.

The bridge, built in the 1960s to cross Cottonwood Creek, is a single span timber plank structure. In the 1990s, the flow in Cottonwood Creek significantly increased after some storm events, and it occasionally overtopped the bridge.

As shown in Figure 3, Goode Road's west-facing embankment is also the streambank of Cottonwood Creek. The roadway embankment was severely eroded by the flow. Particularly, a sewer and a water line crossing the creek caught large amounts of debris, which indirectly led to erosive currents downstream. The abutment of the bridge was eroded by the flow from the drainage swale (see Figure 4) and the scouring flow on the bend area.

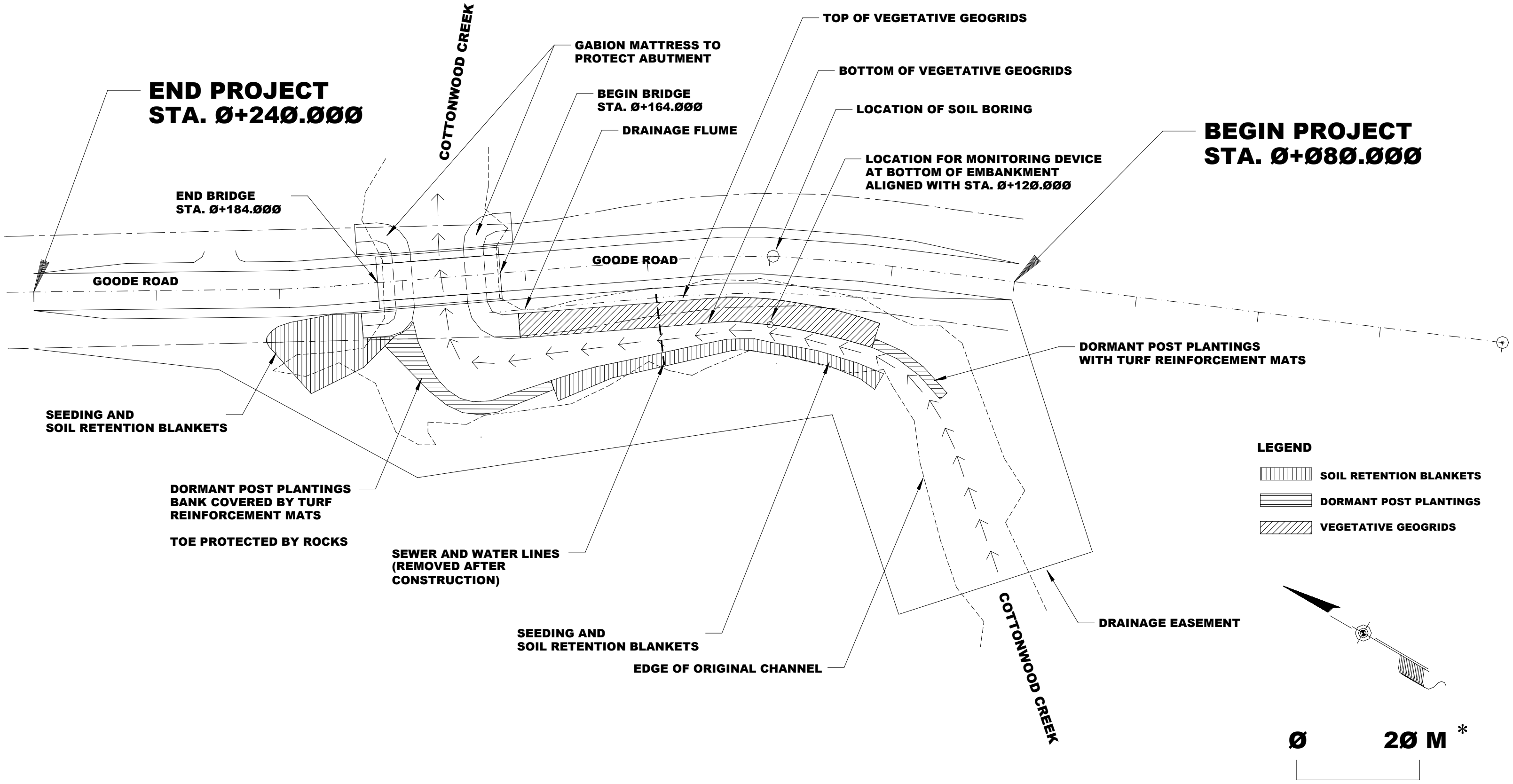


Figure 3. Project Plan.

*Note: Original project plans, sections and details were prepared using the SZ system. 1 m = 3.281 ft.

Figure 4. Erosion Caused by Flow in Drainage Swale.

DESIGN PROCESSES AND APPROACHES

Drainage Study

In the early design stage, TxDOT conducted a drainage study to determine the new bridge elevation. The proposed bridge was designed according to the criteria

- Cost-effectiveness.
- Passing the 50-year flood with a head water elevation that is less than the water surface elevation encountered with the existing structure.
- Passing the 100-year flood at a water surface elevation that is no greater than that calculated using the existing conditions, thus theoretically not encroaching on the 100-year flood plain.

Cottonwood Creek, at Goode Road, flows in an easterly direction and drains east to the Trinity River. The drainage basin affecting Cottonwood Creek is approximately 13.1 square kilometers. The Goode Road bridge drainage basin located in a suburban section of southeast Dallas currently has single-family parcel areas and some parcels with one to several acres.

Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used to model the flow condition of the proposed bridge design. Table 1 shows the results of the proposed design compared with the modeling results of the original bridge design conducted by the Federal Emergency Management Agency (FEMA). As shown, the proposed design will result in lower water surface elevations than the existing structure for 10-, 50- and 100-year floods. Therefore, the proposed bridge design met the aforementioned criteria.

Table 1. Comparison of Water Surface Elevations of Proposed and Existing Structures

Design Return Period (Years)	Existing Structure (Modeled by FEMA)		Proposed Structure (Modeled by FEMA)		Difference of Water Surface Elevation	
	ft	m	ft	m	ft	m
10	426.83	130.09	425.74	129.76	-1.09	-0.33
50	426.63	130.03	427.91	130.42	1.28	0.39
100	429.94	131.04	429.09	130.78	-0.85	-0.26

Soil Data

Soil borings were conducted on the center of the existing roadway (see Figure 3) to investigate the soil type and profile. As shown in Figure 5, clay and sandy clay soils are under the road base and are considered as the original soil type. Researchers found that limestone was 20 –23 feet below the road surface and was also the creek bottom material.

Installed Bank Stabilization System

Gabion Mattress

Biotechnical engineering is not a universal solution. It will not be suitable for areas where there is little or no sunlight. To complement this weakness of biotechnical methods, researchers chose gabion mattress, a traditional engineering method. Gabion mattress, composed of wire cages and rocks, stabilized the bridge abutment (see Figure 6). As shown in Figure 7, the 1V:2H (V, vertical; H, horizontal) slope on the top half followed by the 1:1 slope on the bottom half was designed to increase the flow capacity.

Also, there is no bridge pier blocking the flow. The flexibility of installation on irregular areas as well as shady spots makes gabion mattress practical to this project.

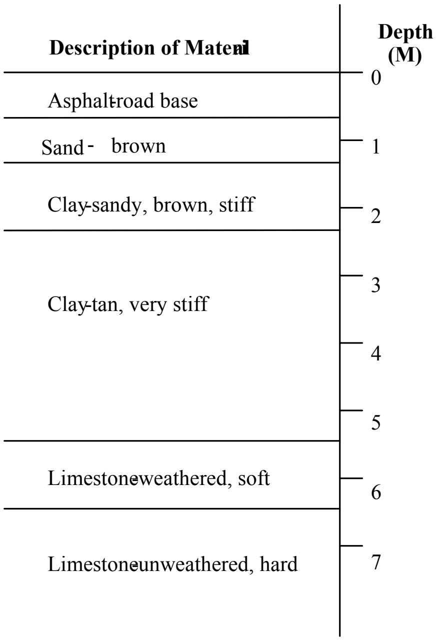


Figure 5. Soil Profile.

Figure 6. Gabion Mattresses.

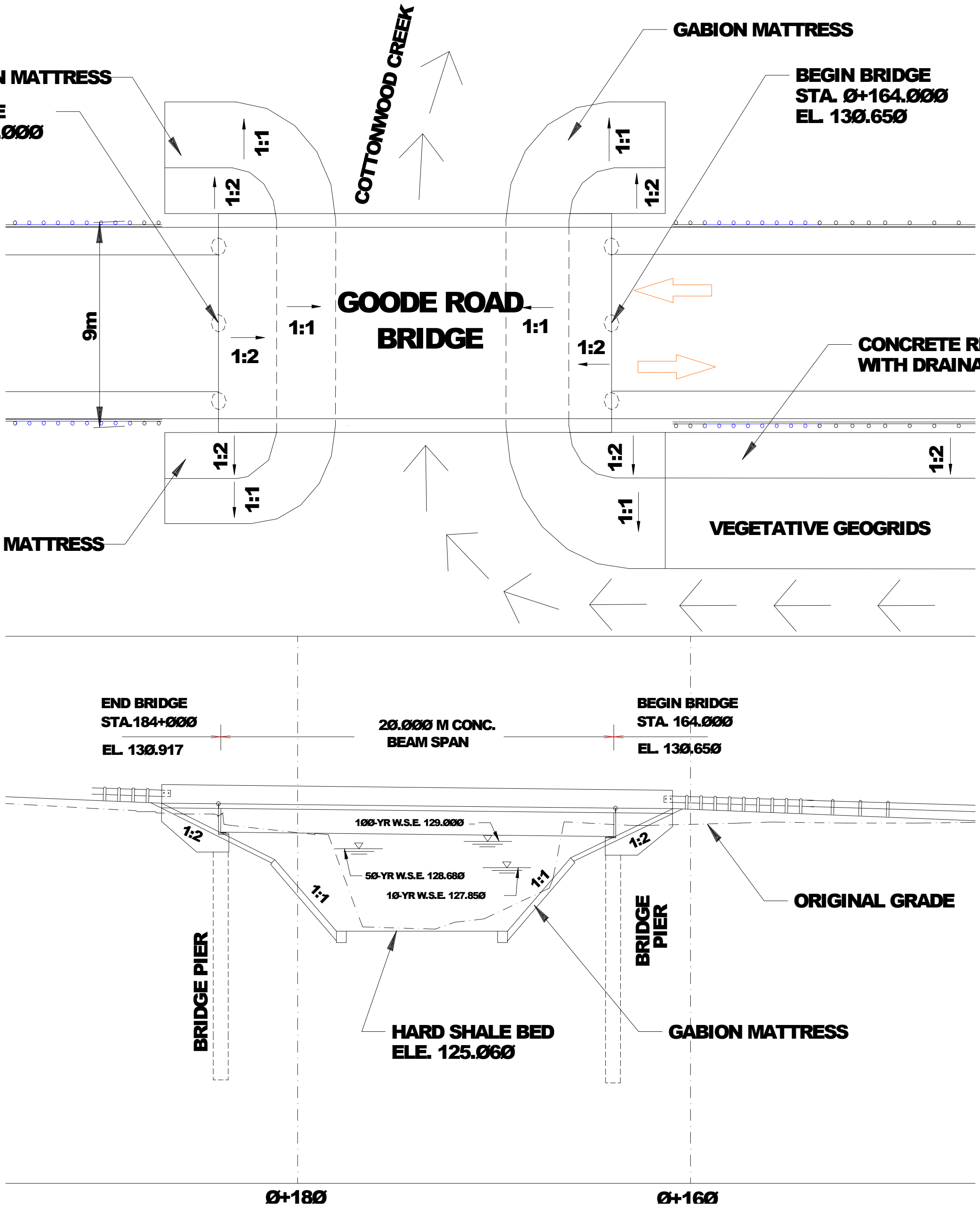


Figure 7. Cross-section of Bridge Design*.

*Note: Original project plans, sections and details were prepared using the SI system. 1 m = 3.281 ft.

Vegetated Geogrids

Vegetated geogrids are layers of live cuttings incorporated with natural or synthetic geogrids/geotextiles. Soils and granular backfills wrapped by geogrids/geotextiles alternate with layers of live cuttings. A schematic drawing of vegetative geogrid is illustrated in Figure 8. Because TxDOT has never constructed embankments using vegetated geogrids, TTI developed a special specification for this technique, which was proved by TxDOT and assigned as SS 3133 Biotechnical Embankments. This technique is the primary stabilization measure for the west-facing roadway embankment as well as the streambank. Black willow (*Salix nigra*) was used in this project. The design of the geogrid reinforcement length (L) was performed using the following equations (also see Figure 8) (Das, 1990):

$$L = l_r + l_e$$

where $l_r = \dfrac{H - z}{\tan(45 + \dfrac{\phi_1}{2})}$

and $l_e = \dfrac{S_v K_a \gamma_1 z [FS_{(p)}]}{2\sigma_v \tan\phi_F}$

where ϕ_1 = friction angle of the granular backfill

K_a = Rankine earth pressure coefficient

γ_1 = unit weight of the granular backfill

$FS_{(p)}$ = 1.3 to 1.5

$\sigma_v = \gamma_1 z$

ϕ_F = friction angle at geotextile-soil interface $\approx \dfrac{2}{3}\phi_1$

Approximately 3.65 m (12 feet) of geogrid reinforcement were installed in the embankment for each layer. Roadway embankments/streambanks of approximately 6 to 7 m (20 to 23 feet) in height were built with the vegetative geogrid technique. This stabilization method can provide immediate streambank protection at the early stage after installation. The root, stems, and foliages that are expected to establish will offer further soil stability and surface protection. Figure 9 shows the newly installed vegetative geogrids.

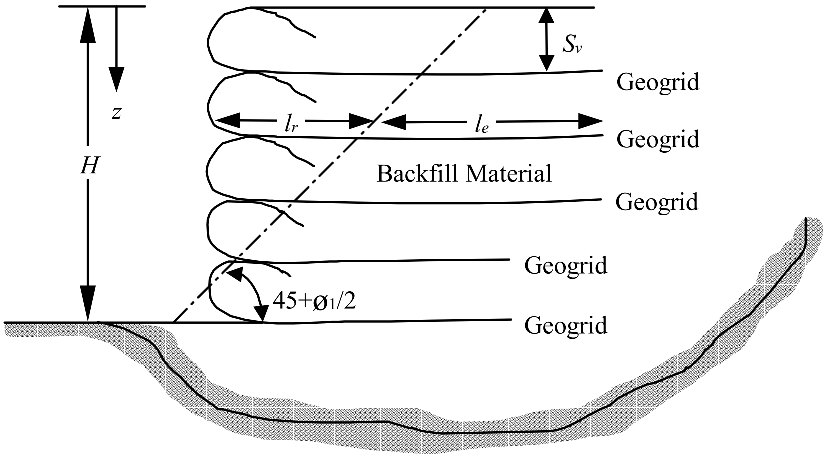


Figure 8. Schematic Illustration of Geogrid Reinforcement.

Figure 9. Installed Vegetative Geogrids in March 2001.

Dormant Post Plantings

Dormant posts of black willow (*Salix nigra*), 76 to 127 mm (3 to 5 inches) in diameter, were installed on two creek bend areas. A schematic drawing illustrates this in Figure 10. Boulders were keyed into the toe of the bend areas to protect the streambank bottom. In addition, turf reinforcement mats were installed along with the dormant posts to reduce the surface erosion (see Figure 11).

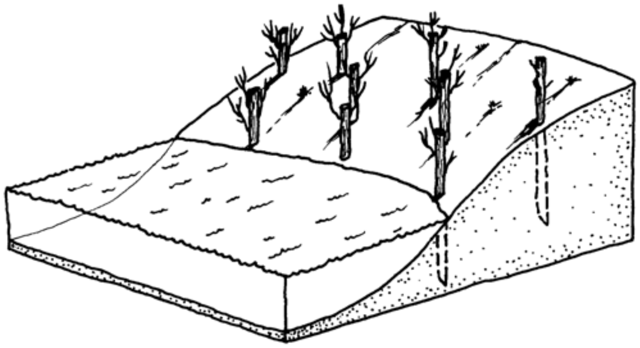


Figure 10. Schematic Drawing of Dormant Post Plantings. Adapted from Li and Eddleman (2002).

Figure 11. Installed Dormant Posts with Erosion Control Blankets.

Drainage Flume

A drainage flume was designed along the shoulder of the roadway to prevent excessive stormwater from entering the embankment (Figure 12). This is because the clay soil type on the embankment is susceptible to cracking caused by periodic wet-dry cycles, which in turn reduces soil strength and lowers slope stability. Storm water from pavement, if not diverted, can infiltrate into the embankment and accelerate the wet-dry effect. By installing a drainage flume, this potentially negative effect can be reduced.

Figure 12. Drainage Flume Along Goode Road.

Post-project Evaluation

Post-project evaluation is a critical process in stream-related projects. Researchers performed a series of monitoring activities following construction to ensure lessons in using biotechnical streambank stabilization were learned. Three major variables were monitored during the post-project evaluation. First, seven cross-sections of Cottonwood Creek were surveyed and the fluvial geomorphic behavior after construction was monitored. Second, the survival of installed cuttings and posts were observed. Surviving cuttings were defined as cuttings with new shoots of two inches or longer one year after planting. Third, an on-site monitoring device constantly recorded a point measurement of water surface elevation and flow velocity. Two steel pipes equipped with water level data loggers were installed; one recorded surface water elevation (pressure head), the other pressure and velocity head (Figure 13). From the recorded data, the mean shear stress at the point can be calculated. The location of the measurement was set where the streambank/embankment is susceptible to severe erosion at the end of the bend.

Figure 13. Monitoring Standpipes: Right Records Pressure and Velocity Head; Left Records Surface Water Elevation.

MONITORING RESULTS

Cutting Survival

Black willow cuttings and posts were monitored for survival after project construction finished. Researchers observed that cuttings installed on the streambank/roadway embankment survived well; save the bottom layer of the vegetated geogrid, cuttings have a survival rate of about 90 percent. The poor survival condition of the bottom layer might be attributed to serious erosive force at the toe of the streambank (see Figure 14). Nevertheless, the streambank appeared to be stabilized by black willow cuttings.

Figure 14. Low Survival on Bottom Layer of Cuttings.

For the creek bends, dormant posts were planted using two different sizes of posts. Similar cuttings used in vegetated geogrids were first installed as "dormant post plantings" due to the contractor misunderstanding the specification. Later, posts of 2 to 4 inches in diameter and 7 to 10 feet in length were installed. Researchers observed that small cuttings survived well (about 82 percent survival rate), but large posts did not (about 11 percent survival rate). The cause of this outcome cannot be identified but may be attributed to the late harvest of large posts in March while small cuttings were harvested in February. Those posts might have grown new shoots at the time when they were harvested. Therefore, use of posts after dormancy has broken may not be effective.

Flow Velocity

Table 2 presents high flow velocity events recorded during the monitoring period. The observed flow velocities corresponding to the water surface elevation (pressure head) decrease as the water depth increases within the range of approximately 3 to 6.2 feet (Figure 15). This result represents only that the condition occurred at the measured point. However, it still indicates that the installed vegetated geogrids might have sustained high flow events at flow velocities of approximately 12.6 feet per second locally.

Table 2. High Flow Events during the Monitoring Period.

Date	Time	Pressure and Velocity Head (ft)	Pressure Head (ft)	Flow Velocity (ft/s)
9/4/01	19:00	5.2077	2.9847	12.62
10/12/01	23:00	6.3087	4.8557	10.47
12/16/01	05:00	7.1627	4.9887	12.49
12/16/01	06:00	6.9427	6.1537	8.18
3/29/02	16:00	6.3347	4.1227	12.59
3/29/02	17:00	6.2997	4.5377	11.38
4/15/02	23:00	7.4967	6.1977	9.99
4/16/02	00:00	5.8327	4.1587	11.13

Creek Channel Profiles

Researchers surveyed seven cross-sections of the creek near the upstream and downstream of the new bridge. Appendix D contains the detailed profile changes in three visits. The 3-3 foot cross-section shows a progressive scouring hole around the monitoring standpipes, while the nearby streambank holds well, which indicates that the vegetated geogrids provide necessary reinforcement for the streambank that is also the roadway embankment. Cross-sections around creek bend areas such as cross-section 2-2’ and 7-7’ show some degree of deposition on the inner bend and erosion on the outer bend. These changes reflect where erosive forces occurred and the corresponding results. It is still unknown whether the dynamic equilibrium is reached or not. However, the change of the profile seems to slow down after vegetation has established. This section of the Cottonwood Creek might have stabilized during normal flow conditions.

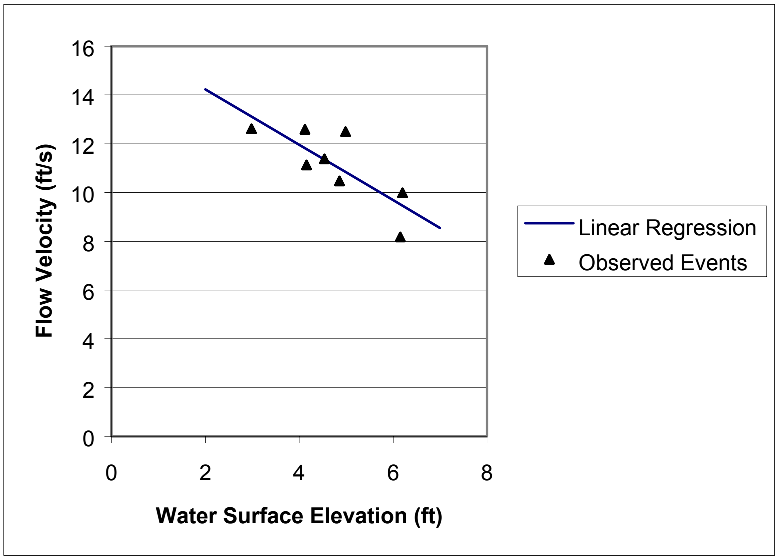


Figure 15. Observed Flow Events between September 2001 and April 2002.

DEMONSTRATION PROJECT CONCLUSION

The difficulty of scheduling construction in the dormant period hinders the application of biotechnical streambank stabilization in Texas. This is why several projects assessed and even designed were not built during the period of this research project. To make biotechnical methods practical in Texas, the time window for biotechnical constructions needs to be expanded. For this reason, researchers conducted an added study that investigates the effectiveness of extending plant dormancy. Experiment details and results are described in the next chapter.

From monitoring the cuttings' survival, flow velocities sustained, and creek cross-section survey, the built biotechnical streambank stabilization project in Hutchins, Texas, demonstrates the potential applicability of biotechnical methods in Texas. Although the contractor did not have the experience of constructing vegetated geogrids and dormant post plantings in the Cottonwood Creek project, the technology transfer was smooth and the results were satisfactory. Monitoring is a very important step when biotechnical methods are utilized, which is also called post-project evaluation. With an appropriate post-project evaluation plan, more lessons can be learned to improve the understanding of the technique.

The intent of building more biotechnical demonstration projects to represent regional application is to develop reference materials/guidelines as one product for the research project. Unfortunately, because there is only one demonstration project built from the research project, a full development of the reference materials/guidelines will not be reliable and wide-ranging. However, lessons learned from the demonstration project and results from the dormancy extension project will be helpful for future specification development.

DORMANCY EXTENSION STUDY

INTRODUCTION

The dormancy extension investigation was proposed in 2000 after researchers discovered some critical problems during the demonstration project process. As mentioned, during the demonstration project design process, five unexpected challenges were encountered, including construction schedule conflicts; short, rainy winters in Texas; short plant dormancy period; shortage of qualified contractors; and insufficient technical guidance. Among these five challenges, the first three are strongly correlated to plant dormancy and planting period because a warm region's short dormant periods make construction scheduling very difficult. As a result of these challenges, the applicability of biotechnical streambank stabilization methods using live cutting techniques in Texas and other warm regions was questioned. Hence, understanding the interaction between plants and a warm region's climate became the first research priority in studying the applicability of biotechnical streambank stabilization in warm regions. Unless researchers resolved the issue of a short dormancy period in warm regions, the use of biotechnical technology would be difficult.

EXPERIMENT DESIGN

The experiment was designed and primarily conducted in the field to evaluate whether harvesting and storing plant cuttings for later planting is practical in warm regions. The test site was located at the Texas A&M University's Riverside Campus in Bryan, Texas. According to the "USDA Plant Hardiness Zone Map" (Cathey, 1990), Bryan is within Zone 8b with the average annual minimum temperature range between –6.7 and –9.4 ^{o}C (15 to 20 ^{o}F), which is considered relatively warm in the United States. In addition, the mean chilling unit accumulation is slow in this area, which may result in some degree of insufficient chilling in any given year (Byrne and Bacon, 1992).

The native Texas black willow (*Salix nigra*) was used for all the experiments.

Black willow is one of the most used plants in biotechnical engineering because:

- it is native to North America (see Figure 16 for black willow's native range),
- it is easy to propagate by stem cuttings (McKnight, 1965), and
- its root system is dense (Gray and Sotir, 1996).

The cut end diameter of harvested cuttings ranged from 11.01 mm (0.438 inch) to 28.19 mm (1.110 inches). The use of various diameters was intended to test whether cutting size has any effect on survival rate. Researchers also recorded the length of cuttings. Table 3 presents the quantity of cuttings installed in each test type. Detailed cutting dimensions are presented in Appendix E.

Three storage treatments were developed based on the research objectives. They were cold storage, onsite storage in compost, and onsite storage in water. These storage treatments were intended to be economical and practical for field application, in which cold storage tried to enforce dormancy while storage in compost and soaking storage attempted to extend planting periods for cuttings.

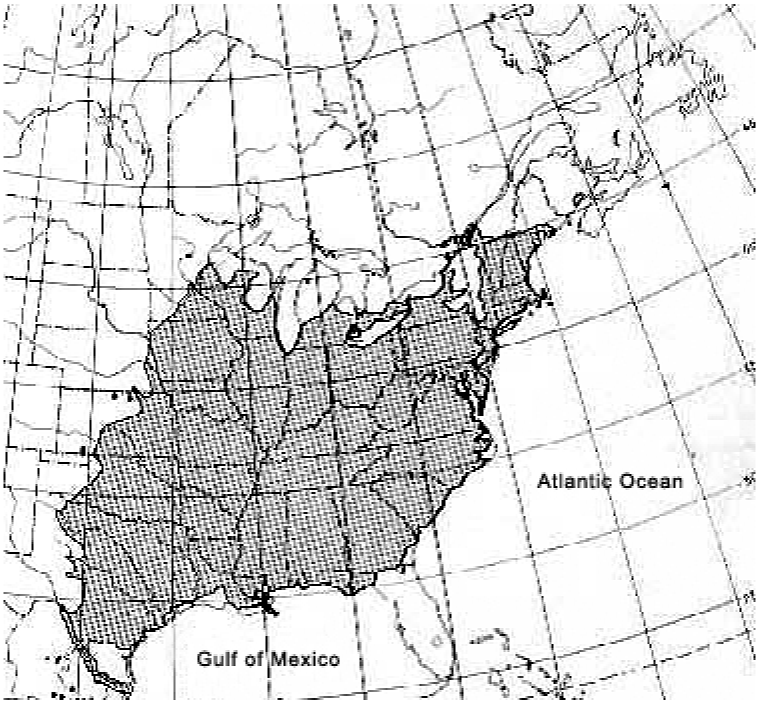


Figure 16. Native Range of Black Willow in the United States. Adapted from McKnight (1965).

Treatments that require the addition of fertilizer or chemical substances to stimulate root growth were not used. The test procedure of each treatment type followed the sequence of:

- harvesting live cuttings during dormant periods, i.e., February 2001,
- storing live cuttings using different storage treatments,
- removing portions of live cuttings from treatments and installing the cuttings in March, April and May 2001, and
- monitoring planted live cuttings until March 2002.

Table 3. Cutting Quantity Installed for Each Test Type.

Test type	Cold storage	Onsite storage in compost	Onsite storage in water	Cuttings with leaves test
March installation	80 [a]	Not conducted	Not conducted	Not conducted
April installation	78 [b]	100 [c]	88 [d]	39 [e]
May installation	80 [f]	84 [g]	76 [h]	Not conducted

[a] Installed on March 6, 2001.
[b] Installed on April 3, 2001.
[c] Installed on April 19, 2001.
[d] Installed on April 3, 2001.
[e] Installed on April 19, 2001.
[f] Installed on May 10, 2001.
[g] Installed on May 11, 2001.
[h] Installed on May 10, 2001.

Cold Storage

This test was conducted to investigate whether the method can be applied in warm regions. Live cuttings were harvested on February 14, 2001, and then stored in a walk-in refrigerator that maintained a constant temperature of 4.4 ^{o}C (40 ^{o}F). While stored in the refrigerator, cuttings were wrapped and covered by black plastic bags to block any light source. Their cut ends were soaked in water to maintain vitality. Before being planted in embankments, cuttings were first removed from the refrigerator and soaked in an outdoor pond for approximately three to five days. This pre-planting soaking was applied because it was economical and effective in enhancing survival (Hoag, 1993). Cuttings were then planted in an embankment of a 33 percent gradient. Three rounds of installation for this storage type were conducted on March 6, April 3, and May 10, 2001, respectively.

Onsite Storage in Compost

This test was conducted to investigate the effectiveness of storing live cuttings in compost followed by planting. This test type was designed based on field applicability, in that compost is a suitable growing media for vegetation and is economically affordable. Live cuttings were harvested on March 1, 2001, laid horizontally, and covered with compost. Periodic watering approximately once or twice a week was provided to maintain the cuttings' vitality. First round cuttings were removed from the compost after approximately four weeks of storage, and second round cuttings after eight weeks. Immediately after removal from compost, cuttings were planted in an embankment of a 33 percent gradient. Pre-planting soaking was not applied to this test type because at the time of planting, most cuttings had grown roots. These roots were very susceptible to damage. To reduce damage to the roots, pre-planting soaking was not conducted. Cuttings were planted on April 19 and May 11, 2001.

Onsite Storage in Water

This test was designed to investigate the effectiveness of storing live cuttings in water followed by planting. This test type was also designed based on field applicability because a water tank can be easily set up in the field if this treatment was proved to be effective. Live cuttings were harvested and bundled on March 1, 2001, and stored outdoors with cut ends in water. Cuttings were checked regularly to determine whether significant root systems developed. Two rounds of cuttings were planted in embankments of a 33 percent gradient on April 3 and May 10, 2001, approximately after six and 10 weeks of soaking.

Other Test Type

In addition to these three treatment type tests, a set of cuttings with grown leaves were harvested on April 13, 2001, and followed by pre-planting soaking. Six days after soaking, cuttings were planted on an embankment. Researchers intended to test the claim that appears in most biotechnical engineering literature such as Hoag (1993) and Gray and Sotir (1996) that "cuttings must be harvested and planted during dormant periods."

Installation and Monitoring

For each installation of cuttings, planting procedures of brushlayering described in the literature were followed, including Gray and Sotir (1996), Bentrup and Hoag (1998), and so on. A graphic illustration of brushlayering is presented in Figure 17. Only one layer of brushlayering was built in the embankment for this study. During installation, cuttings were handled with care to minimize damage. Refilled soils were moistened during planting. Researchers installed cuttings with approximately 3 to 4 feet of stems inside the embankment. These were separated by plastic net for easy monitoring (see Figure 18). All planted cuttings were monitored through March 2002. Monitoring focused on the growth of new shoots. A surviving cutting was defined as a cutting with new shoots of 50.8 mm (2 inches) or longer in the following year.

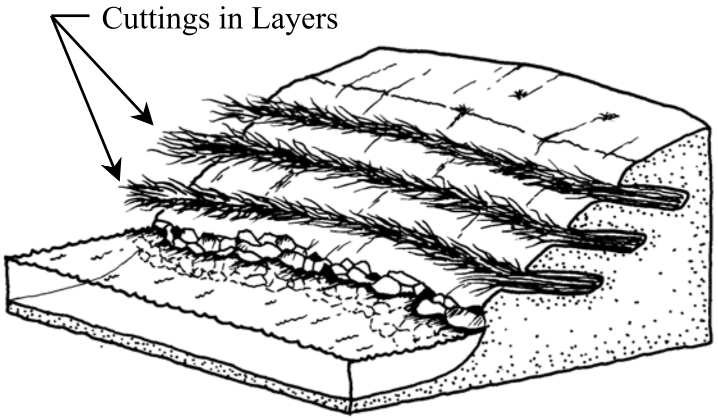


Figure 17. Brushlayering Installed on Streambank. Adapted from Li and Eddleman (2002).

Figure 18. Cuttings Separated by Plastic Net.

RESULTS

Description of Sample

Researchers harvested dormant willow cuttings in two locations. The first stock was harvested in Bryan, Texas, on February 14, 2001; the second in Texarkana, Texas, on March 1, 2001. The original plan was to harvest all the stock from Bryan. However, when it was time to harvest the second stock, willows in Bryan began to break buds. To minimize the difference of the dormant condition between two different stocks, the second stock was harvested from a northern location, Texarkana, where willows had not yet shown bud breaks. Two hundred and thirty-eight (238) cuttings harvested in Bryan were used for the cold storage treatment, while 184 and 154 cuttings from Texarkana were used for the onsite storage in compost and in water treatments, respectively. In addition to dormant cuttings, a set of 39 cuttings was harvested in Bryan on April 13, 2001, after the dormant condition was broken. Detailed dimensions of cuttings are presented in Appendix E. Figure 19 illustrates how cuttings were distributed to different test types.

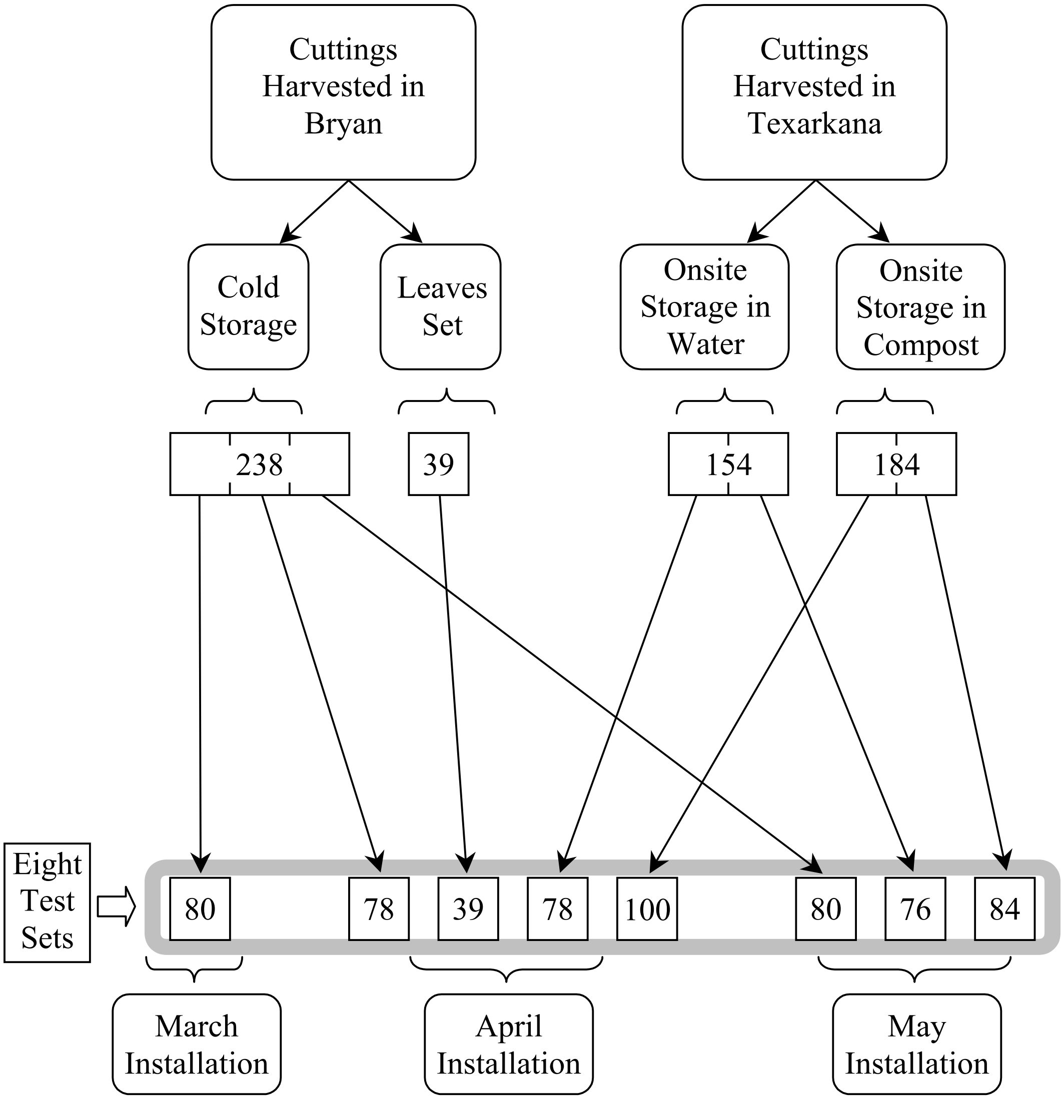


Figure 19. Numbers of Cuttings Harvested and Installed in Each Test.

Cuttings were monitored after installation to ensure that they were still live. Regardless of treatment type, researchers found that all cuttings showed apparent signs of leaf growth a few days after installation. This confirmed the live condition of dormant cuttings after the application of storage treatment.

The means of cutting diameter and the means of cutting length between two stocks of cuttings harvested in Bryan and Texarkana were compared to first investigate the physical size difference. The independent-samples t-test with unknown sample variances was used for the analysis. Researchers found that although two stocks of cuttings were statistically different from each other, their practical difference was insignificant (Table 4). This is because of the large sample size ($n > 30$ in each test) used in the study. A small departure between means will probably be detected even when the difference is of no practical significance (Montgomery and Runger, 1999). As presented in Table 4, the difference of the mean diameter is 0.99 mm (0.04 inch) and the difference of the mean length is 0.23 m (0.77 foot). From a practical viewpoint, such differences are insignificant.

Table 4. Comparison of Cuttings Harvested in Bryan and Texarkana, Texas.

Harvest location	Cuttings from Bryan used in cold storage treatment	Cuttings from Texarkana used in onsite storage in water treatment [a]	Difference of means
Quantity	238	154	
Diameter Mean/standard deviation	17.93 mm / 3.65 mm (0.71 in / 0.14 in)	16.94 mm/ 2.91 mm (0.67 in / 0.11 in)	0.99 mm (0.04 in) $p = 0.003$
Length Mean/standard deviation	1.67 m / 0.29 m (5.46 ft / 0.95 ft)	1.90 m / 0.26 m (6.23 ft / 0.86 ft)	0.23 m (0.77 ft) $p < 0.0001$

[a] Cuttings used in the onsite storage in water treatment were randomly selected from the entire stock harvested in Texarkana.

In summary, all dormant cuttings were still live after the application of storage treatment. The diameter and length differences of cuttings harvested in Bryan and Texarkana are statistically significant. However, the differences of means in diameter and length are too small to be practically significant. Hence, researchers consider the size difference a minor factor in differentiating stocks harvested in different locations.

Applicability of Cold Storage, Onsite Storage in Compost, and Onsite Storage in Water

A storage treatment is considered applicable only if the survival rate of treated cuttings is greater than or equal to that reported in the literature. According to Gray and Sotir (1996), a 40-70 percent survival rate of a regular biotechnical practice is considered satisfactory one year after the installation of cuttings. Hence, following Gray and Sotir's (1996) findings, the researchers for this project used the range of 40-70 percent as the test threshold for applicability. The survival rate falling under 40 percent, between 40 percent and 70 percent, and above 70 percent is labeled as "not applicable," "applicable," and "very applicable," respectively. Because a cutting's survival data (live or dead) was a binomial distribution, the 95 percent confidence interval of a proportion was calculated using (Montgomery and Runger, 1999):

$$\hat{p} - z_{\alpha/2}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \le p \le \hat{p} + z_{\alpha/2}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \tag{1}$$

Where p = Proportion of population

$\hat{p}$ = Proportion of observations in a random sample of size n

$\alpha = 0.05$

$z_{\alpha/2}$ = The upper $\alpha/2$ percentage point of the standard normal distribution. In this case, $z_{\alpha/2} = 1.96$

Table 5 presents the survival results of three storage treatment tests. The onsite storage in compost and in water treatments generate a survival rate of 0 and 0.026, respectively, both of which are apparently not applicable. On the other hand, the mean survival rate of the cold storage treatment is 0.563, with the 95 percent confidence interval of (0.500, 0.626) falling within 0.4 and 0.7; and therefore, the cold storage treatment appears to be applicable.

In summary, cold storage appears to be the only applicable treatment among three storage treatments developed in the study. Further comparison among these three treatments is discussed in the next section.

Table 5. Survival Rate of Cuttings in Different Treatments.

Treatment type	Cold storage [a]	Onsite storage in compost	Onsite storage in water
Live counts	134	0	4
Dead counts	104	184	154
Survival rate	0.563 C.I.[b] = (0.500, 0.626)	0 C.I. = (0, 0)	0.026 C.I. = (0, 0.051)
Applicability	Applicable	Not applicable	Not applicable

[a] Including total cuttings in the cold storage treatment test.

[b] 95 percent confidence interval.

Comparison of Storage Treatments

As discussed in the previous section, the cold storage treatment appears to be applicable while the onsite storage treatments (in compost and in water) do not (Table 5). By comparing the survival rate of 0.563 (cold storage) with 0 (onsite storage in compost) and 0.026 (onsite storage in water), it is obvious that there is a difference of survival between different treatments, in which cold-stored cuttings survived much better than onsite-stored ones. The actual cause of the difference of cutting survival among treatments cannot be identified by the research design.

Problems Due to Selection

The difference in survival rate between cold-stored and onsite-stored cuttings might result from the difference between two harvest locations. Although there is no practical size difference between the two different stocks harvested in Bryan and Texarkana, as discussed earlier, other differences that were not directly measured are still possible. For example, according to the USDA Plant Hardiness Zone Map (Cathey, 1990), Bryan is in Zone 8b and Texarkana in Zone 8a. The difference in zones indicates different climates and may create different physiological conditions for cuttings. There might also be a difference in genotype between cuttings from Bryan and Texarkana. These differences create a “selection” threat to the internal validity due to the difference between the cuttings in one experimental group (cold storage) as opposed to another (onsite storage) (Cook and Campbell, 1979). In this experimental design, the outcome of 0 and 0.026 survival rates from the onsite storage treatment tests cannot be easily explained. Without the premise of a strong internal validity, the external validity (generalizability) is, therefore, weakened.

Possible Inferences

Despite the weak internal and external validities due to the selection threat, it is necessary to discuss three possible inferences related to the survival outcomes:

- The onsite storage treatment is not applicable due to the different locations of cutting harvest and installation.
- The onsite storage treatment is not applicable due to the warm regions.

- The onsite storage treatment is not applicable due to the treatment itself.

The authors would like to discuss these three inferences in a field application perspective. If the first inference is true, no matter what the cause, the solution will be to harvest cuttings in the vicinity of the streambank stabilization project, apply the storage treatment, and then install cuttings on the project site. This solution is often not practical because needed plants may not be available in the surrounding areas. Besides, in the biotechnical engineering practice, transporting plant materials two or three hundreds miles from one site to another within plants' native range is not uncommon. Also, propagation in forestry is typically performed within 50 to 100 miles from the source location. From this inference, the applicability of the live cutting technique is lowered.

If the second inference is true, the onsite storage treatment will not be meaningful to the warm regions – the main focus of the study. Further research into the onsite storage treatment will not solve the problem of the warm regions, and therefore, will be unnecessary.

If the third inference is true, the onsite storage treatment will not be applicable no matter the region (cold and warm) where the treatment is applied. In this case, a possible cause of this conclusion is root damage during installation. In this study, cuttings used for onsite storage treatments were stored for a period of several weeks before planting. At the time of planting, most cuttings had grown roots (see Figure 20[a] and 20[b], and some had shown leaves (see Figure 20[b]). Because the roots on the cuttings were very fragile, damage to the roots during transport and planting were inevitable. Such damage can hinder new root growth. Likewise, cuttings with leaves demand more water.

In summary, the cold storage treatment had the highest survival rate among three storage treatments. Onsite storage methods are probably not applicable because, at the time of planting, most cuttings have grown roots. Damage of these fragile roots in field operation is very likely. Therefore, these cuttings may not survive.

(a) (b)

Figure 20. Conditions of Cuttings in Onsite Storage Treatment: (a) Cuttings in Onsite Storage in Compost Show Roots; (b) Cuttings in Onsite Storage in Water Show Roots and Leaves.

INSTALLATION TIMING AND SIZE OF CUTTING

Logistic Regression Model

Researchers investigated the influence of the installation timing and cutting size on the cutting survival. Only the cold storage treatment data were analyzed in detail because the onsite storage treatments were not applicable due to very low survival rates. Researchers analyzed data using the binary logistic regression because (1) the dependent variable (survival) is dichotomous (live or dead), and (2) the independent variables (month, cutting diameter, cutting length) include both the ordinal type (March, April, and May) and the scale type (numerical values). In the beginning of the analysis process, a full model was established as:

$$\text{Cutting survival} = f\,[\text{cutting diameter, cutting length, installation month, } (\text{cutting diameter})^2, (\text{cutting length})^2] \qquad (2)$$

When encoded in SAS®, the variable names of Equation (2) were abbreviated as:

$$survival = f\,(diam, length, month, diam^2, length^2) \qquad (3)$$

The logistic regression model (also called the logit model) input into SAS® was:

$$Logit(\hat{P}_{Survival=1}) = Ln(\frac{\pi_{Live}}{1-\pi_{Live}}) = \beta_0 + \beta_1 \cdot diam + \beta_2 \cdot length + \beta_3 \cdot month$$
$$+ \beta_4 \cdot diam^2 + \beta_5 \cdot length^2 + \beta_6 \cdot (diam \times length) + \beta_7 \cdot (diam \times month)$$
$$+ \beta_8 \cdot diam^3 + \beta_9 \cdot (diam \times length^2) + \beta_{10} \cdot (length \times month) \qquad (4)$$
$$+ \beta_{11} \cdot (length \times diam^2) + \beta_{12} \cdot length^3 + \beta_{13} \cdot (month \times diam^2)$$
$$+ \beta_{14} \cdot (month \times length^2) + \beta_{15} \cdot (diam^2 \times length^2)$$

where $\hat{P}_{Survival=1}$ = The predicted probability of the cutting survival odds, $\frac{\pi_{Live}}{1-\pi_{Live}}$

$\pi_{Live} = \pi_{Survival=1}$ = The probability that a cutting survives

$Logit(\hat{P}_{Survival=1})$ = The natural logarithm, Ln, of the predicted probability of the cutting survival odds, $\hat{P}_{Survival=1}$; called log odds ratio or "logit"

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8, \beta_9, \beta_{10}, \beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{15}$ = Logit coefficients

The fitted logit model was then developed using the forward selection, in which regressors (independent variables) were added to the model one at a time until there were no additional regressors that explained a significant portion of additional variance. As presented in the selected SAS® output (Figure 21), the regression process ceased after two variables were entered – *month* (installation month) and *diam* (cutting diameter). The fitted logit model became:

$$Logit(\hat{P}_{Survival=1}) = \beta_0 + \beta_1 \cdot diam + \beta_2 \cdot month \qquad (5)$$

where $\hat{P}_{Survival}$ = The predicted probability of the survival odds

$\beta_0 = 3.7049$

$\beta_1 = -0.1878$

$\beta_2 = 1.1159$, when *month* = March

–0.4252, when *month* = April

–0.6907, when *month* = May

The complete SAS® program codes, input data, and outputs for the logistic regression are presented in Appendix F.

Before this fitted model was accepted, diagnosis on the fit of the model was conducted by assessing the deviance residuals of the model and the Hosmer-Lemeshow goodness-of-fit. The deviance residual for cutting *i*, denoted by dev_i, is defined as the signed square root of the contribution of the *i*th case to the sum for the model deviance (Neter et al., 1996, pp.595):

$$dev_i = \pm\{-2[Y_i \ln(\hat{\pi}_i) + (1 - Y_i)\ln(1 - \hat{\pi}_i)]\}^{1/2} \qquad (6)$$

where the sign is positive when Y_i = 1, and negative when Y_i = 0

Y_i = Observed cutting survival for cutting *i* (0: dead; 1: live)

$\hat{\pi}_i = \exp(\beta_0 + \beta_1 \cdot diam + \beta_2 \cdot month)/[1 + \exp(\beta_0 + \beta_1 \cdot diam + \beta_2 \cdot month)]$

= Fitted survival odds for cutting *i*

Appendix G presents the result of the deviance residuals for the fitted model. The index plot of deviance residuals shown in Figure 22 indicates that there is no extreme point causing problems against the fit of the model.

In addition, the Hosmer and Lemeshow goodness-of-fit statistics were examined. The result of the "Hosmer and Lemeshow Goodness-of-Fit Test" in Figure 21 shows that the Hosmer and Lemeshow goodness-of-fit statistic (χ^2) is 8.5890, and the corresponding *p*-value with 8 degrees of freedom is 0.3781. This indicates that the model fits well (Hosmer and Lemeshow, 2000). In view of the fact that the overall goodness-of-fit test based on the model deviance as well as the Hosmer-Lemeshow goodness-of-fit test suggested that the reduced model in Equation (5) is adequate, the model development process was concluded.

```
                                    The LOGISTIC Procedure

                                       Response Profile
                              Ordered                      Total
                                Value     survive      Frequency
                                    1           1            134
                                    2           0            104

Step  0. Intercept entered:
                 …
Step  1. Effect month entered:
                 …
Step  2. Effect diam entered:
                 …
```

Forward selection procedure ceased after variables month and diam were entered.

```
                                   Residual Chi-Square Test
                              Chi-Square       DF     Pr > ChiSq
                                 51.3300       44         0.2084

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

                                 Summary of Forward Selection
                   Effect                            Number         Score
           Step    Entered                  DF           In    Chi-Square    Pr > ChiSq
              1    month                     2            1       30.4849        <.0001
              2    diam                      1            2       20.4810        <.0001

                           Analysis of Maximum Likelihood Estimates
                                                   Standard
       Parameter                 DF    Estimate       Error    Chi-Square    Pr > ChiSq
       Intercept                  1      3.7049      0.7928       21.8393        <.0001
       diam                       1     -0.1878      0.0430       19.0656        <.0001
       month                3     1      1.1159      0.2274       24.0857        <.0001
       month                4     1     -0.4252      0.2065        4.2389        0.0395

                                    Odds Ratio Estimates
                                          Point          95% Wald
                      Effect           Estimate      Confidence Limits
                       diam                0.829       0.762       0.902
                       month  3 vs 5       6.090       2.887      12.847
                       month  4 vs 5       1.304       0.665       2.556

                                    Contrast Test Results
                                                      Wald
                      Contrast            DF    Chi-Square    Pr > ChiSq
                      Month                2       24.7337        <.0001
                      March vs April       1       16.2052        <.0001
                      March vs May         1       24.0857        <.0001
                      April vs May         1        4.2389        0.0395

                           Hosmer and Lemeshow Goodness-of-Fit Test
                              Chi-Square       DF     Pr > ChiSq
                                  8.5890        8         0.3781
```

Figure 21. Selected SAS® Output of Logistic Regression Analysis on Cuttings Treated by Cold Storage Method.

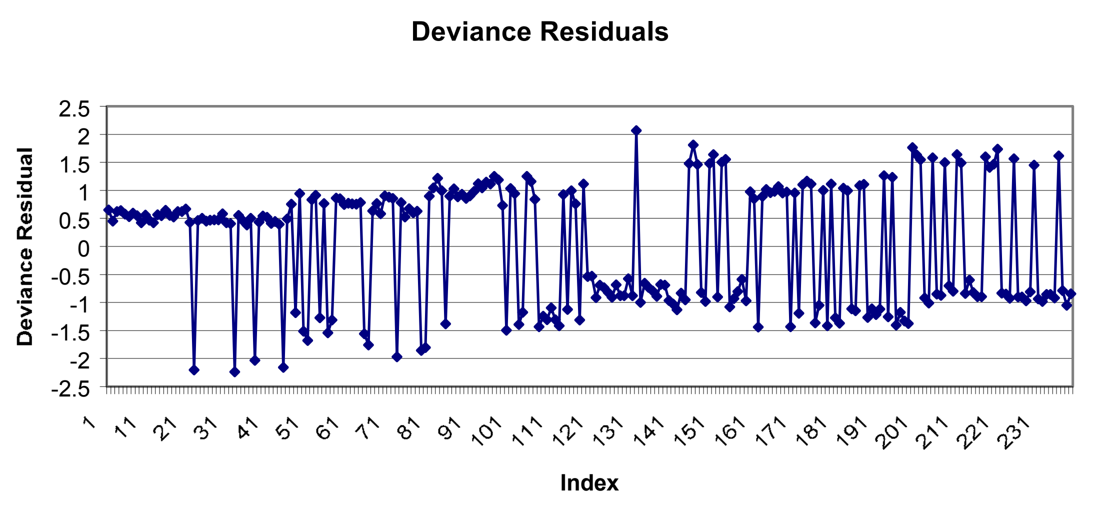


Figure 22. Index Plot of Deviance Residuals of Cold Storage Treatment Data.

Installation Timing

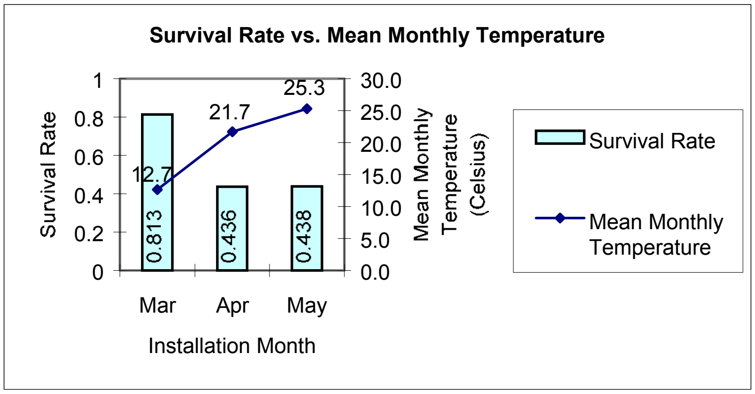
Researchers conducted a contrast test among installation months (March, April and May) in the logistic regression procedure to test whether there is any survival rate difference for cuttings planted in different months. As presented in Figure 21 under the "Contrast Test Results", the Wald statistic (χ^2) is 24.7337, and the corresponding *p*-value with 2 degrees of freedom is less than 0.0001. Hence, the difference is significant. Table 6 summarizes the survival rates of the March, April, and May installations.

The next question is how much different are those survivals in March, April, and May? To compare the difference, researchers used odds ratios to examine the strength of the association between the variable survival and month. As presented in Fig. 21 under the "Odds Ratio Estimates," the odds ratio of March versus May is 6.09, which means that the odds for cuttings to survive are 6.09 times greater for those installed in March than for those installed in May; and the 95 percent confidence interval is (2.887, 12.847), indicating a strong association between the variable survival and month. On the other hand, the odds ratio of April versus May is 1.304, meaning that the odds for cuttings to survive are 1.304 times greater for those installed in April than for those installed in May. This association, however, is not strong because the 95 percent confidence interval of (0.665, 2.556) covers the equal odds ratio 1.

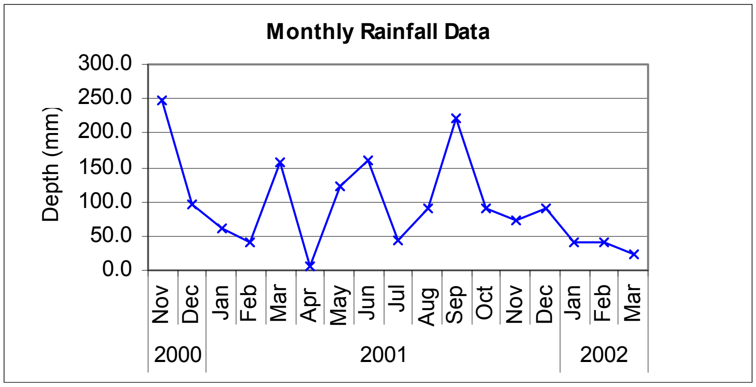
Table 6. Survival Rates of Cold Storage Treatment.

Installation time	Live / dead counts	Survival rate	95% confidence interval	Applicability
March	65/15	0.813	(0.727, 0.898)	Very applicable
April	34/44	0.436	(0.326, 0.546)	Applicable
May	35/45	0.438	(0.329, 0.546)	Applicable

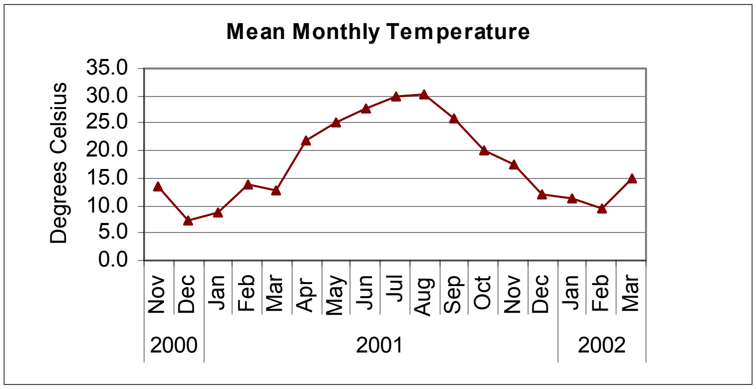
The cause for higher cutting survival in the March installation (0.813) than those in April (0.436) and May (0.438) installations could be related to the weather. As shown in Figure 23(a), the cutting survival rate decreases as the monthly temperature increases. Cuttings installed in March obtained sufficient rains (157.2 mm = 6.19 inches) and were under a mild temperature of approximately 12 ^{o}C (53.6 ^{o}F) (Figures 23[b] and [c]). While the survival rate is high (0.813) in March, it drops in April and May when the mean monthly temperatures jump from 12.7 ^{o}C (54.8 ^{o}F) in March to 21.7 ^{o}C (71.1 ^{o}F) in April, and to 25.3 ^{o}C (77.5 ^{o}F) in May. Probably, cuttings installed in March had a more suitable growing condition (mild temperatures and adequate water supply) than those planted in April and May, which in turn yielded a high survival rate (0.813). As shown in Figure 23(c), the temperature of 15^{o}-20^{o}C (59^{o}-68^{o}F) seems to be a threshold for the cold storage treatment to be considered "very applicable" (survival rate higher than 70 percent). Temperatures above 15 ^{o}-20 ^{o}C (59 ^{o}-68 ^{o}F) tend to suppress survival approximately from 80 percent to 40 percent. The monthly rainfall does not seem to affect the cutting survival in April and May as much as the monthly temperature. The survival rates of April and May installations are very close regardless of the significantly different rainfall depth between April (6.1 mm = 0.24 inch) and May (122.2 mm = 4.81 inches) (see Figure 23[b]).



(a) Survival Rate Versus Mean Monthly Temperature (°F = °C · 9/5 + 32).



(b) Monthly Rainfall Data (1 inch = 25.4 mm).



(c) Mean Monthly Temperature (°F = °C · 9/5 + 32).

Figure 23. Cutting Survival Rate and Weather[1].

[1] Temperature and Rainfall Data Provided by the Office of the State Climatologist for Texas at Texas A&M University.

Cutting Diameter

The fitted logit model was also used to test if cutting size has any effect on survival rate. As shown in Equation (5), the fitted logit model includes two independent variables, *diam* and *month,* that provide a good fit of the model. The logit coefficient for the diameter variable, β_1, is –0.1878 (*p*-value < 0.0001 (Fig. 21)). The negative β_1 value indicates that the probability for a cutting to survive decreases as the cutting diameter increases. This test result is opposite to Hoag's (1993, 1995) statement advocating that cuttings of larger diameters survived better than those of smaller ones. However, the test result is similar to Higdon and Westwood's (1963) findings, in which medium-sized pear cuttings (5-7 mm in diameter) rooted better than small or large ones, and juvenile cuttings rooted better than old ones.

The logit coefficient can be interpreted as the change in the dependent variable, $Logit(\hat{P}_{Survival=1})$, associated with a one-unit change in the independent variable (Menard, 1995). The change in the probability of a cutting to survive, π_{Live}, is not a linear function of the independent variable, *diam*, in the logistic regression model. The relationship between π_{Live} of the March installation and the cutting diameter is plotted in Figure 24. The results indicate that within the diameter range tested in this study, the survival probability decreases as the cutting diameter increases.

In summary, installation timing did affect the survival rate, and small diameter cuttings had a higher survival than large diameter cuttings. To extensively present this relationship, a wider range of cutting diameters needs to be investigated.

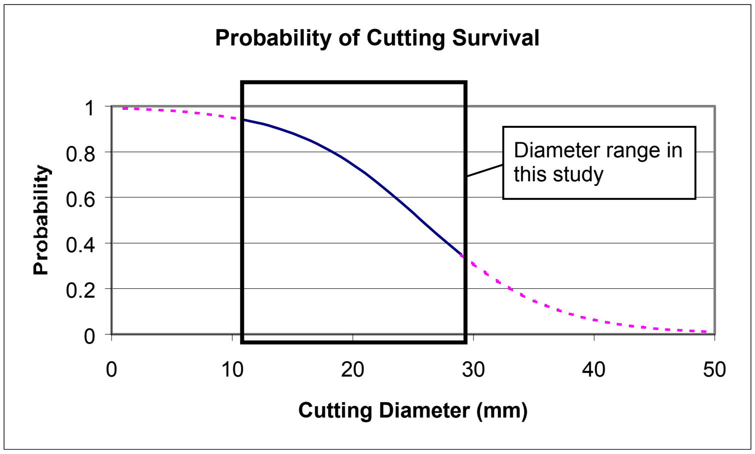


Figure 24. The Relationship between Cutting Diameter and Survival Probability of Cuttings Installed in March after Cold Storage Treatment (1 inch = 25.4 mm).

Dormancy and the Live Cutting Technique

The significance of dormancy to the live-cutting technique is that cuttings should be harvested and planted during the dormant period (Crowder, 1995; Hoag, 1995; Gray and Sotir, 1996; Allen and Leech, 1997; Schiechtl and Stern, 1997). Since no evidence was reported by any of the aforementioned literature, researchers conducted a test to investigate whether the dormancy is critical to the live cutting technique.

The test compared the survival of cuttings with leaves when harvested with the 40-70 percent survival rate reported by Gray and Sotir (1996). Presumably, the survival rate reported by Gray and Sotir (1996) represented their field experience without storage treatment applied to the cuttings. Thus, their reported rate could represent cuttings harvested and planted during dormancy. As presented in Table 7, cuttings harvested and installed beyond the dormant period when they have grown leaves have a very low survival rate of 0.077 with a confidence interval of (0, 0.161). It is obvious that harvesting and installing cuttings after dormancy is broken is not applicable.

In summary, cuttings harvested and installed when they have grown leaves did not have a satisfactory survival using the live-cutting technique. Therefore, harvesting and installing cuttings when they are still dormant is critical to the applicability of the live-cutting technique.

Table 7. Growing Season and Dormant Comparison of Harvested Cuttings.

Test type	Cuttings with leaves test [a]	Gray and Sotir (1996)
Live counts	3	No data
Dead counts	36	No data
Survival rate	0.077 C.I. [b] = (0, 0.161)	0.4 to 0.7 [c]

[a] Cuttings were harvested and soaked on April 13, 2001, and planted on April 19, 2001.
[b] 95 percent confidence interval.
[c] Claimed to be satisfactory one or two years after installation.

Application Potential

Since the cold storage method demonstrated promising results, the next question is whether this method is practical for field operation. A cost analysis for using cold storage in field conditions appears to provide the answer. Trailers with self-contained, diesel-powered refrigerated units are available for lease. A typical 48-foot trailer can store approximately 23,520 cuttings, which can treat about 150 meters (500 feet) of streambank using brushlayering with four lifts. Trailer rental would cost about $1,250 per month plus fuel. If the truck is used for three months, the estimated cost of rental and fuel is about $5,000. For a typical streambank stabilization project of $100,000-$150,000, the cost is no greater than 5 percent, which is reasonable.

Appendix H presents a draft specification outlining the procedure to store cuttings for later planting.

BIOTECHNICAL TECHNOLOGY
REFERENCE/GUIDELINE FOR TXDOT

INTRODUCTION TO BIOTECHNICAL TECHNOLOGY

Biotechnical engineering utilizes live plant materials combined with inert materials, such as geosynthetics and rocks to provide protection of streambanks or slopes. Live plant cuttings are harvested and planted in the dormant period to be effective. Nine biotechnical techniques with application potential for TxDOT include (detailed descriptions of each technique are presented in Appendix C):

- live stakes,
- live fascines,
- brushlayering,
- branchpacking,
- vegetated geogrids,
- live cribwall,
- joint planting,
- brushmattress, and
- dormant post planting.

Recommended Regions

Researchers recommend the eastern half of Texas as the best area for use of biotechnical techniques for streambank stabilization simply because the major plant to be used, black willow (*Salix nigra*), is widely available in this natural range. Although there are other types of plants suitable for use, availability may be an issue. Check the local NRCS Plant Materials Center for detailed information. General plant selection information can also be found in “Chapter 16, Streambank and Shoreline Protection. Engineering Field Handbook” by USDA Natural Resources Conservation Service (USDA/NRCS, 1996), and “Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction. Engineering Field Handbook” by USDA Soil Conservation Service (USDA/SCS, 1992).

Stream Order

Streams with an order of one, two, or three are suitable for biotechnical streambank stabilization. Streams with an order higher than three may need extensive assessment to determine the feasibility of applying biotechnical methods. Stream orders can usually be determined using TxDOT's general highway county maps.

Site Reconnaissance

The following points need to be assessed and documented during site reconnaissance:

- **Geometrics of stream channel**. Shape and slope of a stream will affect the selection of biotechnical technique. Eroded outer stream bends that endanger important structures above streambanks need to be identified, which will also affect the selection of biotechnical techniques.
- **Visibility to the general public**. Some of TxDOT's streambank erosion problems are located within public parks. For these cases, aesthetics of a treatment will be very important in addition to the stabilization performance.
- **Infrastructure**. Identify infrastructure that is endangered by streambank failures. For TxDOT, bridges are the major structure to be protected.
- **Soil**. Soil boring data are necessary to determine what techniques should be selected. If clay is the major soil in the project site, shrink-and-swell of the streambank surface may be a problem that needs to be addressed. Using soil retention blankets before vegetation establishes will protect fine materials from erosion.
- **Right-of-way.** The width of the right-of-way will determine how long a streambank needs to be treated and the limit of work.
- **Utilities.** Abandoned or in-use utility pipelines need to be identified. Pipelines crossing a stream that significantly interfere with stream flow or catch large debris should be removed.
- **Access for construction.** In urban areas, direct access to a stream may not be available. Cases such as this will require planning for access. Temporary

construction easements and agreements with landowners may be needed for access.

Project Schedule

Harvest and installation of plant cuttings should be scheduled within the dormant period. In most parts of Texas, the dormant season begins about December 1 and ends around the first of March. For warmer regions, such as the Rio Grande Valley, shorter dormant periods should be expected. If scheduling within the dormant season is difficult, the engineer can decide whether the cold storage method is to be used, based on their schedule and budget. Special specification for cold storage can be found in Appendix H.

Right-of-Way Issues

Existing utilities that encroach on the waterway will need relocation or removal prior to construction. Coordinate with local officials to complete the clearance of right-of-way issues to ensure the construction will not be delayed. Any delays to biotechnical techniques increase the probability for failure when conducting all related work during the dormant period.

Technique Selection

The most important weakness in the current knowledge base is adequate objective design information for selecting and applying biotechnical techniques. Review of the literature shows that almost all of the design and selection information for biotechnical streambank and channel protection is developed from just a few literature sources and case studies, with little numerical or laboratory underpinning. There is very little evidence-based selection guidelines. For this reason, researchers suggest the following solely on the basis of literature review and design experience gained from the demonstration project.

Shade Condition

Biotechnical techniques should not be applied to areas with no or very little sunlight. Consider use of structural methods for this situation.

Slope of Streambank

Techniques such as live stakes, live fascines, or brushlayering are suitable for streambanks of 33 percent or flatter slopes and should not be used to stabilize streambanks of 33 percent or steeper slopes. Joint planting and brushmattress could be used for 50 percent slopes and; vegetated geogrids for 100 percent. In extreme cases of more than 100 percent slopes, live cribwall may be used. To repair local slope failures, branchpacking will be a cost-effective measure.

Cost and Strength

The cost-strength matrix presented in Appendix C provides basic knowledge for design engineers to judge which techniques to select. Normally, cost of a biotechnical technique increases with strength. The coordinate "strength" is the mean shear stress that a biotechnical technique may sustain. The following graphic example (Figure 25) is the cost-strength matrix that includes two axis's with three levels: low (L), medium (M), and high (H). The location of the bull's eye circle indicates the cost-strength information for specific biotechnical methods, in which the dark circle is located approximately at the mean value, and the large circle covers most of the varied values from the literature. It should be noted that the strength of biotechnical methods enhances with time. For those methods that have much weaker strength at the early stage after completion, a gray bull's eye that indicates the early strength is shown. The units for "Cost" and "Strength" are dollars per linear foot, and pounds per square foot, respectively, with the relative values shown on Figure 25.

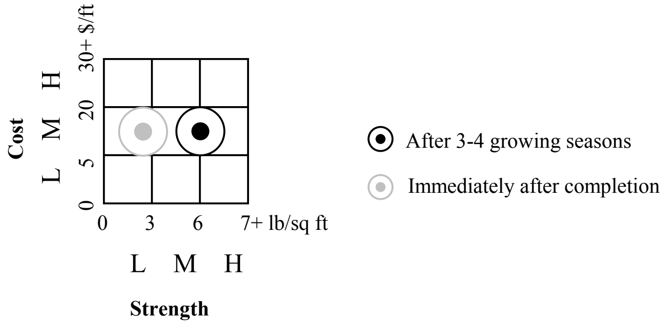


Figure 25. Cost-strength Matrix for Biotechnical Technique.

Using the three strength categories in the cost-strength matrix, biotechnical techniques can be grouped in low, medium, and high strength groups:

- Low strength: live stakes, live fascines, and brushlayering;
- Medium strength: branchpacking, vegetated geogrids, joint planting, brushmattress, and dormant post planting; and
- High strength: live cribwall.

Plant Selection

Black willow (*Salix nigra*) is recommended for biotechnical streambank stabilization. Eastern cottonwood (*Populus deltoids*) may be used in certain areas. For more selections or projects with purposes other than streambank stabilization that need other plants, contact local NRCS Plant Materials Centers.

CONCLUSIONS

Researchers based the following conclusions on the literature review, demonstration design and monitoring process, and dormancy extension investigation in this project.

- Biotechnical streambank stabilization techniques have been successfully applied in many areas of the United States. Despite the of lack of evidence, details of construction procedures are widely available, and design guidelines still remain brief and general in the literature.
- Although their use in Texas is still very rare, biotechnical techniques have great application potential in Texas, judged by their ease of technology transfer, stabilization mechanism, long-term cost-effectiveness, and availability of suitable plant materials.
- The site-specific characteristics of streambank stabilization projects hint that the design procedure and selection of biotechnical technique cannot be easily standardized.
- The short dormancy period coupled by rainy winters in Texas make biotechnical construction scheduling very difficult. Most of Texas, even in western parts of the state, is characterized by very short, wet winters. Wet winters make access to stream bottoms difficult. Many of the biotechnical techniques require access to the toe of the slope. Also, live cuttings must be harvested and installed in the dormant period. With the short winters in Texas, the harvest and installation window is limited to about three months, from December 15 to March 15. Given the difficulty of document preparation in the letting cycle, normal weather and any delays makes construction very difficult.
- Combining the difficulty of scheduling construction in the short dormant period and TxDOT's complicated letting procedure will make biotechnical application in Texas even more difficult.

- From the monitoring results of the demonstration project in Hutchins, Texas, the built biotechnical streambank stabilization project demonstrates the potential applicability of biotechnical methods in Texas. Although the contractor did not have the experience of constructing vegetated geogrids and dormant post plantings in the Cottonwood Creek project, the technology transfer was smooth, and the results were satisfactory. Post-project monitoring should always be implemented when biotechnical projects are built. With an appropriate post-project evaluation plan, more lessons can be learned to improve understanding of the technique.
- The dormancy extension experiment utilizing the cold storage treatment appears to be a practical solution to ease the difficulty of scheduling biotechnical construction. Cold-stored cuttings that were harvested in February 2001 had a survival rate of 0.813, 0.436, and 0.438 when they were planted in March, April, and May 2001, respectively. This indicates that the survival rates of cold-stored cuttings are satisfactory.
- In contrast, cuttings harvested and installed after leaves have grown may not survive. The live-cutting technique must be conducted when plants are dormant. Using cuttings harvested after their buds have broken and leaves have grown will not be effective.
- A cost analysis for using cold storage in field conditions appears to be practical. Trailers with self-contained, diesel-powered refrigerated units are available for lease. A typical 48-foot trailer can store approximately 23,520 cuttings, which can treat about 150 meters (500 feet) of streambank using brushlayering with four lifts. Trailer rental would cost about $1,250 per month plus fuel. If the truck is used for three months, the estimated cost of rental and fuel is about $5,000. For a typical streambank stabilization project of $100,000-$150,000, the cost is no greater than 5 percent, which is reasonable.
- The promising results and application potential from the cold storage treatment encourage further studies focusing on the application of different plant species to cover warm regions with different, but potentially workable

plants. Researchers anticipate that with continued efforts, thorough plant harvest, storage, and installation guidelines can be generated, and the dormancy limitation on biotechnical streambank stabilization in warm regions can be reduced. Given these factors, using live cuttings to stabilize streambanks may have practical applicability in warm regions.

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APPENDIX A
RECOMMENDED SPECIAL SPECIFICATIONS

SPECIAL SPECIFICATION
ITEM XXXX
LIVE STAKES

1. Description. This Item shall govern for the placement and handling of all materials for the construction of live stakes at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live stakes supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with "Hortus Third by Liberty Hyde Bailey Hortorium." The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, between 1 inch and 1.5 inches. Branches shall be reasonably straight, and a minimum of 30 inches long. Always leave at least 50 percent of the selected stand for future regeneration.

All stakes shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live stakes should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches shall be removed, but bark must be kept intact.

During transportation, the live stake bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live stakes must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live stakes shall be installed within two days after cutting.

3. Construction Methods.

(1) General. After the designated areas have been completed to the lines, grades, and cross sections shown on the plans and as provided for in other items of this contract, live stakes shall be installed in accordance with the requirements hereinafter described.

(2) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(3) Installation of Live Stakes. Tamp the live stakes perpendicularly into slopes or banks using a dead blow hammer. Where the subsoil is firm, use a steel rebar to create pilot holes so that when tamping the live stakes, they will not be damaged. The basal end of the stake shall fit snugly in the hole while leaving the top growing tips slightly above the face of the ground. Live stakes shall be installed at the density and spacing indicated in the plans.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of live stakes in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the square yard of material complete in place.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for “Live Stakes.” This price shall be full compensation for necessary earthwork, furnishing, hauling and placing live plant materials, soil, water and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
LIVE FASCINES

1. Description. This Item shall govern for the placement and handling of all materials for the construction of live fascines at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live plant materials supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with “Hortus Third by Liberty Hyde Bailey Hortorium.” The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, no less than 0.5 inch and no greater than 1.5 inches. Branches shall be reasonably straight. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live plant materials shall be installed within two days after cutting.

(2) Live Stakes. Item XXXX, "Live Stakes" should be used in addition to live branch cuttings.

(3) Wood Stakes. Dead stout stakes used to secure the live fascines shall be 2.5-foot long, untreated, 2 x 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length. Only new, unused lumber should be used, and any stakes that shatter upon installation shall be discarded.

(4) Soil Retention Blankets. Item 169, "Soil Retention Blanket" should be used as specified in the plans and details.

(5) Toe Protection Materials. Toe protection materials shall be installed if the areas to be treated are adjacent to any watercourses, and shall be of the type shown on the plans.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Constructing Embankments. Construction of the embankment shall be in accordance with Item 110, "Excavation" and Item 132, "Embankment" or as directed by the Engineer, except for measurement and payment. The grade shall be prepared to the steepness and dimensions shown in the plans.

(3) Preparing Live Fascines. Live branch cuttings should be bundled together using twines to form a cylindrical form of 6 to 8 inches in diameter. Live fascine bundles should be prepared immediately before installation.

(4) Installing Live Fascines. The contractor shall ensure that the construction of each trench follows the contours of embankments above the base flow to the locations and dimensions shown in the plans and details. Install Item 169, “Soil Retention Blanket” on the embankment and trenches as specified in the plans and details. Place the live fascines into the trench, and anchor them by driving the wood stakes directly through the live fascines. Install live stakes as indicated in the details, leaving 3 inches to protrude above the top of the embankment surface. Place moist soil along sides of live fascines, and compact the backfill with care.

(5) Installing Toe Protection. Toe protection shall be installed prior to the installation of live fascines if it is shown in the plan, and shall conform to the dimensions in the plans.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of live fascines in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the square yard of surface area as shown on the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Live Fascines." This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing all toe protection and live plant materials, wire, stake, soil, water, and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
BRUSHLAYERING

1. Description. This Item shall govern for the placement and handling of all materials for the construction of brushlayering at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live plant materials supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with "Hortus Third by Liberty Hyde Bailey Hortorium." The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, no less than 0.5 inch and no greater than 1.5 inches. Branches shall be reasonably straight. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live plant materials shall be installed within two days after cutting.

(2) Toe Protection Materials. Toe protection materials shall be installed if the areas to be treated are adjacent to any watercourses, and shall be of the type shown on the plans.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Installing Toe Protection. Toe protection shall be installed prior to the installation of brushlayering if it is shown in the plan, and shall conform to the dimensions in the plans.

(3) Installing Brushlayering. The Contractor shall ensure that the construction of each layer or lift conforms to the dimensions shown in the plans and details. Each layer of earthen embankment shall be wetted uniformly to the moisture content required to obtain a density comparable with the adjacent undisturbed soil. Compaction shall be accomplished by mechanical tamps or rammers or as directed by the Engineer. The use of rolling equipment of the type generally used in compacting embankments will be permitted on portions that are accessible to such equipment. Regardless of the equipment used, special care shall be exercised so that live plant materials will not be damaged by the compaction.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of brushlayering in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the square yard of surface area as shown on the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Brushlayering." This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing all toe protection and live plant materials, wire, stake, soil, water and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
BRANCH PACKING

1. Description. This Item shall govern for the placement and handling of all materials for the construction of branch packing at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live plant materials supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with “Hortus Third by Liberty Hyde Bailey Hortorium.” The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, between 0.5 inch and 2 inches. The length of the branches will vary but must be long enough to touch the undisturbed soil of the bank of the treated area. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live plant materials shall be installed within two days after cutting.

(2) Wood Stakes. Wood stakes shall be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 x 4 lumber.

(3) Toe Protection Materials. Toe protection materials shall be installed if the voids to be treated are adjacent to any watercourses, and shall be of the type shown on the plans.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Installing Branch Packing. Starting at the lowest point, drive the wood stakes vertically 3 to 4 feet into the ground at a 1 to 1.5 foot spacing. Place the first layer of live branches 4 to 6 inches thick in the bottom of the void between wood stakes with the pattern and direction as shown in the plans. On top of the branches, fill with a layer of soils. The Contractor shall ensure that the construction of each layer conforms to the dimensions shown in the plans and details. Each layer of filled soils shall be wetted uniformly to the moisture content required to obtain a density comparable with the adjacent undisturbed soil. Compaction shall be applied to ensure intimate contact with the branches. Special care shall be exercised so that live plant materials will not be damaged by the compaction. Repeat the process of placing a layer of live branches followed by a layer of compacted soils until the final grade and dimension are achieved.

Where the voids to be treated are adjacent to any watercourses, toe protection shall be installed. The material type and dimension of toe protection shall conform to those in the plans.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of branch packing in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by (1) the square yard of the final filled area, or by (2) the cubic yard in its final position as the volume of branch packing computed in place between (1) the original ground surfaces or the surface upon which the embankment is to be constructed, and (2) the lines, grades and slopes of the accepted embankment, using the average end area method.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for “Branch Packing.” This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing all live plant materials and toe protection, stake, soil, water and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM XXXX

VEGETATED GEOGRIDS

1. Description. This Item shall govern for the placement and handling of all materials for the construction of vegetated geogrids at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Geogrid. The geogrid supplied shall be a synthetic material meeting the requirements of Departmental Materials Specification DMS-6240, "Geogrid for Base/Embankment Reinforcement," of the type as shown on the plans.

(2) Filter Fabric. The filter fabric shall meet the requirements of Department Material Specification DMS-6200, "Filter Fabric," of the type as shown on the plans.

(3) Live Plant Materials. The live cuttings supplied shall be black willow (*Salix nigra*) or rough-leafed dogwood (*Cornus drummondii*) cuttings. Plant names indicated comply with "Hortus Third by Liberty Hyde Bailey Hortorium." Common and scientific names are provided. The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants should be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, when the species has dropped its leaves. The Contractor shall notify the owner's representative of the location of the source prior to harvesting. For black willow and rough-leafed dogwood, select branches with a diameter measured at the base of the cuttings, of no less than 0.5 inch and no greater than 1.5 inches. Cuttings should be a minimum of 5 feet long. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water or moist soil, shaded, and protected from the wind. They must be protected from drying at all times. All live plant material should be installed within two days after cutting.

(4) Rock Aggregate for Embankment Foundation. Rock aggregate shall consist of gravel, crushed slag, or crushed stone. Aggregate size shall be 3 to 6 inches.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Constructing Rock Foundation. The rock foundation shall consist of aggregate completely encased within an approved filter fabric. The foundation will be placed on firm soil. The foundation lift will be inclined as indicated in the plans, dipping towards the existing bank.

(3) Constructing Embankments. Construction of the vegetated geogrids shall be in accordance with Item 110, “Excavation” and Item 132, “Embankment” or as directed by the Engineer except for measurement and payment.

The Contractor shall ensure that the construction of each layer or lift conforms to the dimensions shown in the plans and details, using as needed, suitable form work to insure uniformity in the face of the lifts. Each layer of earthen embankment shall be wetted uniformly to the moisture content required to obtain a density comparable with the adjacent undisturbed soil. Compaction shall be accomplished by mechanical tamps or rammers or as directed by the Engineer. The use of rolling equipment of the type generally used in compacting embankments will be permitted on portions that are accessible to such equipment. Regardless of the equipment used, special care shall be exercised so that live plant materials will not be damaged by the compaction.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of vegetated geogrids in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the “Lump Sum” of all vegetated geogrids in this project, complete in place within the limits as shown in the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for “Vegetated Geogrids.” This price shall be full compensation for excavation and embankment, furnishing, hauling, and placing all foundation material, geogrid, filter fabric, organic growing medium, water and live plant materials and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM XXXX

LIVE CRIBWALL

1. Description. This Item shall govern for the placement and handling of all materials for the construction of live cribwall at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Crib Members. Crib members shall be round or square timbers, no less than 6 inches in diameter or dimension with the required length for different locations specified in the plans.

(2) Live Plant Materials. The live plant materials supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with "Hortus Third by Liberty Hyde Bailey Hortorium." The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, of no less than 0.5 inch and no greater than 1.5 inches. Branches shall be a minimum of five (5) feet long. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live plant material shall be installed within two days after cutting.

(3) Rock Aggregate. Rock aggregate shall consist of gravel, crushed slag, or crushed stone. Aggregate size shall be 3 to 6 inches.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Installing Brush Mattress. At the base of the streambank to be treated, excavate 2 to 3 feet below the streambed, and ensure that the base of the excavation is battered as indicated in the plans. Place the first course of logs or timbers at the front and back of the excavated foundation, parallel to the slope contour. Place the next course of logs or timbers at right angles on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches. Secure the top and bottom courses of logs or timbers with nails or reinforcement bars. This process shall be repeated until the designed structural height is reached as indicated in the plans.

During erection of the crib wall, the crib shall be filled with rock aggregate, soil and live willow cuttings in the following manner: The rock aggregate shall be placed at the base of the crib approximately 2 to 3 feet in depth. After the base is filled with rocks, live willow cuttings and soils shall be placed in the crib alternately. The density of the live willow cuttings shall be in accordance with the one indicated in the plans. When refilling soils into the crib, slightly compact the soil, and ensure that there are no apparent voids between the logs or timbers and live willow cuttings. The Contractors shall ensure that live willow cuttings will not be damaged by the compaction.

When placing willow cuttings, the cuttings shall be uniformly spread on the logs or timbers, with the tips extending one to two feet beyond the face of the cribwall, and ensure that the cuttings are battered into the crib.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of live cribwall in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the cubic yard in its final position as the volume of live cribwall computed in place between (1) the original ground surfaces or the surface upon which the live cribwall is to be constructed, and (2) the lines, grades and slopes of the accepted embankment, using the average end area method.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for “Live Cribwall.” This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing crib members, live plant materials, soil, rock aggregates, water, and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
JOINT PLANTING

1. Description. This Item shall govern for the placement and handling of all materials for the construction of joint planting at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live stakes supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with "Hortus Third by Liberty Hyde Bailey Hortorium." The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, between 1 inch and 1.5 inches. Branches shall be reasonably straight, and a minimum of 30 inches long. Always leave at least 50 percent of the selected stand for future regeneration.

All stakes shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live stakes should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches shall be removed but bark must be kept intact.

During transportation, the live stake bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live stakes must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live stakes shall be installed within two days after cutting.

(2) Stone Riprap. Stone for riprap shall meet the requirements as of Item 432.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Constructing Stone Riprap (Common). The stone riprap shall be constructed in accordance with Article 432.4.(2).(c). The grade shall be prepared to the steepness and dimensions shown in the plans.

(**3) Installation of Live Stakes.** After constructing stone riprap, tamp the live stakes perpendicularly into openings or joints between the stone using a dead blow hammer. Where the openings are tight or the subsoil is firm, use a steel rebar to create pilot holes so that when tamping the live stakes, they will not be damaged. The basal end of the stake shall fit snugly in the hole beneath the stone riprap while leaving the top growing tips slightly above the face of the stone riprap. Live stakes shall be installed at the density and spacing indicated in the plans.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of joint planting in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the cubic yard of material complete in place. Cubic yards will computed on the basis of the measured area and the thickness shown on the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Joint Planting." This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing live plant materials, stone, soil, water and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
BRUSH MATTRESS

1. Description. This Item shall govern for the placement and handling of all materials for the construction of brush mattress at locations designated in the plans and in accordance with this Item.

2. Materials.

(1) Live Plant Materials. The live plant materials supplied shall be willow (*Salix spp*) cuttings with the species indicated on the plan. Plant names indicated shall comply with "Hortus Third by Liberty Hyde Bailey Hortorium." The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, no less than 0.5 inch. Branches shall be reasonably straight, and a minimum of six (6) feet long. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Plant material must arrive on the job site within 12 hours of cutting. Plants not installed on the day of arrival at the job site should be stored with butt ends in the water, shaded, and protected from the wind. They must be protected from drying at all times. All live plant materials shall be installed within two days after cutting.

(2) Wood Stakes. Dead stout stakes used to secure the brush mattresses shall be 2.5-foot long, untreated, 2 x 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length. Only new, unused lumber should be used, and any stakes that shatter upon installation shall be discarded.

(3) Wire. Wire used for securing the brush mattress shall be 16-gauge galvanized wire or materials as approved by the Engineer.

(4) Toe Protection Materials. Toe protection materials shall be of the type shown on the plans.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Constructing Embankments. Construction of the embankment shall be in accordance with Item 110, “Excavation” and Item 132, “Embankment” or as directed by the Engineer except for measurement and payment. The grade shall be prepared to the steepness and dimensions shown in the plans.

(3) Installation of Brush Mattress. Excavate an 8 to 12 inch deep trench above the base flow, at the toe of the streambank along the length of the area to be treated. Place willow cuttings in the trench, and ensure that the cut ends reach the bottom of the trench. The willow cuttings shall be spread uniformly along the streambank with the density indicated in the plans. Drive the dead stout stakes every 2 to 3-foot center in a grid pattern. Secure the willow cuttings using 16 gauge galvanized wire by wrapping the wire around each dead stout stake no closer than 6 inches from its top. The wire shall be installed in both horizontal and diagonal runs as indicated in the plans. After wiring the mattress, drive the dead stout stakes further into the ground to compress the cuttings tightly against the streambank. Wet the brush mattress and then fill voids between willow cuttings with thin layers of soil, but leave the top surface of the cuttings slightly exposed.

(4) Toe Protection. The Toe of the brush mattress shall be protected with materials as shown in details on the plans. After installing the toe protection, fill the trench that holds the brush mattress with soil. The filled soil shall cover the cut end of the willow cuttings at least 12 inches.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of brush mattress in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the square yard of surface area as shown on the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for “Brush Mattress.” This price shall be full compensation for necessary earthwork, furnishing, hauling, and placing all toe protection and live plant materials, wire, stake, soil, water and for all labor, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION
ITEM XXXX
DORMANT POST PLANTINGS

1. Description. This Item shall consist of furnishing and installing dormant post plantings in accordance with the lines and grades shown on the plans.

2. Materials.

(1) Live Plant Materials. The dormant posts supplied shall be black willow (*Salix nigra*) and native poplar (*Poplar spp*) posts. Plant names indicated comply with "Hortus Third by Liberty Hyde Bailey Hortorium." Common and scientific names are provided. The Contractor shall provide stock true to the botanical name. Stock furnished shall be in the specified range for branch caliper diameter and length. Appropriate stands of indigenous plants should be found along streambanks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, when the species has dropped its leaves. The Contractor shall notify the owner's representative of the location of the source prior to harvesting.

Live posts shall be a minimum of 3 meters (10 ft) long and 75 to 125 millimeters (3 to 5 inches) in diameter. All live posts shall be cleanly made at a blunt angle.

During transportation, the dormant posts should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The dormant posts must be covered with a tarpaulin during transportation to prevent drying.

The dormant posts must arrive on the job site within 12 hours of harvesting. Posts not installed on the day of arrival at the job site should be stored with butt ends in the water or moist soil, shaded, and protected from the wind. They must be protected from drying at all times. All live plant material should be installed within two days after harvesting.

(2) Toe Protection Materials. Toe protection materials shall be of the type shown on the plans.

3. Construction Methods.

(1) Planting Season. All planting of dormant plant materials shall be done between January 1 and March 1, except as specifically authorized by the Engineer in writing.

(2) Installation. The Contractor shall ensure that the construction of each live post conforms to the dimensions shown in the plans and details. The toe of the post planting section shall be protected with materials as shown in details on the plans. Special care shall be exercised to avoid damage to the live posts during construction.

4. Watering. Watering shall conform to the pertinent requirements of Item 168, Vegetative Watering. After the completion of the work, watering is not required unless there is a specific watering requirement by the Engineer or there is a drought condition in the first growing season between March 1 and November 15. Drought is defined as 28 consecutive days without measurable rainfall (0.1 inch in depth). A minimum of 0.5 inch of water shall be applied to all areas of dormant post plantings in each watering event. The rate of watering shall be slow enough to ensure that no significant runoff occurs at the bottom of the slope. If there is still no measurable rainfall within seven days after the supplemental irrigation, another 0.5 inch of water shall be supplied. This process shall be repeated until measurable rainfall occurs.

5. Measurement. This Item will be measured by the square meter of surface area as shown on the plans.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Dormant Post Plantings." This price shall be full compensation for all necessary earth work prior to post planting, labor, materials, freight, water, tools, equipment, and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM XXXX

CONCRETE ARMOR UNIT

1. Description. This Item shall govern for furnishing the materials and installing concrete armor unit as the toe protection shown on the plans and required by this Item.

2. Materials. The individual concrete armor unit shall consist of a homogeneous mass of consolidated concrete and shall be machine-made by a vibration and compression process, and composed of approved aggregates with a no-slump concrete mix. The mix water used shall be clean, fresh, free from oil, acids, soluble salts, and organic impurities. Cement shall conform to ASTM C150 requirements (Portland Cement). Test procedures shall conform to ASTM C140. Aggregates shall conform to ASTM C33. When potentially reactive aggregates are used, 25 to 35 percent of the cement shall be replaced with a Class F fly ash meeting the requirements of Departmental Material Specification DMS-8900; or 50 percent of the cement shall be replaced with Grade 100 or Grade 120 GGBF slag meeting the requirements of ASTM C989. Type II cement shall be used in sulfate and/or salt-water environments as determined by the Engineer.

The manufacturer of the concrete armor units shall furnish the installed system's Hydraulic Stability Test Report that complies with the test procedures under Federal Highway Guideline Report FHWA-RD-88-181 or FHWA-RD-89-199 to determine the system's critical shear stress value. The manufacturer must provide test data derived from the concrete armor units as specified herein with regards to shear stress capacity measured in pounds per square foot. Any extrapolation of test data derived from the testing of any other methods or different sizes of the concrete armor units will not be approved. Anchoring methods such as compacting and regrading of filled materials shall be performed in the field in accordance with the manner in which they were used during the hydraulic stability testing.

The concrete armor units shall exhibit a capacity to withstand the specified hydraulic data and physical application dimensions as shown on the plans, with a factor of safety of not less than 1.5. The factor of safety calculations shall be in accordance with Hydraulic Engineering Circular 23, FHWA HI-97-030 HEC 23, Bridge Scour and Stream Instability Countermeasures.

The geometry of a concrete armor unit shall consist of six equally spaced arms extending from a central hub, with each arm spaced at 90 degrees from the four adjacent arms. When placed in the most stable configuration, each unit shall rest on three of the six arms. The concrete armor units shall meet the following physical characteristics requirements:

Compressive Strength (min) @ 28 days	4500 lbs/sq. inch	ASTM C140
Water Absorption (max)	10%	ASTM C140
Specific Weight (min)	130 lbs/cubic ft.	ASTM C140
Minimum Critical Shear Stress	44 lbs/sq. ft	
Total Length (Fig. A-1)	24 inches	
Arm Width (Fig. A-1)	3.68 inches	

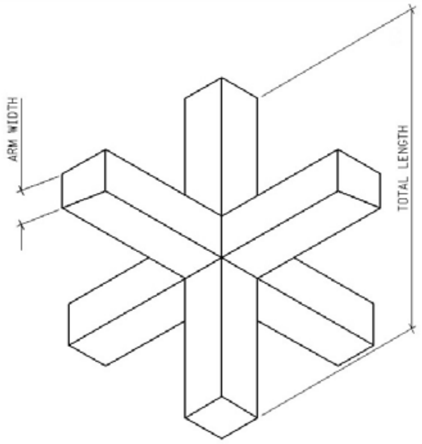


Figure A-1. Characteristics of Concrete Armor Units.

4. Construction Methods.

(1) Subgrade Preparation. Subgrade soil shall be prepared to the lines, grades and cross-sections shown on the plans. Excavate a trench, with the dimensions indicated on the plans, above the base flow, at the toe of the streambank along the length of the area to be treated. Trenches and transitions between slopes or slopes and toes shall be uniformly graded to facilitate the intimate contact between the concrete armor units and the underlying grade.

Subgrade soil shall be approved by the Engineer to confirm that the actual subgrade soil conditions meet or exceed the required material standards and conform to the design calculations and assumptions. Soils not meeting the required standards shall be removed and replaced with acceptable material and compacted (95 percent Standard Proctor density, ASTM 698).

Care shall be exercised so as not to excavate below the grades shown on the plans, unless directed by the Engineer to remove unsatisfactory materials, and any excessive excavation should be filled with approved backfill material and compacted. Where it is impractical, in the opinion of the Engineer, to dewater the area to be filled, over-excavations shall be backfilled with crushed rock or stone conforming to the grading and quality requirements of 0.75 inch maximum size coarse aggregate for concrete.

The areas above the water line that are to receive the concrete armor unit shall be graded to a smooth surface to ensure that intimate contact is achieved between the subgrade surface and the bedding layer, and between the bedding layer and the bottom surface of the concrete armor unit. Unsatisfactory soils and soils having a natural in-place moisture content in excess of 40 percent, and soils containing roots, sod, brush, or other organic materials, shall be removed, backfilled with select material, and compacted. The subgrade shall be uniformly compacted to a minimum of 95 percent of Standard proctor density (ASTM D-698). Should the subgrade surface for any reason become rough, corrugated, uneven, textured, or traffic marked to the extent that voids beneath the armor system are created, such unsatisfactory portion shall be scarified, reworked, recompacted, or replaced as directed by the Engineer.

Excavation of the subgrade, above the water line, shall not be more than 4 inches below the grade indicated on the contract drawings. Excavation of the subgrade below the water line shall not be more than 8 inches below the grade indicated on the plans. Where such areas are below the allowable grades, they shall be brought to grade by placing thin layers of select material and compacted. Where such areas are above allowable grades, they shall be brought to grade by removing material or reworking existing material and compacting as directed by the Engineer. Immediately prior to placing the bedding and concrete armor units, the prepared subgrade shall be inspected and approved by the Engineer.

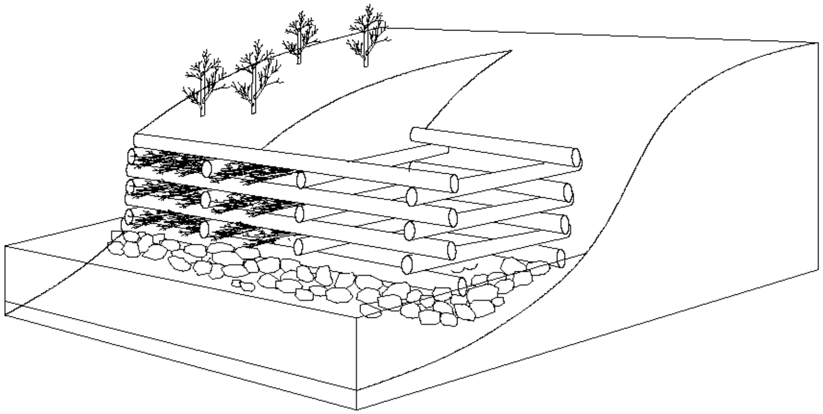
(2) Installing Concrete Armor Units. The concrete armor units shall be placed on the bedding layer in such a manner as to produce a densely-interlocked matrix in intimate contact with the bedding layer. Care shall be taken during installation so as to avoid damage to the concrete armor units during the installation process.

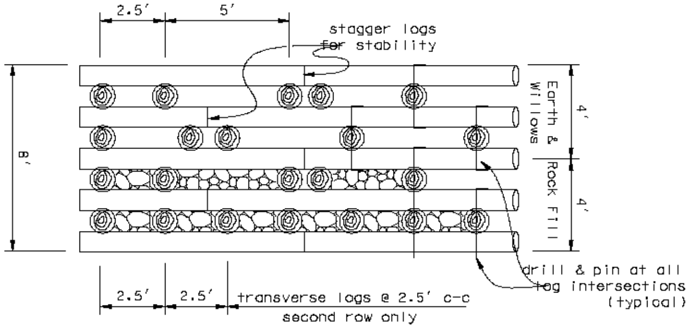
(3) Finishing. Sediment excavated from the toe or trenches shall be used to fill the voids of the installed concrete armor units. Trenches shall be backfilled and compacted flush with the top of the concrete armor units. The integrity of a soil trench backfill must be maintained so as to ensure a surface that is flush with the top surface of the concrete armor units for the entire service life. Top, toe and side termination trenches shall be backfilled with suitable material and compacted immediately after backfilling.

5. Measurement. This Item will be measured by the linear foot as shown on the plans, complete in place.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Concrete Armor Unit." This price shall be full compensation for necessary earthwork; furnishing, hauling, assembling, and placing all concrete armor units; backfill materials and for all labor, tools, equipment, and incidentals necessary to complete the work.

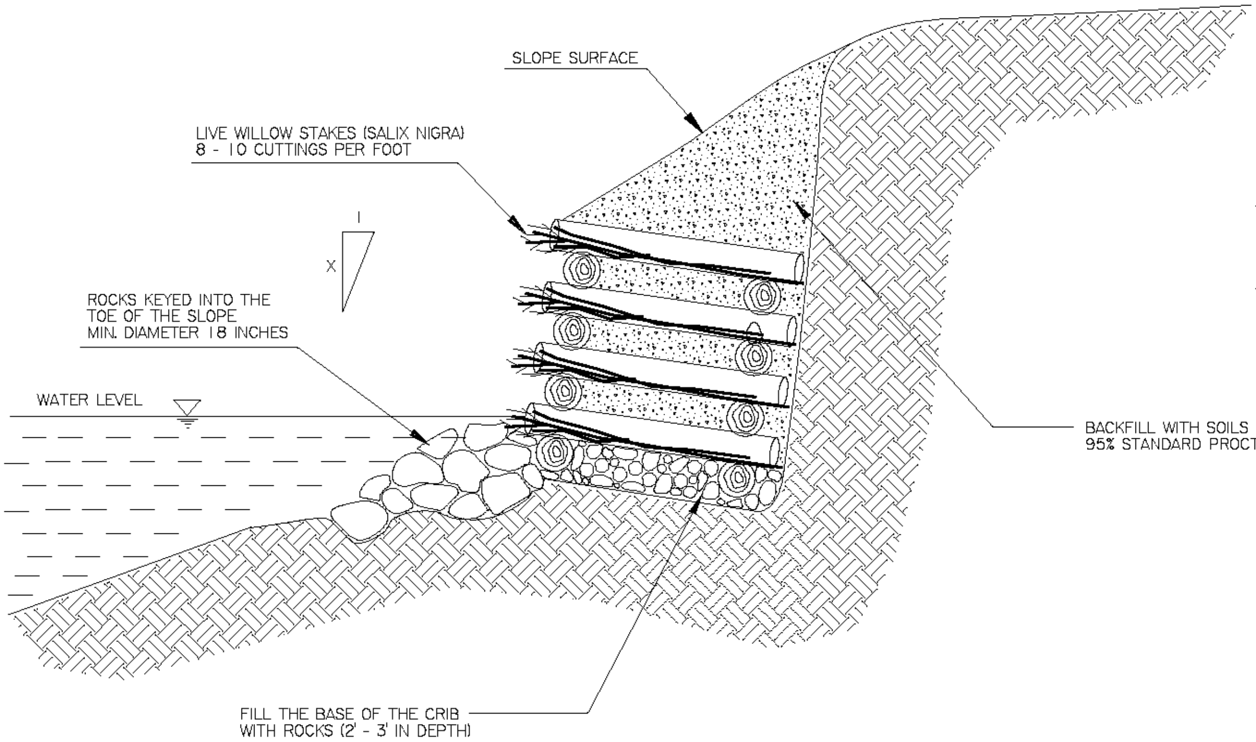
APPENDIX B
DETAIL DRAWINGS





FRONT VIEW

Logs shall be alder, or fir. 1.
8″-12″ diameter.
Drill and pin with #4 or larger 2.
rebar. Bend over both ends
where possible.



LIVE CRIBWALL NOTES:
1. CUT LINE OF EXISTING CONCRETE RIPRAP SHALL BE DIRECTED BY THE ENGINEER.
2. WILLOW CUTTINGS SHALL BE SALIX NIGRA.
3. ROCK RIPRAP SHALL BE USED FOR TOE PROTECTION.
4. THE DENSITY OF CUTTINGS SHALL BE 8 -10 CUTTINGS PER FOOT.
5. CONTRACTORS SHALL ENSURE THAT CUTTINGS ARE NOT DAMAGED WHEN COMPACTING FILLED MATERIALS.

LIVE CRIBWALL

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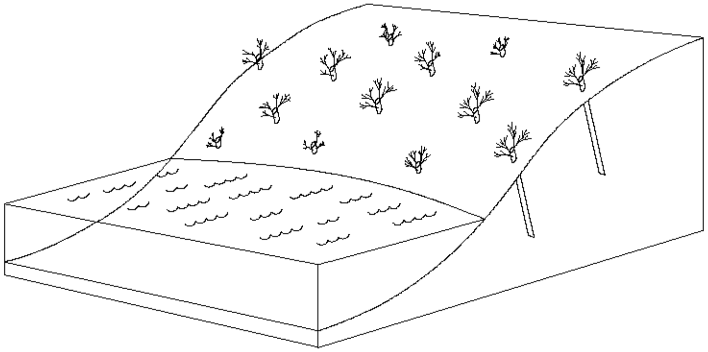

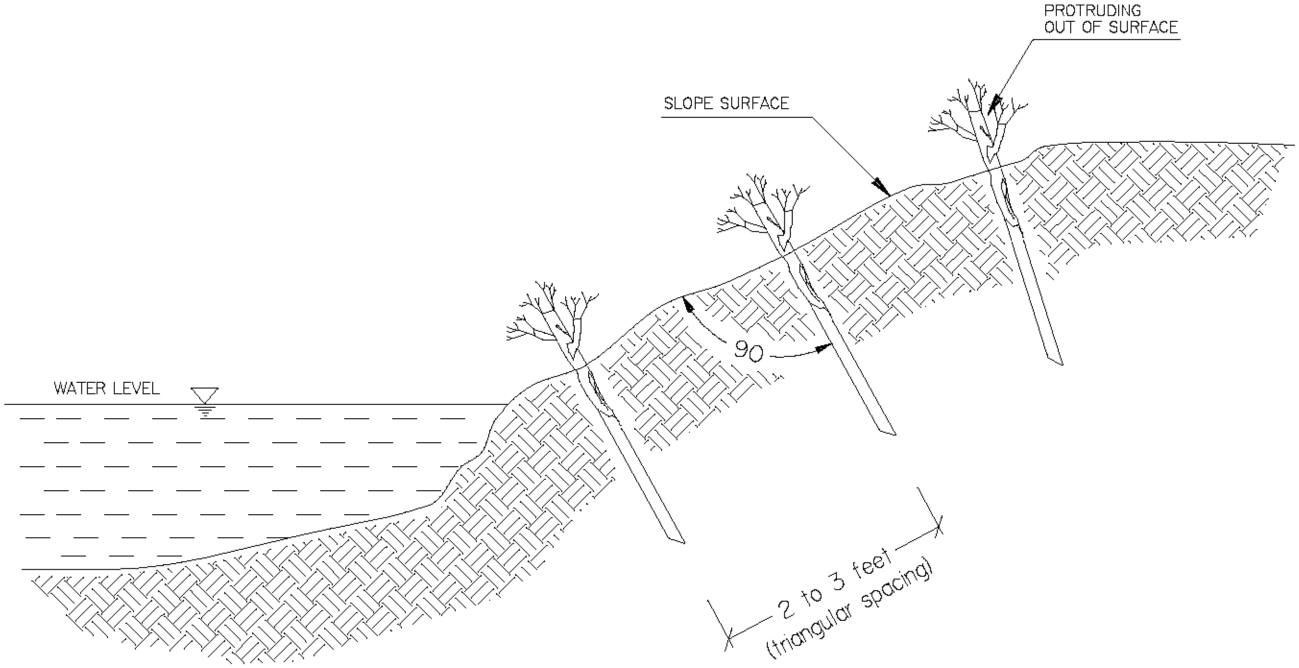

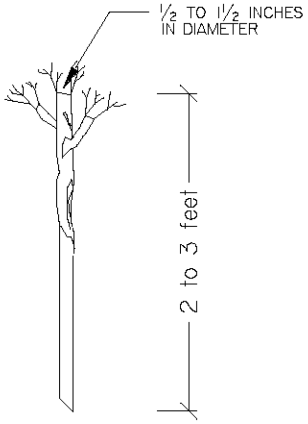

LIVE STAKE DETAIL

NOTES:

1. PROTECT LIVE STAKES FROM DAMAGE DURING INSTALLATION.
2. USE PRY BAR TO MAKE OPENING OR USE TUBING TO PROVIDE OPENING.
3. LIVE STAKES SHOULD HAVE GOOD CONTACTS WITH SOILS AFTER INSTALLATION.

LIVE STAKES

Texas Department of Transportation
(512) 416-2055

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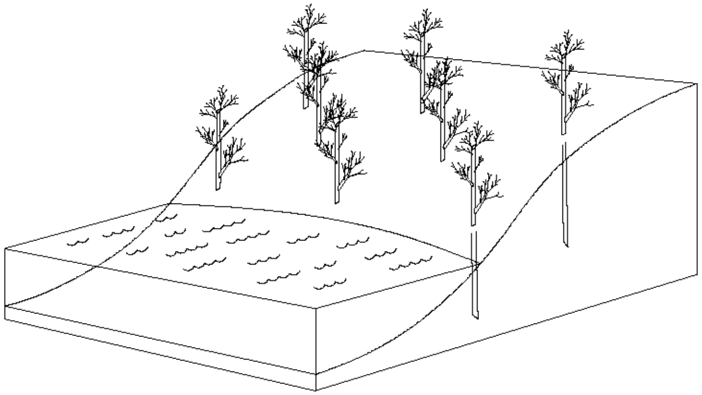

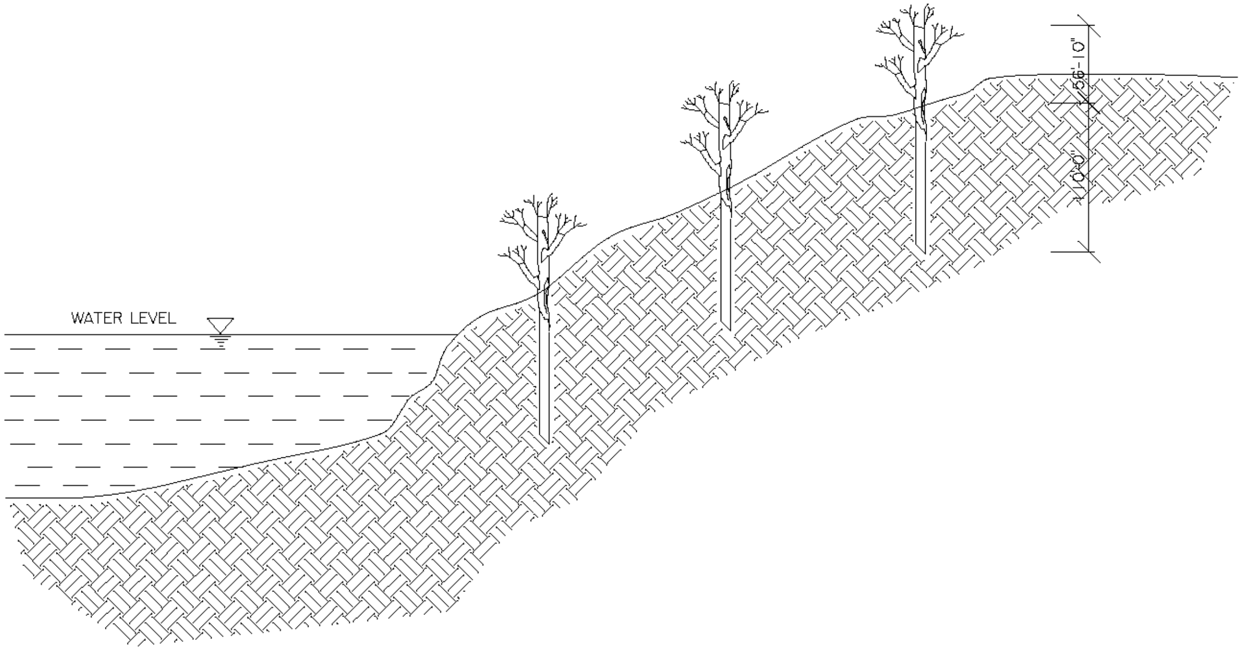

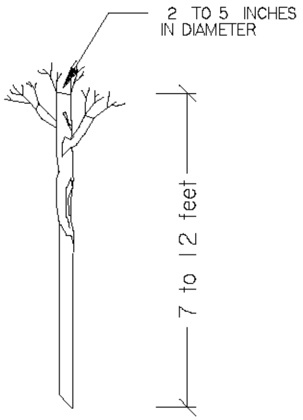

LIVE STAKE DETAIL

DORMANT POST PLANTINGS

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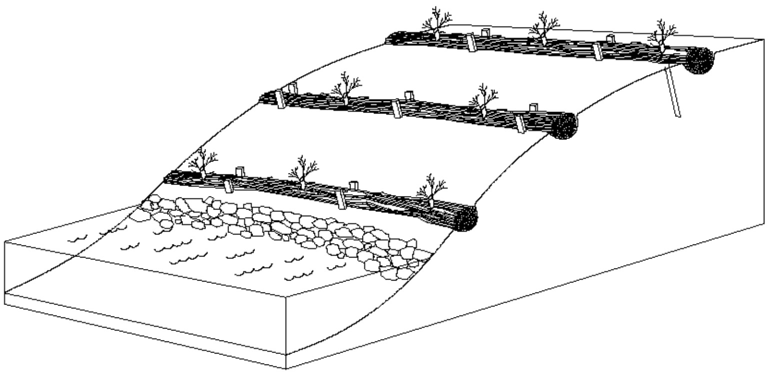

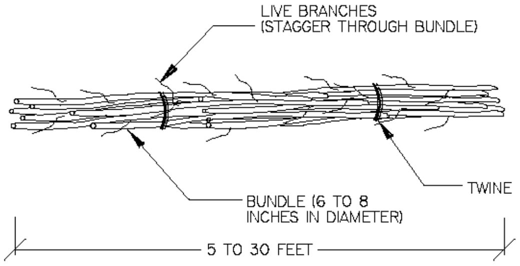

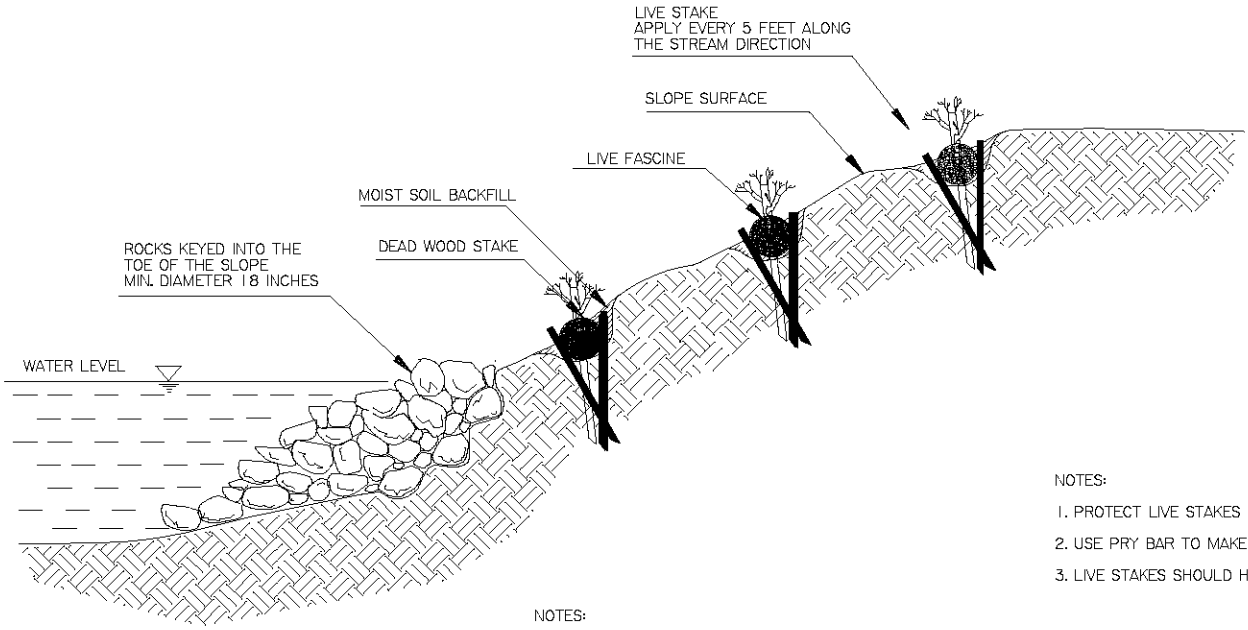

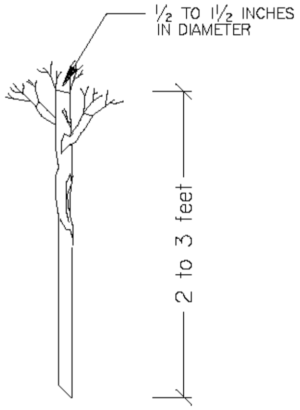

LIVE STAKE DETAIL

NOTES:

1. PROTECT LIVE STAKES FROM DAMAGE DURING INSTALLATION.
2. USE PRY BAR TO MAKE OPENING OR USE TUBING TO PROVIDE OPENING.
3. LIVE STAKES SHOULD HAVE GOOD CONTACTS WITH SOILS AFTER INSTALLATION.

NOTES:

1. FASCINES CONSTRUCTED OF A MINIMUM 35% LIVE, QUICK ROOTING MATERIAL PLACED ON THE BOTTOM OF THE BUNDLE. THE BALANCE MAY BE DEAD MATERIAL UNLESS SPECIFIED OTHERWISE.
2. BRANCHES FOR FASCINE CONSTRUCTION SHALL BE 15 MM TO 50 MM IN DIAMETER.
3. LIGHTLY TAMP MOIST SOIL INTO AND AROUND THE SIDES OF FASCINE. DO NOT COVER FASCINE ENTIRELY.

LIVE FASCINES

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LEVELS DISPLAYED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
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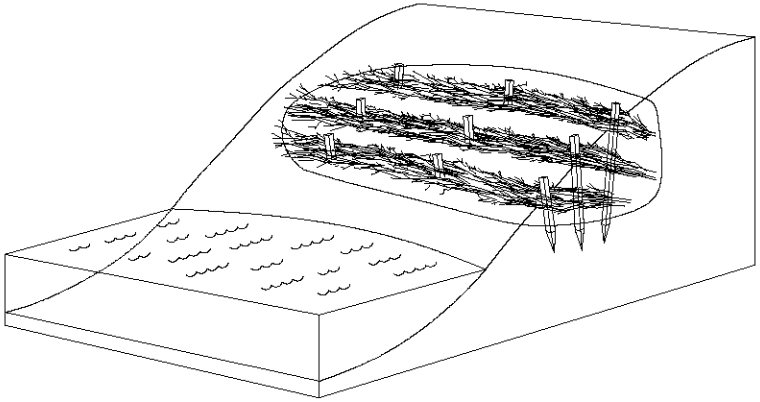
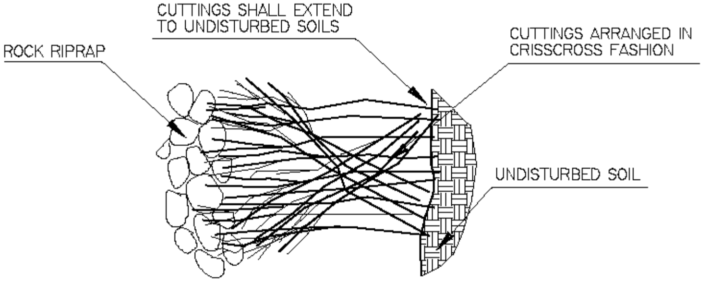
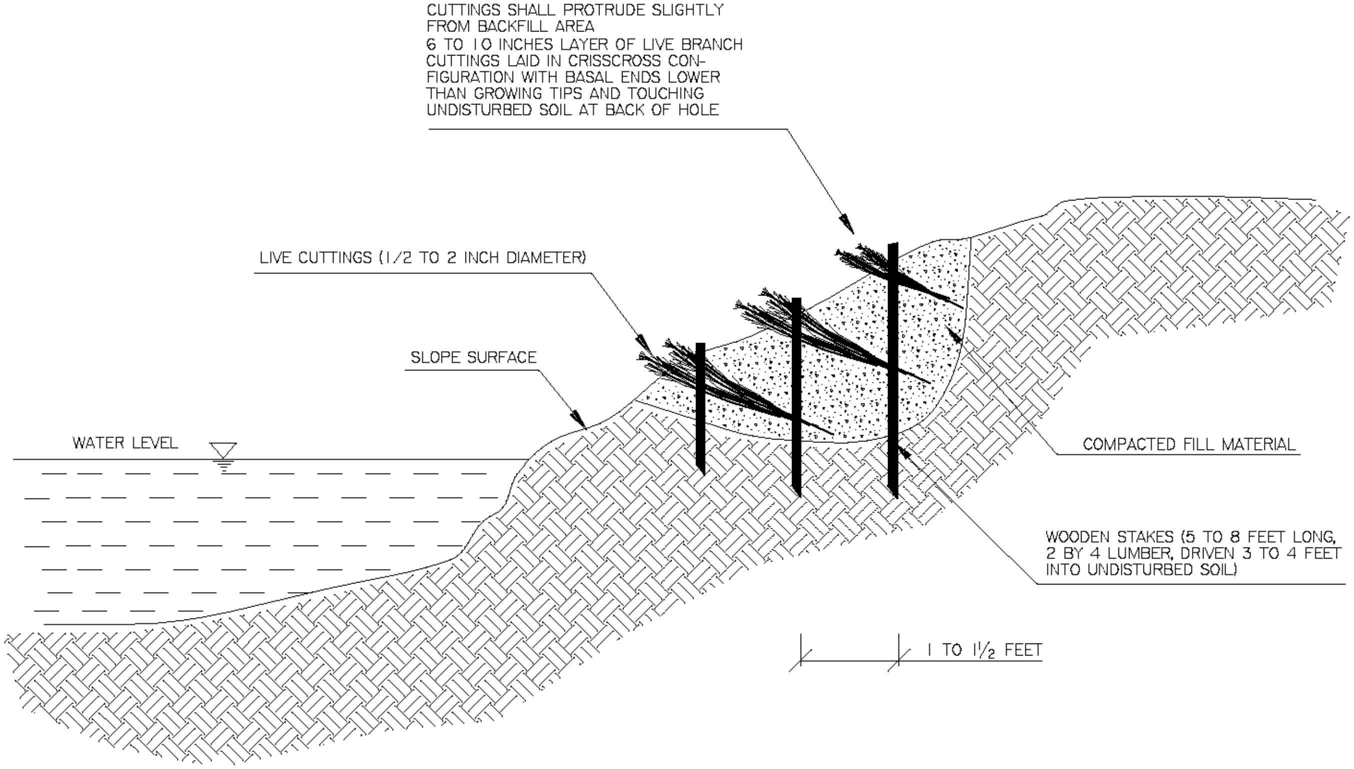




BRUSHLAYERING PLAN VIEW



BRANCHPACKING

DR-SL001.DWG

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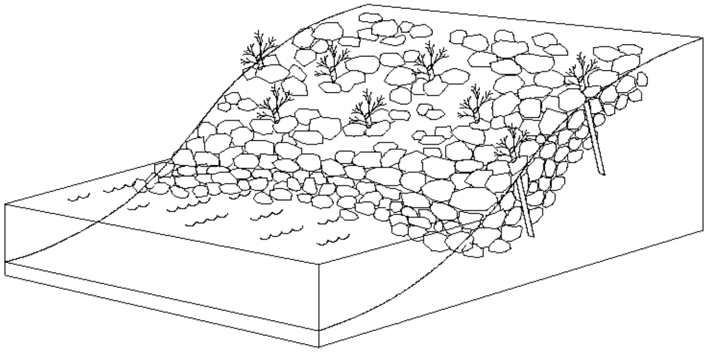
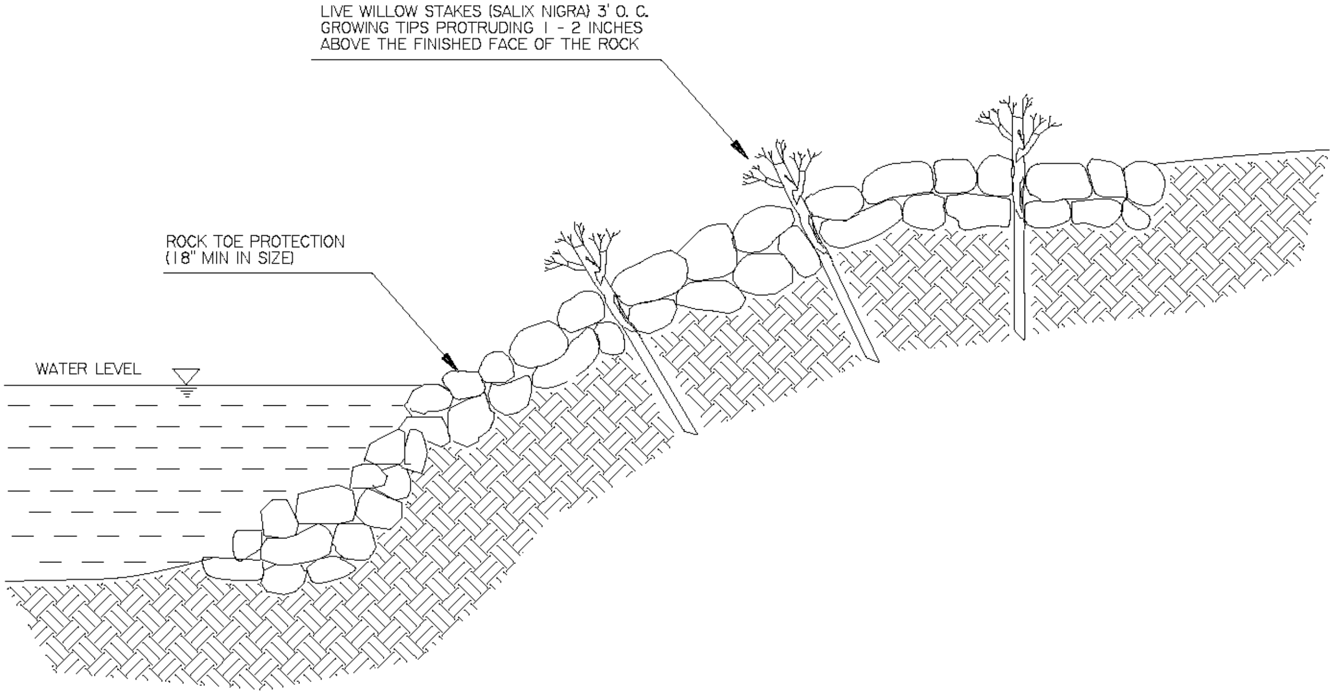
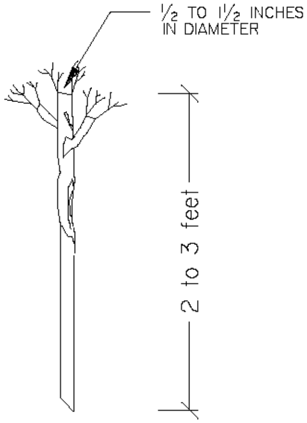




JOINT PLANTING



LIVE STAKE DETAIL

NOTES:

1. PROTECT LIVE STAKES FROM DAMAGE DURING INSTALLATION.
2. USE PRY BAR TO MAKE OPENING OR USE TUBING TO PROVIDE OPENING.
3. LIVE STAKES SHOULD HAVE GOOD CONTACTS WITH SOILS AFTER INSTALLATION.

STANDARD DETAIL SHEET

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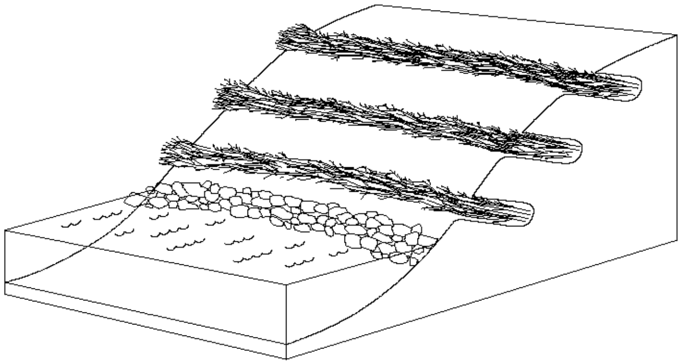
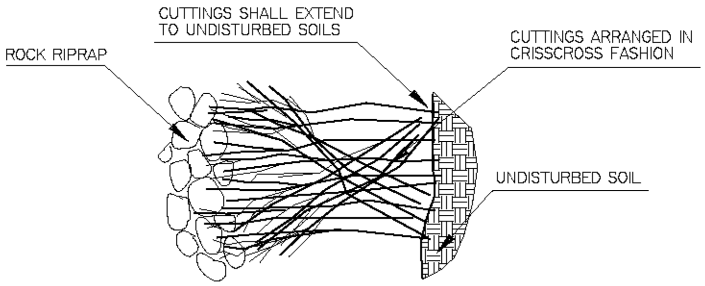
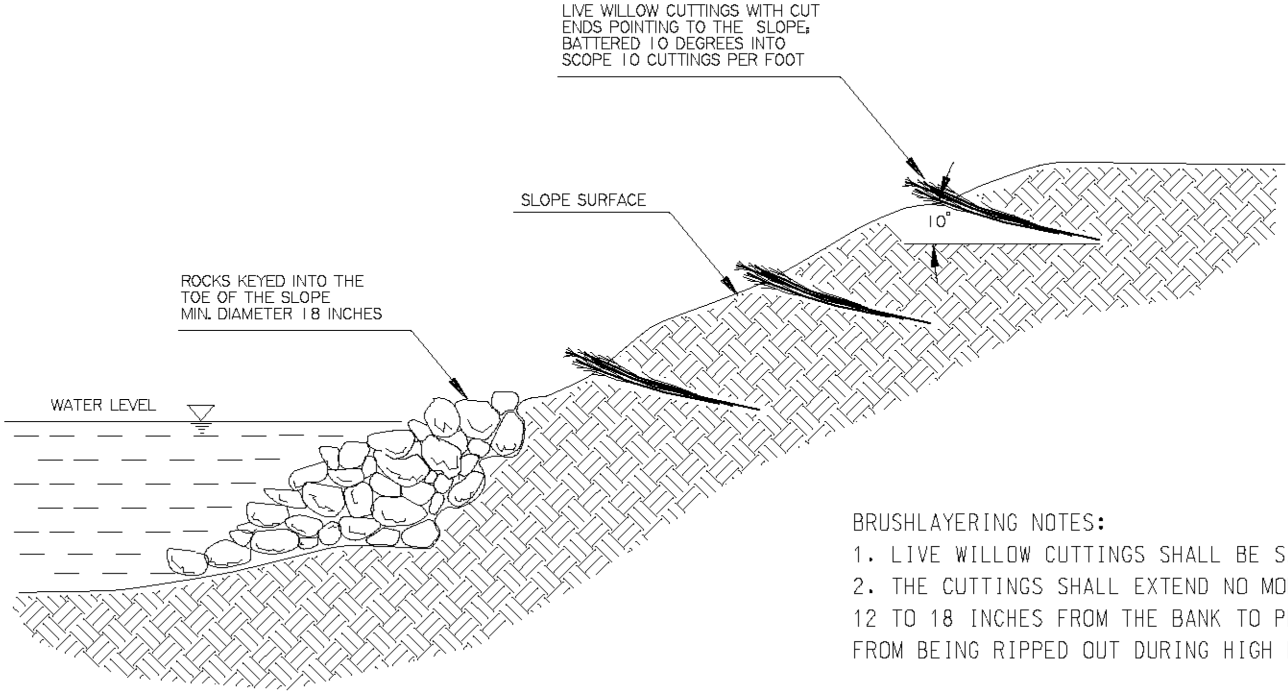




BRUSHLAYERING PLAN VIEW



BRUSHLAYERING NOTES:

1. LIVE WILLOW CUTTINGS SHALL BE SALIX NIGRA.
2. THE CUTTINGS SHALL EXTEND NO MORE THAN 12 TO 18 INCHES FROM THE BANK TO PREVENT FROM BEING RIPPED OUT DURING HIGH FLOW.

BRUSH LAYERING

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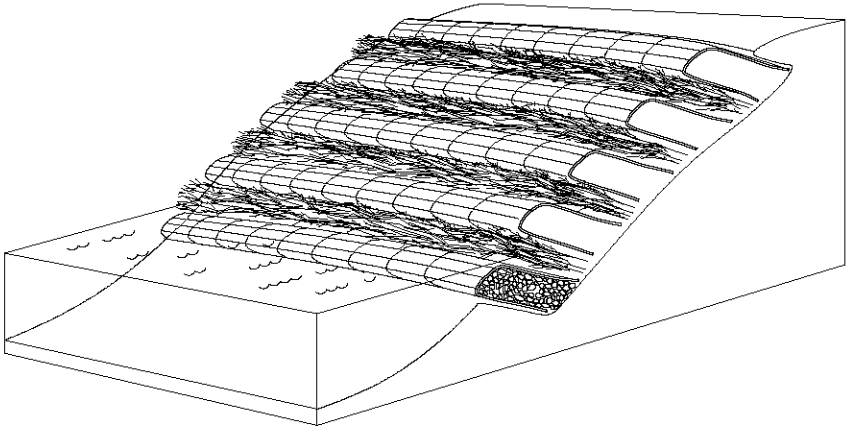

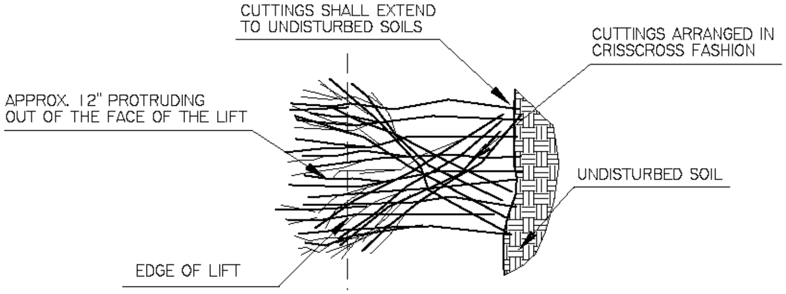

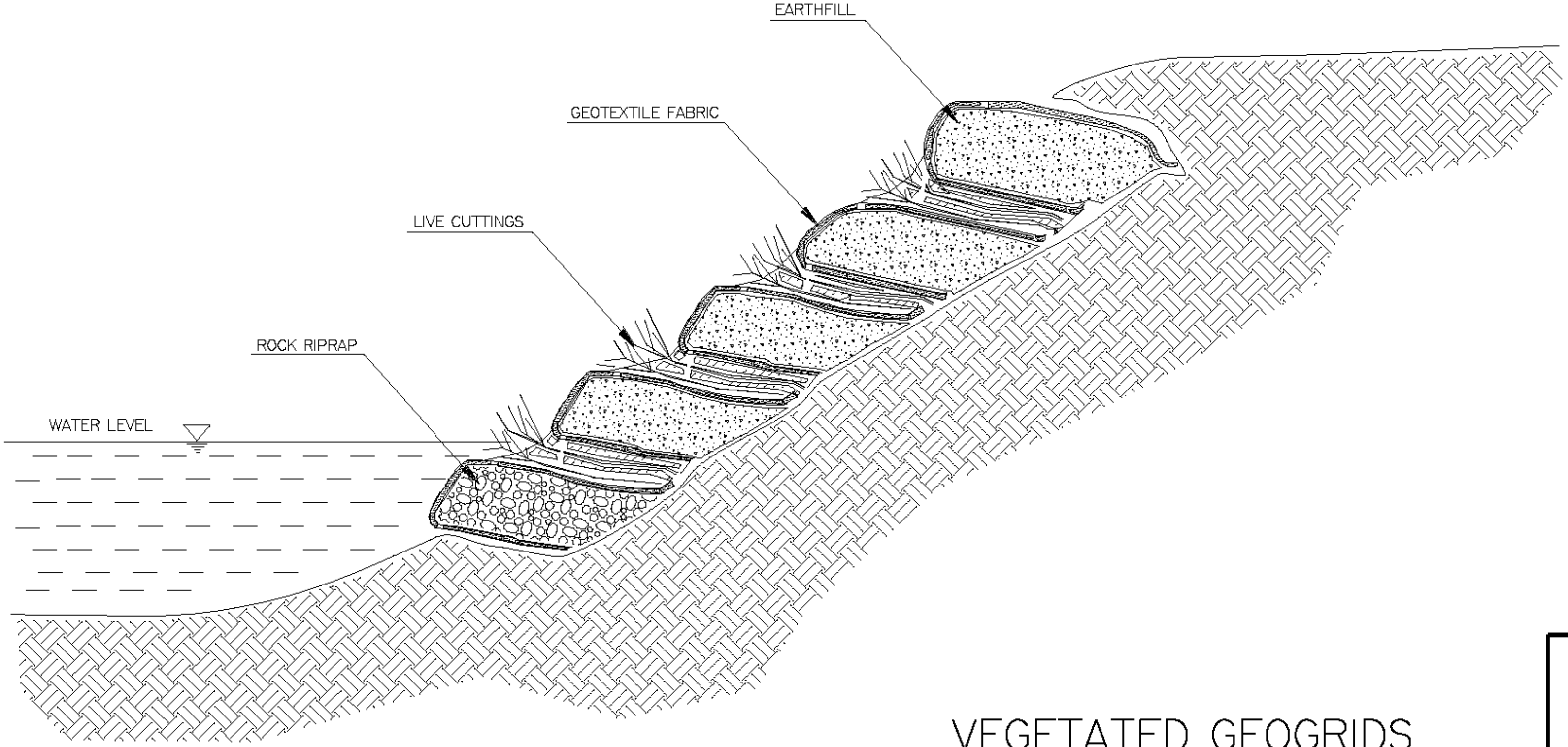

VEGETATED GEOGRIDS

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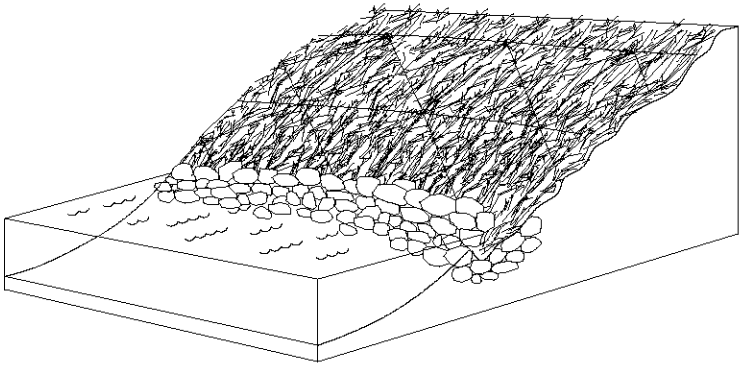
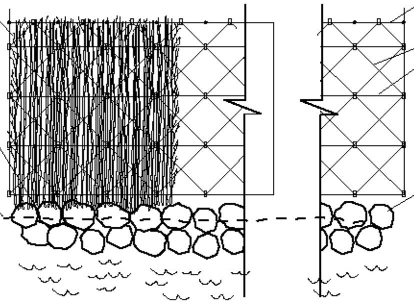
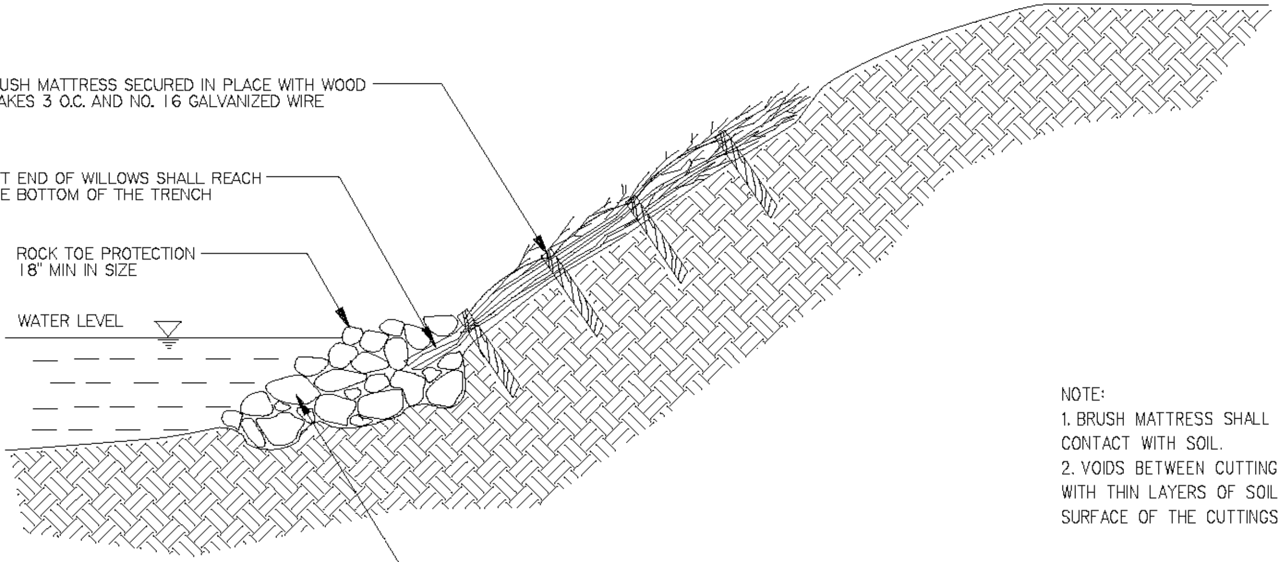
FIG. 4.2







NOTE:

1. BRUSH MATTRESS SHALL BE LAID IN GOOD CONTACT WITH SOIL.
2. VOIDS BETWEEN CUTTINGS SHALL BE FILLED WITH THIN LAYERS OF SOIL. LEAVE THE TOP SURFACE OF THE CUTTINGS SLIGHTLY EXPOSED.

BRUSHMATTRESS

STANDARD DETAIL SHEET

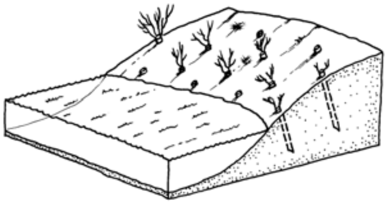
DRAWN BY:	DATE:		
DESIGN FILE	FEDERAL AID PROJECT NO.		SHEET NO.
STATE	DIST.	COUNTY	
TEXAS			
CONT.	SECT.	JOB	HIGHWAY NO.

APPENDIX C
BIOTECHNICAL TECHNOLOGIES

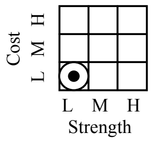
Table C-1. Biotechnical Technologies (Adapted from Li and Eddleman [2002]).

Live Stakes

Live, rootable woody cuttings inserted and tamped directly into soil. Root system binds soils together; foliages help reduce flow energy.



Cost/Strength Matrix:

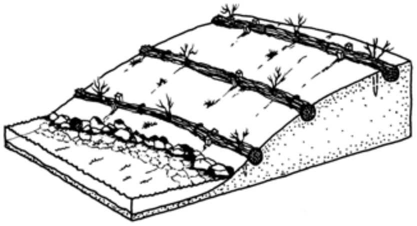


Application and Properties:

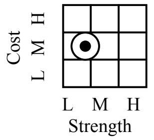
- Most effective when used on small, simple problem sites.
- Suitable for streambanks with gentle slopes.
- Enhances performance of surface erosion control materials, such as rolled erosion control products (RECPs).
- Stabilizes transitional areas between different biotechnical techniques.
- Inexpensive.

Live Fascines

Live cuttings tied together in linear cylindrical bundles. Installed in shallow trenches that normally match contours.



Cost/Strength Matrix:

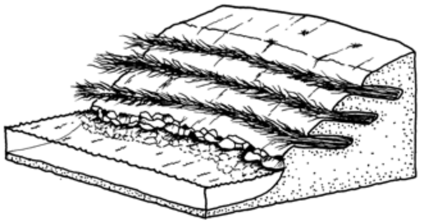


Application and Properties:

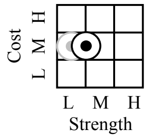
- Terrace and check dam-like structures break up slope length and reduce sheet flow velocity.
- Protects slopes from shallow slide failures (1 to 2 feet in depth).
- Effective on gentle slopes (less than 33 percent).
- Causes little site disturbance if installed properly.
- Other techniques such as live staking, post plants, and RECPs can be easily applied together.

Brushlayering

Live cuttings installed into streambanks between layers of soil in crisscross or overlapping pattern.



Cost/Strength Matrix:



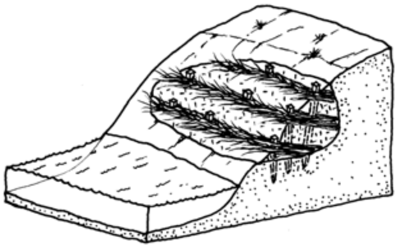
Application and Properties:

- Live cuttings protruding beyond the face of the streambank increase the hydraulic roughness, which reduces runoff velocity.
- Layers of live cuttings can filter sediment out of the slope runoff.
- Stabilizes slopes against shallow sliding.
- Cuttings installed inside the streambanks reinforce slopes by the root-stem-soil structure.
- Preferred on fill rather than cut slopes.

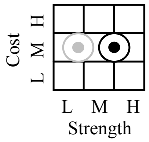
Table C-1. Biotechnical Technologies
(Adapted from Li and Eddleman [2002]) (continued).

Branchpacking

Brushlayering with wood staking and compacted backfill, used to repair small slumps and holes in streambanks.



Cost/Strength Matrix:

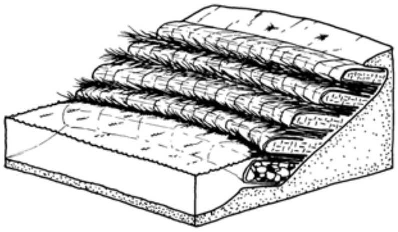


Application and Properties:

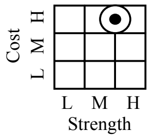
- Effective and inexpensive method to repair holes in streambanks that range from 0.75 to 1.5 meters in height and depth.
- Provides immediate soil reinforcement.
- Not effective in slump areas greater than 1.5 meters deep or 1.5 meters wide.

Vegetated Geogrids

Brushlayering incorporated with natural or synthetic geotextiles wrapped around each soil lift between the layers of live cuttings.



Cost/Strength Matrix:

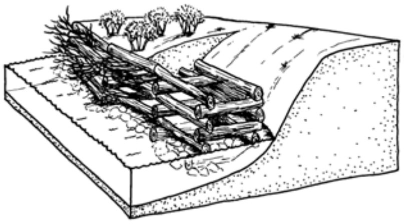


Application and Properties:

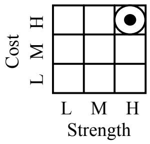
- High strength technique that stabilizes steep slopes up to 1:1.
- The system must be built during low flow conditions.
- Labor intensive; can be complex and expensive.
- Useful in restoring outside bends where erosion is a problem.
- Captures sediments, which rapidly rebuild to further stabilize the toe of the streambank.
- Provides immediate stabilization without vegetation growth.

Live Cribwall

Box-like interlocking arrangement of untreated log or timber members. Structure is filled with suitable backfill material and layers of live cuttings that root inside the crib structure and extend into the slope.



Cost/Strength Matrix:



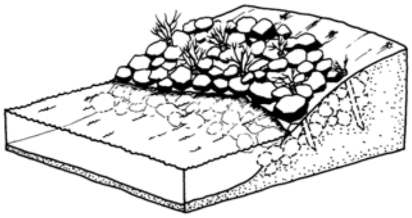
Application and Properties:

- Effective on outside bends of streams where high strength is needed.
- Appropriate at the base of a slope as a toe protection.
- Effective where a steep slope face is needed and a more vertical structure is required.
- Maintains a natural appearance and provides excellent habitats.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Has to be battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.

Table C-1. Biotechnical Technologies (Adapted from Li and Eddleman [2002]) (continued).

Joint Planting

Rock ripraps with live stakes tamped into joints or openings between rocks.



Cost/Strength Matrix:

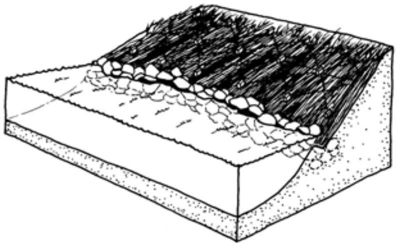
Cost			
H			
M			●
L			
	L	M	H
	Strength		

Application and Properties:

- Enhances aesthetics of existing rock ripraps.
- Provides better habitats than riprap alone.
- Improvse the strength of ripraps alone.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Many available design guidelines because the riprap is widely used.

Brushmattress

Live cuttings installed with branches parallel to the slope direction to form a mattress. Cut ends of live cuttings keyed into the toe protection at the slope bottom.



Cost/Strength Matrix:

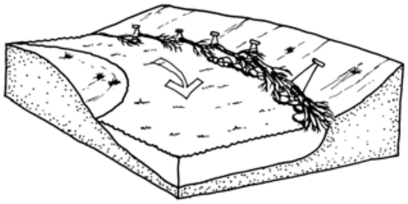
Cost			
H			
M	○		●
L			
	L	M	H
	Strength		

Application and Properties:

- Provides immediate but low-strength protection on streambanks.
- Effective on streambanks with steepness less than 50 percent.
- Captures sediment during floods.
- Rapidly restores riparian vegetation and streamside habitat.

Tree Revetment

A series of whole, dead trees cabled together and anchored by earth anchors in the streambank.



N/A

Application and Properties:

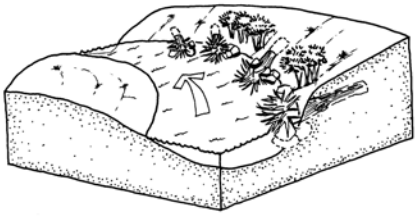
- Semi-permanent; has a limited life.
- Uses inexpensive, readily available materials.
- May require periodic maintenance to replace damaged or deteriorating trees.
- Has self-repairing abilities following damage after flood events if used in combination with biotechnical techniques.
- Should be used in combination with other biotechnical techniques.
- Not appropriate near bridges or other structures where downstream damage is possible if the revetment dislodges during flood events.

Table C-1. Biotechnical Technologies (Adapted from Li and Eddleman [2002]) (continued).

Log and Rootwad Revetment

Logs and rootwad systems anchored on streambanks that provide wildlife and fish habitats.

(Rootwad is shown below.)



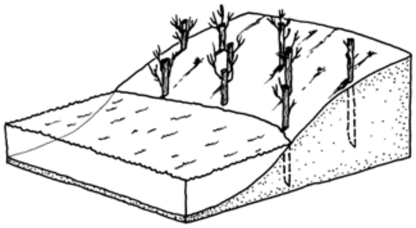
N/A

Application and Properties:

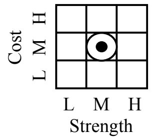
- Have limited life depending on climate and tree species used.
- Creates instream structures for improved fish habitat.
- Effective on meandering streams with out-of-bank flow conditions.
- Sustains high shear stress if logs and rootwads are well anchored.
- Should be used in combination with other biotechnical techniques.
- Enhances diversity of riparian corridor.

Dormant Post Plantings

Woody live posts planted along streambanks in a square or triangular pattern.



Cost/Strength Matrix:

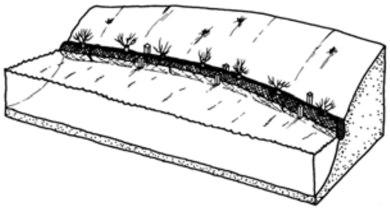


Application and Properties:

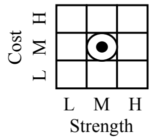
- Enhances conditions for colonization of native species.
- Self-repairing, damaged posts can develop multiple stems.
- Can be used in combination with other biotechnical techniques.
- Posts protruding out of streambanks can deflect higher streamflows and trapping sediment.
- Well suited to smaller, non-gravely streams where ice damage is not a problem.

Coconut Fiber Rolls

Coconut husk fibers bound together with twine woven from coconut to form a cylindrical structure. Installed at the toe of the slope, generally at the stream-forming flow stage.



Cost/Strength Matrix:



Application and Properties:

- Traps sediment that encourages plant growth within the fiber roll and provides toe protection.
- Flexible; can mold to existing curvature of streambank.
- Produces a well-reinforced streambank with little site disturbance.
- Prefabricated materials can be expensive.
- Should be used in combination with other biotechnical techniques.

APPENDIX D
SURVEYED CROSS-SECTIONS OF THE GOODE ROAD PROJECT

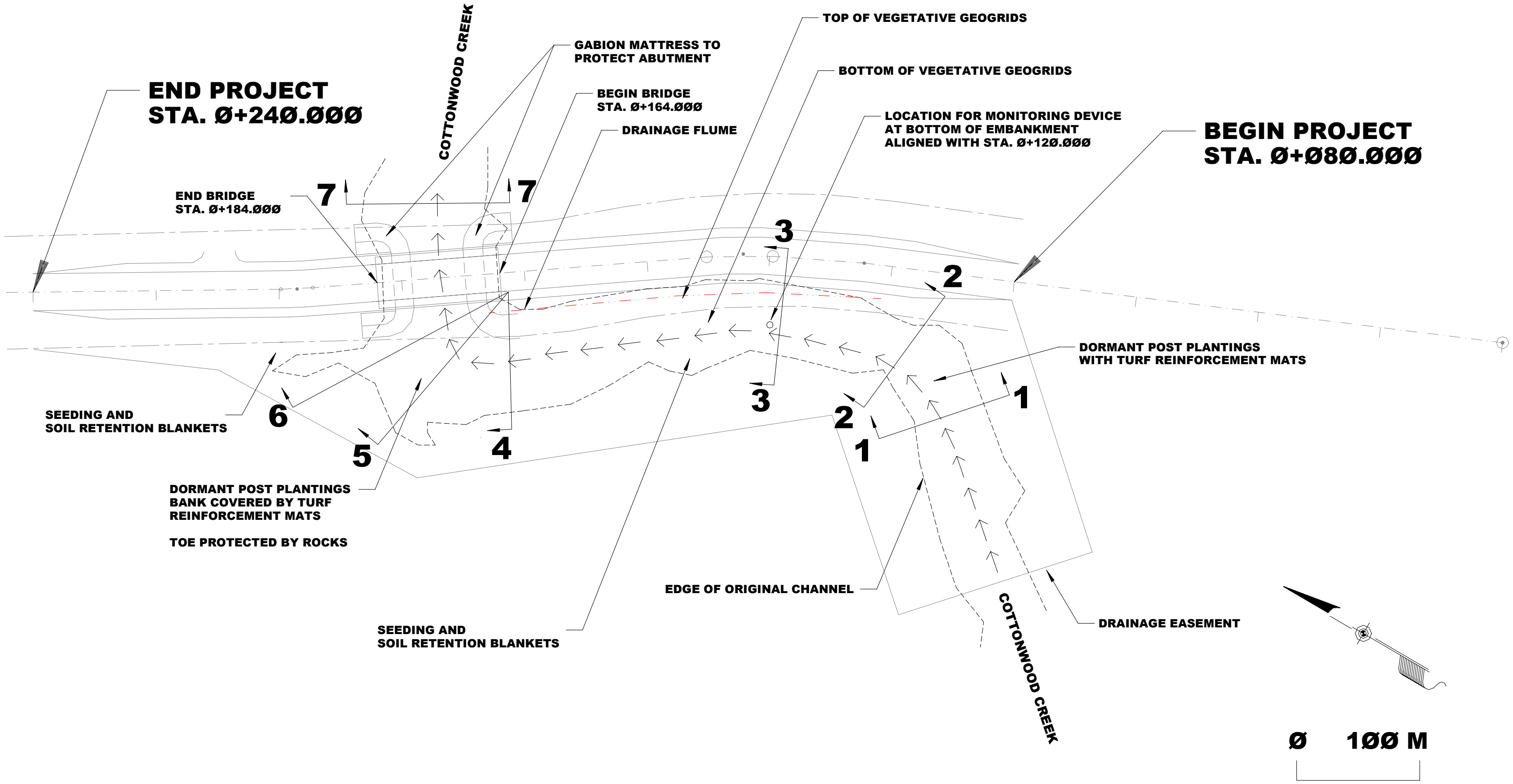


Figure D-1. Cut Lines of Surveyed Cross-sections.

Figure D-1. Cut Lines of Surveyed Cross-sections.

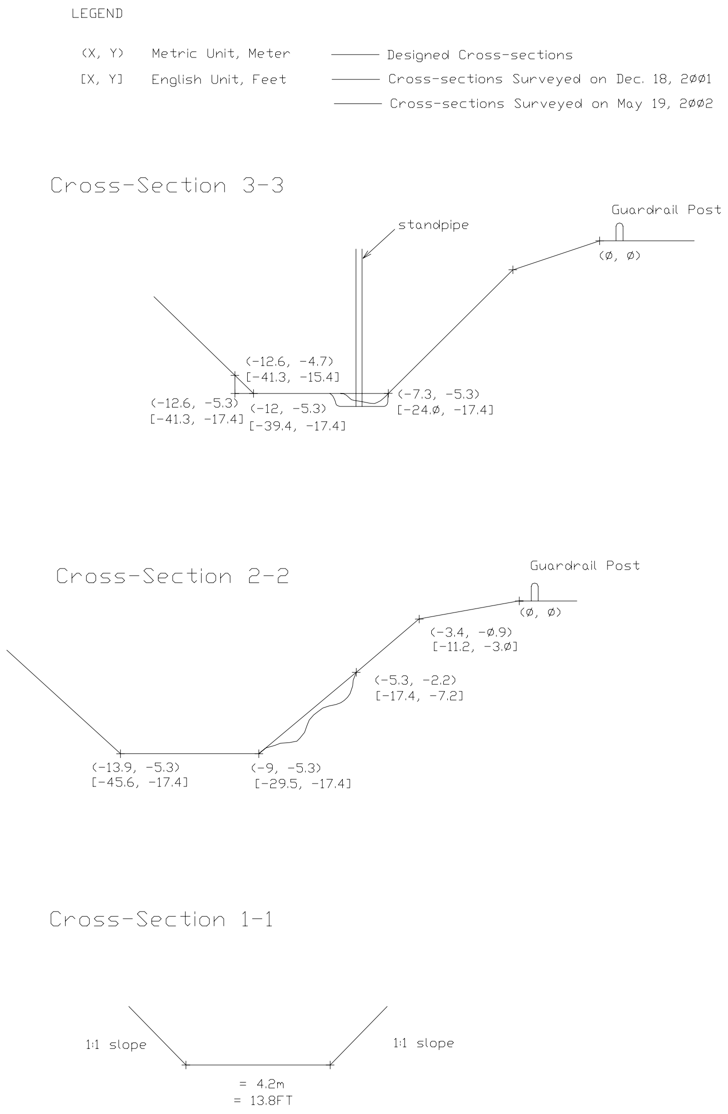
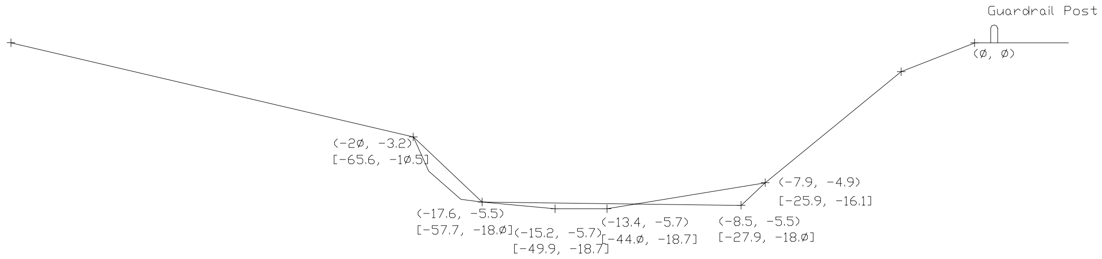
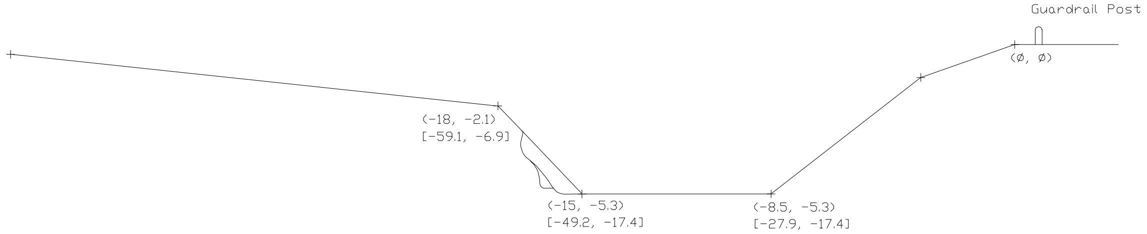


Figure D-1. Cut Lines of Surveyed Cross-sections (continued).

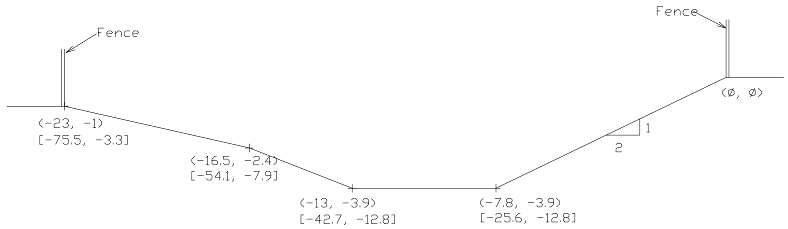
Cross-Section 5-5



Cross-Section 4-4



Cross-Section 7-7



APPENDIX E
SIZES OF SAMPLE CUTTINGS

Table E-1. Cutting Size in Cold Storage Treatment (March Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	18.01	0.709	1.37	4.5
2	13.74	0.541	1.52	5
3	17.40	0.685	1.83	6
4	17.81	0.701	1.83	6
5	16.51	0.65	1.83	6
6	15.57	0.613	1.68	5.5
7	16.87	0.664	1.68	5.5
8	15.95	0.628	2.13	7
9	13.06	0.514	2.13	7
10	16.23	0.639	1.83	6
11	14.22	0.56	1.37	4.5
12	13.08	0.515	1.52	5
13	16.33	0.643	1.22	4
14	15.95	0.628	1.52	5
15	17.91	0.705	2.13	7
16	16.10	0.634	1.37	4.5
17	15.49	0.61	1.07	3.5
18	17.42	0.686	1.07	3.5
19	17.40	0.685	1.68	5.5
20	18.29	0.72	1.52	5
21	13.18	0.519	1.22	4
22	13.23	0.521	1.22	4
23	14.05	0.553	1.37	4.5
24	15.04	0.592	1.83	6
25	13.79	0.543	1.37	4.5
26	14.20	0.559	1.52	5
27	14.38	0.566	1.68	5.5
28	14.33	0.564	1.68	5.5
29	16.71	0.658	1.68	5.5
30	12.98	0.511	1.52	5
31	12.57	0.495	1.52	5
32	12.83	0.505	1.37	4.5
33	16.05	0.632	2.13	7
34	14.00	0.551	2.13	7
35	11.94	0.47	1.52	5
36	14.96	0.589	1.52	5
37	15.37	0.605	1.52	5
38	13.28	0.523	1.37	4.5
39	15.80	0.622	1.52	5
40	15.37	0.605	1.37	4.5
43	12.27	0.483	0.91	3
44	13.84	0.545	1.22	4
45	14.71	0.579	1.22	4
46	19.71	0.776	1.83	6
47	25.63	1.009	1.83	6
48	22.58	0.889	1.83	6
49	21.62	0.851	1.68	5.5
50	19.69	0.775	1.83	6
51	21.01	0.827	2.13	7
52	22.17	0.873	1.68	5.5
53	24.51	0.965	1.52	5
54	19.96	0.786	2.13	7
55	21.26	0.837	1.68	5.5
56	24.00	0.945	1.52	5
57	21.41	0.843	1.37	4.5
58	21.29	0.838	1.68	5.5
59	19.63	0.773	1.52	5
60	19.99	0.787	1.83	6
61	19.84	0.781	2.13	7
62	19.74	0.777	1.83	6
63	20.22	0.796	1.98	6.5
64	21.08	0.83	1.83	6
65	18.75	0.738	1.52	5
66	17.70	0.697	1.52	5
67	19.96	0.786	1.52	5
68	16.71	0.658	1.83	6
69	22.02	0.867	1.68	5.5
70	21.69	0.854	1.98	6.5
71	21.34	0.84	1.98	6.5
72	16.15	0.636	1.68	5.5
73	20.17	0.794	1.68	5.5
74	15.49	0.61	1.83	6
75	18.36	0.723	1.83	6
76	16.99	0.669	1.83	6
77	17.60	0.693	1.68	5.5
78	17.58	0.692	1.83	6
79	18.19	0.716	1.68	5.5
80	21.89	0.862	1.22	4

Table E-2. Cutting Size in Cold Storage Treatment (April Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	15.77	0.621	1.37	4.5
2	17.93	0.706	1.37	4.5
3	15.04	0.592	1.37	4.5
4	14.99	0.59	1.37	4.5
5	13.74	0.541	1.07	3.5
6	15.54	0.612	1.07	3.5
7	13.56	0.534	1.83	6
8	14.17	0.558	1.37	4.5
9	13.16	0.518	1.22	4
10	13.79	0.543	1.22	4
11	14.94	0.588	1.22	4
12	16.69	0.657	1.83	6
13	15.72	0.619	1.37	4.5
14	17.09	0.673	1.22	4
15	16.66	0.656	1.37	4.5
16	18.34	0.722	1.68	5.5
17	17.60	0.693	1.68	5.5
18	11.13	0.438	1.07	3.5
19	13.64	0.537	1.52	5
20	15.62	0.615	1.37	4.5
21	14.33	0.564	1.68	5.5
22	14.83	0.584	1.52	5
23	17.45	0.687	1.52	5
24	18.34	0.722	1.37	4.5
25	17.20	0.677	1.98	6.5
26	12.90	0.508	1.22	4
27	14.38	0.566	1.52	5
28	16.61	0.654	1.68	5.5
29	15.85	0.624	1.68	5.5
30	18.52	0.729	1.98	6.5
31	15.88	0.625	2.13	7
32	14.55	0.573	1.52	5
33	14.12	0.556	1.68	5.5
34	18.11	0.713	1.68	5.5
35	15.09	0.594	1.37	4.5
36	11.58	0.456	1.52	5
37	15.82	0.623	1.52	5
38	16.61	0.654	1.37	4.5
39	27.38	1.078	2.13	7
40	27.56	1.085	2.13	7
41	21.01	0.827	1.98	6.5
42	24.43	0.962	1.98	6.5
43	23.67	0.932	1.83	6
44	22.33	0.879	2.13	7
45	21.08	0.83	1.68	5.5
46	24.59	0.968	1.52	5
47	21.49	0.846	1.83	6
48	21.49	0.846	1.52	5
49	26.54	1.045	1.83	6
50	21.44	0.844	1.83	6
51	28.19	1.11	2.13	7
52	19.79	0.779	1.98	6.5
53	25.02	0.985	1.68	5.5
54	23.80	0.937	2.13	7
55	22.78	0.897	1.83	6
56	21.26	0.837	1.83	6
57	24.66	0.971	2.13	7
58	24.41	0.961	1.68	5.5
59	20.24	0.797	2.13	7
60	19.43	0.765	1.98	6.5
61	18.08	0.712	2.13	7
62	22.12	0.871	1.98	6.5
63	20.37	0.802	1.83	6
64	21.08	0.83	1.98	6.5
65	24.99	0.984	2.13	7
66	20.88	0.822	1.83	6
67	22.28	0.877	1.98	6.5
68	20.02	0.788	1.98	6.5
69	21.11	0.831	1.83	6
70	22.96	0.904	1.83	6
71	21.11	0.831	1.98	6.5
72	21.36	0.841	1.52	5
73	22.00	0.866	1.52	5
74	18.72	0.737	1.52	5
75	20.73	0.816	1.68	5.5
76	22.58	0.889	1.83	6
77	26.34	1.037	1.68	5.5
78	20.19	0.795	1.83	6

Table E-3. Cutting Size in Cold Storage Treatment (May Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	13.39	0.527	1.98	6.5
2	11.63	0.458	1.83	6
3	12.88	0.507	1.37	4.5
4	12.19	0.48	1.22	4
5	13.94	0.549	1.22	4
6	13.18	0.519	1.37	4.5
7	13.46	0.53	1.22	4
8	14.63	0.576	1.22	4
9	13.08	0.515	1.22	4
10	13.34	0.525	1.37	4.5
11	12.95	0.51	1.37	4.5
12	13.08	0.515	1.37	4.5
13	15.88	0.625	1.37	4.5
14	15.06	0.593	1.37	4.5
15	15.90	0.626	1.52	5
16	15.24	0.6	1.68	5.5
17	13.77	0.542	1.52	5
18	17.65	0.695	1.68	5.5
19	13.77	0.542	1.22	4
20	13.13	0.517	1.83	6
21	15.24	0.6	1.98	6.5
22	14.88	0.586	1.68	5.5
23	13.72	0.54	1.52	5
24	14.27	0.562	1.52	5
25	13.67	0.538	1.07	3.5
26	16.84	0.663	1.83	6
27	16.43	0.647	1.83	6
28	14.88	0.586	1.68	5.5
29	15.19	0.598	1.98	6.5
30	14.91	0.587	1.37	4.5
31	16.87	0.664	1.37	4.5
32	15.57	0.613	1.37	4.5
33	16.76	0.66	1.98	6.5
34	17.12	0.674	1.22	4
35	15.09	0.594	1.68	5.5
36	16.71	0.658	1.52	5
37	13.28	0.523	1.98	6.5
38	16.05	0.632	1.68	5.5
39	14.20	0.559	1.37	4.5
40	13.61	0.536	1.37	4.5
41	23.06	0.908	1.68	5.5
42	21.51	0.847	1.52	5
43	20.52	0.808	1.83	6
44	19.46	0.766	1.83	6
45	18.24	0.718	2.13	7
46	20.88	0.822	2.44	8
47	20.45	0.805	1.68	5.5
48	20.12	0.792	1.68	5.5
49	19.89	0.783	1.83	6
50	22.86	0.9	1.98	6.5
51	21.23	0.836	1.68	5.5
52	21.56	0.849	1.98	6.5
53	19.84	0.781	1.83	6
54	20.65	0.813	1.68	5.5
55	24.69	0.972	1.98	6.5
56	20.93	0.824	1.68	5.5
57	19.81	0.78	1.68	5.5
58	19.79	0.779	1.83	6
59	21.08	0.83	2.29	7.5
60	18.90	0.744	1.83	6
61	19.58	0.771	2.13	7
62	22.71	0.894	1.98	6.5
63	20.75	0.817	1.98	6.5
64	20.47	0.806	1.68	5.5
65	19.43	0.765	1.83	6
66	20.73	0.816	1.52	5
67	19.74	0.777	1.52	5
68	19.69	0.775	1.52	5
69	18.80	0.74	1.68	5.5
70	21.11	0.831	2.13	7
71	19.38	0.763	1.68	5.5
72	19.23	0.757	1.83	6
73	18.59	0.732	1.68	5.5
74	20.40	0.803	1.83	6
75	20.37	0.802	1.98	6.5
76	19.46	0.766	1.68	5.5
77	21.29	0.838	1.68	5.5
78	21.41	0.843	2.29	7.5
79	17.68	0.696	1.68	5.5
80	20.55	0.809	1.52	5

Table E-4. Cutting Size in Onsite Storage in Water Treatment (April Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	13.44	0.529	1.98	6.5
2	17.25	0.679	2.13	7
3	16.23	0.639	2.13	7
4	17.37	0.684	2.13	7
5	12.55	0.494	1.98	6.5
6	18.19	0.716	2.13	7
7	17.70	0.697	1.68	5.5
8	17.88	0.704	1.98	6.5
9	14.73	0.58	2.13	7
10	14.48	0.57	1.83	6
11	16.64	0.655	1.83	6
12	14.00	0.551	1.83	6
13	16.61	0.654	1.52	5
14	12.83	0.505	2.13	7
15	15.93	0.627	2.13	7
16	15.19	0.598	2.13	7
17	12.85	0.506	2.13	7
18	13.54	0.533	1.68	5.5
19	16.08	0.633	1.83	6
20	18.67	0.735	2.13	7
21	16.76	0.66	1.98	6.5
22	14.45	0.569	1.83	6
23	15.77	0.621	1.83	6
24	17.65	0.695	1.83	6
25	14.27	0.562	1.98	6.5
26	11.94	0.47	1.68	5.5
27	15.39	0.606	2.13	7
28	12.90	0.508	1.98	6.5
29	15.90	0.626	1.98	6.5
30	13.54	0.533	1.83	6
31	12.40	0.488	1.98	6.5
32	12.37	0.487	1.68	5.5
33	13.77	0.542	1.68	5.5
34	15.42	0.607	1.83	6
35	13.89	0.547	1.52	5
36	13.41	0.528	1.83	6
37	13.69	0.539	1.98	6.5
38	15.82	0.623	1.98	6.5
39	16.97	0.668	1.83	6
40	14.27	0.562	1.83	6
41	17.20	0.677	2.13	7
42	16.81	0.662	1.98	6.5
43	16.99	0.669	1.98	6.5
44	17.15	0.675	1.83	6
45	16.71	0.658	1.83	6
46	17.86	0.703	2.13	7
47	19.25	0.758	2.13	7
48	20.02	0.788	2.13	7
49	22.23	0.875	2.13	7
50	16.84	0.663	2.13	7
51	19.56	0.77	1.98	6.5
52	18.08	0.712	2.13	7
53	19.25	0.758	1.37	4.5
54	17.40	0.685	1.83	6
55	17.02	0.67	1.83	6
56	18.85	0.742	2.13	7
57	19.76	0.778	1.52	5
58	16.99	0.669	2.13	7
59	18.44	0.726	1.83	6
60	20.37	0.802	1.83	6
61	17.65	0.695	2.13	7
62	21.13	0.832	1.83	6
63	18.82	0.741	1.83	6
64	17.12	0.674	1.68	5.5
65	17.42	0.686	1.98	6.5
66	21.89	0.862	1.98	6.5
67	24.05	0.947	2.13	7
68	22.99	0.905	1.83	6
69	17.75	0.699	1.83	6
70	19.53	0.769	1.83	6
71	18.42	0.725	1.68	5.5
72	17.30	0.681	1.98	6.5
73	20.62	0.812	2.13	7
74	16.26	0.64	1.98	6.5
75	18.95	0.746	1.98	6.5
76	14.91	0.587	2.13	7
77	17.50	0.689	2.13	7
78	16.21	0.638	2.13	7

Table E-5. Cutting Size in Onsite Storage in Water Treatment (May Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	13.06	0.514	1.52	5
2	13.79	0.543	1.52	5
3	12.19	0.48	1.68	5.5
4	11.89	0.468	1.22	4
5	14.78	0.582	1.68	5.5
6	13.06	0.514	1.68	5.5
7	14.00	0.551	1.68	5.5
8	14.05	0.553	1.37	4.5
9	13.67	0.538	1.52	5
10	12.24	0.482	1.68	5.5
11	13.21	0.52	1.52	5
12	12.93	0.509	2.13	7
13	13.94	0.549	1.68	5.5
14	14.35	0.565	1.52	5
15	12.78	0.503	1.37	4.5
16	13.79	0.543	1.52	5
17	13.26	0.522	1.68	5.5
18	12.67	0.499	1.83	6
19	14.38	0.566	1.37	4.5
20	16.00	0.63	1.83	6
21	12.88	0.507	1.98	6.5
22	15.77	0.621	1.68	5.5
23	18.49	0.728	1.98	6.5
24	15.67	0.617	1.83	6
25	16.26	0.64	2.29	7.5
26	15.70	0.618	1.98	6.5
27	15.65	0.616	1.37	4.5
28	17.98	0.708	1.83	6
29	14.81	0.583	2.29	7.5
30	16.36	0.644	1.98	6.5
31	15.19	0.598	2.13	7
32	14.27	0.562	2.13	7
33	15.85	0.624	1.83	6
34	12.04	0.474	1.52	5
35	13.97	0.55	1.52	5
36	19.89	0.783	2.29	7.5
37	17.42	0.686	1.83	6
39	15.67	0.617	1.68	5.5
40	17.20	0.677	1.98	6.5
41	21.36	0.841	2.13	7
42	20.17	0.794	2.13	7
43	20.80	0.819	1.98	6.5
44	19.69	0.775	2.29	7.5
45	21.11	0.831	2.29	7.5
46	18.82	0.741	2.29	7.5
47	19.79	0.779	1.83	6
48	19.56	0.77	1.68	5.5
49	18.52	0.729	2.44	8
50	18.03	0.71	2.29	7.5
51	23.47	0.924	1.83	6
52	20.78	0.818	2.13	7
53	22.48	0.885	1.98	6.5
54	22.15	0.872	2.59	8.5
55	21.31	0.839	1.83	6
56	20.73	0.816	1.52	5
57	21.64	0.852	1.98	6.5
58	20.78	0.818	1.68	5.5
59	23.39	0.921	1.98	6.5
60	20.70	0.815	1.83	6
61	20.17	0.794	1.83	6
62	19.69	0.775	2.13	7
63	19.56	0.77	2.44	8
64	19.02	0.749	2.29	7.5
65	19.18	0.755	1.83	6
66	19.25	0.758	1.52	5
67	22.35	0.88	2.44	8
68	19.41	0.764	2.44	8
69	19.58	0.771	2.44	8
70	16.84	0.663	1.68	5.5
71	16.84	0.663	1.98	6.5
72	18.44	0.726	1.52	5
73	18.52	0.729	1.68	5.5
74	18.16	0.715	1.68	5.5
75	16.69	0.657	1.52	5
76	16.36	0.644	1.52	5

Table E-6. Size of Cuttings with Leaves (April Installation).

Cutting No.	Diameter		Length	
	mm	in	m	ft
1	19.71	0.776	1.68	5.5
2	17.75	0.699	1.68	5.5
3	21.01	0.827	1.83	6
4	20.68	0.814	1.98	6.5
5	17.96	0.707	1.83	6
6	17.30	0.681	1.37	4.5
7	19.84	0.781	1.68	5.5
8	18.06	0.711	1.83	6
9	17.70	0.697	1.52	5
10	20.40	0.803	1.37	4.5
11	19.94	0.785	1.52	5
12	17.96	0.707	1.83	6
13	19.91	0.784	1.68	5.5
14	18.52	0.729	1.68	5.5
15	18.31	0.721	1.52	5
16	21.39	0.842	2.13	7
17	19.71	0.776	1.07	3.5
18	17.07	0.672	1.52	5
19	15.85	0.624	1.37	4.5
20	17.96	0.707	1.52	5
21	18.01	0.709	1.83	6
22	18.87	0.743	1.52	5
23	14.91	0.587	1.37	4.5
24	16.15	0.636	1.52	5
25	21.29	0.838	1.68	5.5
26	19.53	0.769	1.68	5.5
27	17.55	0.691	1.52	5
28	20.98	0.826	1.68	5.5
29	18.95	0.746	2.13	7
30	15.29	0.602	1.37	4.5
31	15.19	0.598	2.13	7
32	19.63	0.773	1.98	6.5
33	17.09	0.673	1.83	6
34	18.80	0.74	1.98	6.5
35	21.36	0.841	1.98	6.5
36	21.34	0.84	1.98	6.5
37	19.58	0.771	2.13	7
38	21.23	0.836	1.83	6
39	14.76	0.581	1.98	6.5

Onsite Storage in Compost

Due to the difficulty of separating compost and cuttings during installation, diameter and length measurements were not taken in order to minimize the damage to grown roots of cuttings.

APPENDIX F
LOGISTIC REGRESSION ANALYSIS
SAS® CODE, INPUT DATA, AND RESULT OUTPUT

```
*******************************************
*               SAS program               *
*******************************************
option ls=80 ps=55 nodate nonumber nocenter;
title 'Logistic Regression For Cold Storage Treatment';
data willow;
input survive month $ diam length @@;
datalines;
      1   3   18.0086   1.371533069                  0   3    19.685    1.828710759
      1   3   13.7414   1.523925632                  1   3    21.0058   2.133495885
      1   3   17.399    1.828710759                  1   3    22.1742   1.676318196
      1   3   17.8054   1.828710759                  0   3    24.511    1.523925632
      1   3   16.51     1.828710759                  1   3    19.9644   2.133495885
      1   3   15.5702   1.676318196                  0   3    21.2598   1.676318196
      1   3   16.8656   1.676318196                  0   3    24.003    1.523925632
      1   3   15.9512   2.133495885                  1   3    21.4122   1.371533069
      1   3   13.0556   2.133495885                  1   3    21.2852   1.676318196
      1   3   16.2306   1.828710759                  1   3    19.6342   1.523925632
      1   3   14.224    1.371533069                  1   3    19.9898   1.828710759
      1   3   13.081    1.523925632                  1   3    19.8374   2.133495885
      1   3   16.3322   1.219140506                  1   3    19.7358   1.828710759
      1   3   15.9512   1.523925632                  1   3    20.2184   1.981103322
      1   3   17.907    2.133495885                  0   3    21.082    1.828710759
      1   3   16.1036   1.371533069                  0   3    18.7452   1.523925632
      1   3   15.494    1.066747943                  1   3    17.7038   1.523925632
      1   3   17.4244   1.066747943                  1   3    19.9644   1.523925632
      1   3   17.399    1.676318196                  1   3    16.7132   1.828710759
      1   3   18.288    1.523925632                  1   3    22.0218   1.676318196
      1   3   13.1826   1.219140506                  1   3    21.6916   1.981103322
      0   3   13.2334   1.219140506                  1   3    21.336    1.981103322
      1   3   14.0462   1.371533069                  0   3    16.1544   1.676318196
      1   3   15.0368   1.828710759                  1   3    20.1676   1.676318196
      1   3   13.7922   1.371533069                  1   3    15.494    1.828710759
      1   3   14.1986   1.523925632                  1   3    18.3642   1.828710759
      1   3   14.3764   1.676318196                  1   3    16.9926   1.828710759
      1   3   14.3256   1.676318196                  1   3    17.6022   1.676318196
      1   3   16.7132   1.676318196                  0   3    17.5768   1.828710759
      1   3   12.9794   1.523925632                  0   3    18.1864   1.676318196
      1   3   12.573    1.523925632                  1   3    21.8948   1.219140506
      0   3   12.827    1.371533069                  1   4    15.7734   1.371533069
      1   3   16.0528   2.133495885                  1   4    17.9324   1.371533069
      1   3   13.9954   2.133495885                  1   4    15.0368   1.371533069
      1   3   11.938    1.523925632                  0   4    14.986    1.371533069
      1   3   14.9606   1.523925632                  1   4    13.7414   1.066747943
      0   3   15.367    1.523925632                  1   4    15.5448   1.066747943
      1   3   13.2842   1.371533069                  1   4    13.5636   1.828710759
      1   3   15.7988   1.523925632                  1   4    14.1732   1.371533069
      1   3   15.367    1.371533069                  1   4    13.1572   1.219140506
      1   3   12.7254   1.371533069                  1   4    13.7922   1.219140506
      1   3   13.6652   1.219140506                  1   4    14.9352   1.219140506
      1   3   12.2682   0.914355379                  1   4    16.6878   1.828710759
      0   3   13.843    1.219140506                  1   4    15.7226   1.371533069
      1   3   14.7066   1.219140506                  1   4    17.0942   1.219140506
      1   3   19.7104   1.828710759                  1   4    16.6624   1.371533069
      0   3   25.6286   1.828710759                  1   4    18.3388   1.676318196
      1   3   22.5806   1.828710759                  1   4    17.6022   1.676318196
      0   3   21.6154   1.676318196                  1   4    11.1252   1.066747943
      0   4   13.6398   1.523925632                  1   4    16.6116   1.371533069
      1   4   15.621    1.371533069                  0   4    27.3812   2.133495885
      1   4   14.3256   1.676318196                  0   4    27.559    2.133495885
      0   4   14.8336   1.523925632                  0   4    21.0058   1.981103322
      0   4   17.4498   1.523925632                  0   4    24.4348   1.981103322
      1   4   18.3388   1.371533069                  0   4    23.6728   1.828710759
      1   4   17.1958   1.981103322                  0   4    22.3266   2.133495885
      1   4   12.9032   1.219140506                  0   4    21.082    1.676318196
      0   4   14.3764   1.523925632                  0   4    24.5872   1.523925632
      0   4   16.6116   1.676318196                  0   4    21.4884   1.828710759
      0   4   15.8496   1.676318196                  0   4    21.4884   1.523925632
      0   4   18.5166   1.981103322                  0   4    26.543    1.828710759
      0   4   15.875    2.133495885                  0   4    21.4376   1.828710759
      0   4   14.5542   1.523925632                  1   4    28.194    2.133495885
      1   4   14.1224   1.676318196                  0   4    19.7866   1.981103322
      0   4   18.1102   1.676318196                  0   4    25.019    1.676318196
      1   4   15.0876   1.371533069                  0   4    23.7998   2.133495885
      1   4   11.5824   1.523925632                  0   4    22.7838   1.828710759
      0   4   15.8242   1.523925632                  0   4    21.2598   1.828710759
```

Figure F-1. SAS$^{®}$ Codes of Logistic Regression Analysis.

```
      0   4   24.6634   2.133495885                   0   5   14.9098   1.371533069
      0   4   24.4094   1.676318196                   0   5   16.8656   1.371533069
      0   4   20.2438   2.133495885                   0   5   15.5702   1.371533069
      0   4   19.431    1.981103322                   0   5   16.764    1.981103322
      0   4   18.0848   2.133495885                   1   5   17.1196   1.219140506
      0   4   22.1234   1.981103322                   0   5   15.0876   1.676318196
      0   4   20.3708   1.828710759                   1   5   16.7132   1.523925632
      1   4   21.082    1.981103322                   0   5   13.2842   1.981103322
      1   4   24.9936   2.133495885                   0   5   16.0528   1.676318196
      1   4   20.8788   1.828710759                   0   5   14.1986   1.371533069
      0   4   22.2758   1.981103322                   0   5   13.6144   1.371533069
      0   4   20.0152   1.981103322                   1   5   23.0632   1.676318196
      1   4   21.1074   1.828710759                   1   5   21.5138   1.523925632
      1   4   22.9616   1.828710759                   1   5   20.5232   1.828710759
      0   4   21.1074   1.981103322                   0   5   19.4564   1.828710759
      1   4   21.3614   1.523925632                   0   5   18.2372   2.133495885
      1   4   21.9964   1.523925632                   1   5   20.8788   2.438281012
      0   4   18.7198   1.523925632                   0   5   20.447    1.676318196
      0   4   20.7264   1.676318196                   0   5   20.1168   1.676318196
      0   4   22.5806   1.828710759                   1   5   19.8882   1.828710759
      0   4   26.3398   1.676318196                   0   5   22.86     1.981103322
      0   4   20.193    1.828710759                   0   5   21.2344   1.676318196
      1   5   13.3858   1.981103322                   1   5   21.5646   1.981103322
      1   5   11.6332   1.828710759                   1   5   19.8374   1.828710759
      0   5   12.8778   1.371533069                   0   5   20.6502   1.676318196
      1   5   12.192    1.219140506                   0   5   24.6888   1.981103322
      1   5   13.9446   1.219140506                   0   5   20.9296   1.676318196
      1   5   13.1826   1.371533069                   0   5   19.812    1.676318196
      1   5   13.462    1.219140506                   0   5   19.7866   1.828710759
      1   5   14.6304   1.219140506                   1   5   21.082    2.285888449
      1   5   13.081    1.219140506                   1   5   18.8976   1.828710759
      1   5   13.335    1.371533069                   1   5   19.5834   2.133495885
      0   5   12.954    1.371533069                   1   5   22.7076   1.981103322
      1   5   13.081    1.371533069                   0   5   20.7518   1.981103322
      0   5   15.875    1.371533069                   0   5   20.4724   1.676318196
      1   5   15.0622   1.371533069                   0   5   19.431    1.828710759
      1   5   15.9004   1.523925632                   1   5   20.7264   1.523925632
      1   5   15.24     1.676318196                   0   5   19.7358   1.523925632
      0   5   13.7668   1.523925632                   0   5   19.685    1.523925632
      0   5   17.653    1.676318196                   0   5   18.796    1.676318196
      1   5   13.7668   1.219140506                   0   5   21.1074   2.133495885
      0   5   13.1318   1.828710759                   1   5   19.3802   1.676318196
      1   5   15.24     1.981103322                   0   5   19.2278   1.828710759
      0   5   14.8844   1.676318196                   0   5   18.5928   1.676318196
      0   5   13.716    1.523925632                   0   5   20.3962   1.828710759
      1   5   14.2748   1.523925632                   0   5   20.3708   1.981103322
      1   5   13.6652   1.066747943                   0   5   19.4564   1.676318196
      0   5   16.8402   1.828710759                   1   5   21.2852   1.676318196
      0   5   16.4338   1.828710759                   0   5   21.4122   2.285888449
      1   5   14.8844   1.676318196                   0   5   17.6784   1.676318196
      1   5   15.1892   1.981103322                   0   5   20.5486   1.523925632
run;
****************************************************
*                 Test Logit Model                 *
*              Using Forward Selection             *
****************************************************
;
proc logistic data=willow descending;
class month;
model survive=diam | length | month | diam*diam | length*length /
               selection=f
               ctable pprob=(0 to 1 by .1)
               lackfit
               risklimits;
**************************************************************
*           The following contrasts were added               *
*           after the logit model was output as:             *
*           survive = b0 + b1(month) + b2(diam)              *
**************************************************************
;
contrast 'Month' month 1 -1 0, month 1 0 -1, month 0 1 -1;
contrast 'March vs April' month 1 -1 0;
contrast 'March vs May' month 1 0 -1;
contrast 'April vs May' month 0 1 -1;
run;
```

Figure F-1. SAS® Codes of Logistic Regression Analysis (continued).

```
                      Logistic Regression For Cold Storage Treatment

                                  The LOGISTIC Procedure



                                    Model Information
                         Data Set                      WORK.WILLOW
                         Response Variable             survive
                         Number of Response Levels     2
                         Number of Observations        238
                         Link Function                 Logit
                         Optimization Technique        Fisher's scoring

                                     Response Profile
                                Ordered                      Total
                                  Value      survive     Frequency
                                      1            1           134
                                      2            0           104

                                 Forward Selection Procedure


                                 Class Level Information
                                                    Design
                                                  Variables
                                  Class     Value      1      2
                                  month     3          1      0
                                            4          0      1
                                            5         -1     -1

Step  0. Intercept entered:

                                  Model Convergence Status
                         Convergence criterion (GCONV=1E-8) satisfied.

                                  Residual Chi-Square Test
                               Chi-Square       DF     Pr > ChiSq
                                  89.9440       47         0.0002

Step  1. Effect month entered:

                                  Model Convergence Status
                         Convergence criterion (GCONV=1E-8) satisfied.

                                    Model Fit Statistics
                                                         Intercept
                                            Intercept        and
                             Criterion        Only       Covariates
                             AIC             328.146        299.708
                             SC              331.619        310.125
                             -2 Log L        326.146        293.708

                             Testing Global Null Hypothesis: BETA=0
                     Test                 Chi-Square       DF     Pr > ChiSq
                     Likelihood Ratio        32.4384        2         <.0001
                     Score                   30.4849        2         <.0001
                     Wald                    27.4758        2         <.0001

                                  Residual Chi-Square Test
                               Chi-Square       DF     Pr > ChiSq
                                  67.5709       45         0.0163
```

Figure F-2. SAS® Outputs of Logistic Regression Analysis.

```
Step  2. Effect diam entered:

                                   Model Convergence Status
                        Convergence criterion (GCONV=1E-8) satisfied.

                                     Model Fit Statistics
                                                          Intercept
                                           Intercept         and
                            Criterion        Only       Covariates
                            AIC              328.146        280.580
                            SC               331.619        294.469
                            -2 Log L         326.146        272.580

                            Testing Global Null Hypothesis: BETA=0
                    Test                 Chi-Square       DF     Pr > ChiSq
                    Likelihood Ratio        53.5661        3         <.0001
                    Score                   48.7780        3         <.0001
                    Wald                    40.6848        3         <.0001

                                   Residual Chi-Square Test
                              Chi-Square       DF     Pr > ChiSq
                                 51.3300       44         0.2084

NOTE: No (additional) effects met the 0.05 significance level for entry into the model.

                                 Summary of Forward Selection
                   Effect                            Number         Score
           Step    Entered                   DF          In    Chi-Square    Pr > ChiSq
              1    month                      2           1       30.4849        <.0001
              2    diam                       1           2       20.4810        <.0001

                                 Type III Analysis of Effects
                                                         Wald
                   Effect                    DF    Chi-Square    Pr > ChiSq
                   diam                       1       19.0656        <.0001
                   month                      2       24.7337        <.0001

                           Analysis of Maximum Likelihood Estimates
                                                   Standard
       Parameter                 DF    Estimate       Error    Chi-Square    Pr > ChiSq
       Intercept                  1      3.7049      0.7928       21.8393        <.0001
       diam                       1     -0.1878      0.0430       19.0656        <.0001
       month                3     1      1.1159      0.2274       24.0857        <.0001
       month                4     1     -0.4252      0.2065        4.2389        0.0395

                                     Odds Ratio Estimates
                                           Point          95% Wald
                       Effect           Estimate      Confidence Limits
                       diam                0.829       0.762       0.902
                       month  3 vs 5       6.090       2.887      12.847
                       month  4 vs 5       1.304       0.665       2.556

                 Association of Predicted Probabilities and Observed Responses
                       Percent Concordant     76.5    Somers' D    0.531
                       Percent Discordant     23.3    Gamma        0.532
                       Percent Tied            0.2    Tau-a        0.262
                       Pairs                 13936    c            0.766
```

Figure F-2. SAS® Outputs of Logistic Regression Analysis (continued).

```
            Wald Confidence Interval for Adjusted Odds Ratios
    Effect                Unit     Estimate     95% Confidence Limits
    diam                1.0000        0.829        0.762        0.902
    month  3 vs 5       1.0000        6.090        2.887       12.847
    month  4 vs 5       1.0000        1.304        0.665        2.556

                         Contrast Test Results
                                           Wald
           Contrast            DF    Chi-Square    Pr > ChiSq
           Month                2       24.7337        <.0001
           March vs April       1       16.2052        <.0001
           March vs May         1       24.0857        <.0001
           April vs May         1        4.2389        0.0395

                          Partition for the Hosmer and Lemeshow Test
                               survive = 1             survive = 0
     Group       Total    Observed    Expected    Observed    Expected
         1          24           8        5.08          16       18.92
         2          24           7        7.21          17       16.79
         3          24           7        8.30          17       15.70
         4          24           6       10.83          18       13.17
         5          24          13       13.09          11       10.91
         6          25          16       15.30           9        9.70
         7          24          18       16.08           6        7.92
         8          24          19       18.47           5        5.53
         9          24          22       20.56           2        3.44
        10          21          18       19.08           3        1.92

                Hosmer and Lemeshow Goodness-of-Fit Test
                   Chi-Square       DF     Pr > ChiSq
                       8.5890        8         0.3781

                          Classification Table
          Correct      Incorrect                Percentages
 Prob          Non-          Non-           Sensi-  Speci-  False  False
Level  Event  Event  Event  Event  Correct  tivity  ficity    POS    NEG
0.000    134      0    104      0     56.3   100.0     0.0   43.7      .
0.100    133      0    104      1     55.9    99.3     0.0   43.9  100.0
0.200    131      6     98      3     57.6    97.8     5.8   42.8   33.3
0.300    121     23     81     13     60.5    90.3    22.1   40.1   36.1
0.400    112     53     51     22     69.3    83.6    51.0   31.3   29.3
0.500    105     65     39     29     71.4    78.4    62.5   27.1   30.9

                          Classification Table
          Correct      Incorrect                Percentages
 Prob          Non-          Non-           Sensi-  Speci-  False  False
Level  Event  Event  Event  Event  Correct  tivity  ficity    POS    NEG
0.600     87     80     24     47     70.2    64.9    76.9   21.6   37.0
0.700     58     93     11     76     63.4    43.3    89.4   15.9   45.0
0.800     45     97      7     89     59.7    33.6    93.3   13.5   47.8
0.900     12    101      3    122     47.5     9.0    97.1   20.0   54.7
1.000      0    104      0    134     43.7     0.0   100.0      .   56.3
```

Figure F-2. SAS® Outputs of Logistic Regression Analysis (continued).

APPENDIX G
DEVIANCE RESIDUALS FOR LOGISTIC REGRESSION

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data.

Cutting i	Survival Y_i	Month $X_{month\ i}$	Diam (mm) $X_{diam\ i}$	Fitted Value $\hat{\pi}_i$	Deviance Residuals dev_i
1	1	March	18.0086	0.7931	0.6809
2	1	March	13.7414	0.8783	0.5094
3	1	March	17.3990	0.8075	0.6539
4	1	March	17.8054	0.7980	0.6718
5	1	March	16.5100	0.8272	0.6160
6	1	March	15.5702	0.8462	0.5779
7	1	March	16.8656	0.8195	0.6309
8	1	March	15.9512	0.8387	0.5931
9	1	March	13.0556	0.8888	0.4856
10	1	March	16.2306	0.8330	0.6044
11	1	March	14.2240	0.8705	0.5267
12	1	March	13.0810	0.8884	0.4864
13	1	March	16.3322	0.8309	0.6086
14	1	March	15.9512	0.8387	0.5931
15	1	March	17.9070	0.7955	0.6764
16	1	March	16.1036	0.8357	0.5992
17	1	March	15.4940	0.8477	0.5748
18	1	March	17.4244	0.8069	0.6550
19	1	March	17.3990	0.8075	0.6539
20	1	March	18.2880	0.7862	0.6936
21	1	March	13.1826	0.8869	0.4899
22	0	March	13.2334	0.8862	-2.0847
23	1	March	14.0462	0.8734	0.5203
24	1	March	15.0368	0.8563	0.5571
25	1	March	13.7922	0.8775	0.5112
26	1	March	14.1986	0.8709	0.5258
27	1	March	14.3764	0.8679	0.5323
28	1	March	14.3256	0.8688	0.5304
29	1	March	16.7132	0.8228	0.6245
30	1	March	12.9794	0.8899	0.4830
31	1	March	12.5730	0.8957	0.4694
32	0	March	12.8270	0.8921	-2.1103
33	1	March	16.0528	0.8367	0.5972
34	1	March	13.9954	0.8743	0.5184
35	1	March	11.9380	0.9042	0.4489
36	1	March	14.9606	0.8576	0.5542
37	0	March	15.3670	0.8501	-1.9483
38	1	March	13.2842	0.8854	0.4934
39	1	March	15.7988	0.8418	0.5869
40	1	March	15.3670	0.8501	0.5699
41	1	March	12.7254	0.8936	0.4744
42	1	March	13.6652	0.8795	0.5067
43	1	March	12.2682	0.8998	0.4594

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data (continued).

44	0	March	13.8430	0.8767	-2.0461
45	1	March	14.7066	0.8622	0.5446
46	1	March	19.7104	0.7486	0.7610
47	0	March	25.6286	0.5530	-1.2690
48	1	March	22.5806	0.6604	0.9110
49	0	March	21.6154	0.6917	-1.5342
50	0	March	19.6850	0.7493	-1.6634
51	1	March	21.0058	0.7107	0.8265
52	1	March	22.1742	0.6738	0.8886
53	0	March	24.5110	0.5935	-1.3418
54	0	March	19.9644	0.7414	-1.6447
55	0	March	21.2598	0.7029	-1.5580
56	1	March	24.0030	0.6116	0.9917
57	1	March	21.4122	0.6981	0.8478
58	1	March	21.2852	0.7021	0.8411
59	1	March	19.6342	0.7507	0.7573
60	1	March	19.9898	0.7407	0.7748
61	1	March	19.8374	0.7450	0.7673
62	1	March	19.7358	0.7479	0.7623
63	0	March	20.2184	0.7341	-1.6277
64	0	March	21.0820	0.7084	-1.5699
65	0	March	18.7452	0.7746	-1.7261
66	1	March	17.7038	0.8004	0.6673
67	1	March	19.9644	0.7414	0.7736
68	0	March	16.7132	0.8228	-1.8605
69	1	March	22.0218	0.6787	0.8804
70	1	March	21.6916	0.6893	0.8626
71	1	March	21.3360	0.7005	0.8437
72	1	March	16.1544	0.8346	0.6013
73	1	March	20.1676	0.7356	0.7837
74	1	March	15.4940	0.8477	0.5748
75	1	March	18.3642	0.7843	0.6971
76	1	March	16.9926	0.8167	0.6363
77	1	March	17.6022	0.8028	0.6628
78	0	March	17.5768	0.8034	-1.8036
79	0	March	18.1864	0.7887	-1.7632
80	1	March	21.8948	0.6828	0.8735
81	1	April	15.7734	0.5922	1.0236
82	1	April	17.9324	0.5132	1.1551
83	1	April	15.0368	0.6183	0.9806
84	0	April	14.9860	0.6201	-1.3912
85	1	April	13.7414	0.6625	0.9074
86	1	April	15.5448	0.6004	1.0102
87	1	April	13.5636	0.6684	0.8976

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data (continued).

88	1	April	14.1732	0.6481	0.9314
89	1	April	13.1572	0.6816	0.8755
90	1	April	13.7922	0.6608	0.9102
91	1	April	14.9352	0.6219	0.9747
92	1	April	16.6878	0.5591	1.0784
93	1	April	15.7226	0.5940	1.0206
94	1	April	17.0942	0.5441	1.1032
95	1	April	16.6624	0.5600	1.0769
96	1	April	18.3388	0.4981	1.1807
97	1	April	17.6022	0.5254	1.1346
98	1	April	11.1252	0.7432	0.7704
99	0	April	13.6398	0.6659	-1.4807
100	1	April	15.6210	0.5976	1.0147
101	0	April	14.3256	0.6429	-1.4350
102	0	April	14.8336	0.6254	-1.4013
103	0	April	17.4498	0.5310	-1.2306
104	1	April	18.3388	0.4981	1.1807
105	1	April	17.1958	0.5404	1.1095
106	1	April	12.9032	0.6898	0.8619
107	0	April	14.3764	0.6411	-1.4317
108	0	April	16.6116	0.5618	-1.2847
109	1	April	15.8496	0.5895	1.0282
110	0	April	18.5166	0.4915	-1.1630
111	0	April	15.8750	0.5885	-1.3327
112	0	April	14.5542	0.6351	-1.4199
113	1	April	14.1224	0.6498	0.9286
114	0	April	18.1102	0.5066	-1.1886
115	0	April	15.0876	0.6165	-1.3845
116	1	April	11.5824	0.7301	0.7932
117	0	April	15.8242	0.5904	-1.3360
118	1	April	16.6116	0.5618	1.0738
119	0	April	27.3812	0.2059	-0.6791
120	0	April	27.5590	0.2017	-0.6711
121	0	April	21.0058	0.4005	-1.0116
122	0	April	24.4348	0.2865	-0.8217
123	0	April	23.6728	0.3102	-0.8618
124	0	April	22.3266	0.3545	-0.9356
125	0	April	21.0820	0.3978	-1.0071
126	0	April	24.5872	0.2819	-0.8139
127	0	April	21.4884	0.3834	-0.9834
128	0	April	21.4884	0.3834	-0.9834
129	0	April	26.5430	0.2270	-0.7176
130	0	April	21.4376	0.3852	-0.9864
131	1	April	28.1940	0.1869	1.8315

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data (continued).

132	0	April	19.7866	0.4446	-1.0845
133	0	April	25.0190	0.2691	-0.7919
134	0	April	23.7998	0.3062	-0.8550
135	0	April	22.7838	0.3391	-0.9101
136	0	April	21.2598	0.3915	-0.9967
137	0	April	24.6634	0.2796	-0.8099
138	0	April	24.4094	0.2873	-0.8230
139	0	April	20.2438	0.4279	-1.0568
140	0	April	19.4310	0.4577	-1.1062
141	0	April	18.0848	0.5075	-1.1902
142	0	April	22.1234	0.3614	-0.9471
143	0	April	20.3708	0.4233	-1.0492
144	1	April	21.0820	0.3978	1.3579
145	1	April	24.9936	0.2699	1.6185
146	1	April	20.8788	0.4050	1.3445
147	0	April	22.2758	0.3562	-0.9385
148	0	April	20.0152	0.4362	-1.0706
149	1	April	21.1074	0.3969	1.3595
150	1	April	22.9616	0.3332	1.4826
151	1	April	21.1074	0.3969	1.3595
152	1	April	21.3614	0.3879	1.3763
153	1	April	21.9964	0.3658	1.4183
154	1	April	18.7198	0.4840	1.2048
155	0	April	20.7264	0.4105	-1.0280
156	0	April	22.5806	0.3459	-0.9214
157	1	April	26.3398	0.2324	1.7085
158	1	April	20.1930	0.4298	1.2996
159	1	May	13.3858	0.6239	0.9714
160	1	May	11.6332	0.6827	0.8738
161	0	May	12.8778	0.6414	-1.4322
162	1	May	12.1920	0.6645	0.9042
163	1	May	13.9446	0.6042	1.0038
164	1	May	13.1826	0.6309	0.9598
165	1	May	13.4620	0.6212	0.9758
166	1	May	14.6304	0.5797	1.0443
167	1	May	13.0810	0.6344	0.9540
168	1	May	13.3350	0.6256	0.9685
169	0	May	12.9540	0.6388	-1.4271
170	1	May	13.0810	0.6344	0.9540
171	1	May	15.8750	0.5341	1.1200
172	1	May	15.0622	0.5640	1.0703
173	1	May	15.9004	0.5332	1.1215
174	1	May	15.2400	0.5575	1.0811
175	0	May	13.7668	0.6105	-1.3733

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data (continued).

176	0	May	17.6530	0.4682	-1.1239
177	1	May	13.7668	0.6105	0.9934
178	0	May	13.1318	0.6327	-1.4153
179	1	May	15.2400	0.5575	1.0811
180	0	May	14.8844	0.5704	-1.3000
181	0	May	13.7160	0.6123	-1.3766
182	1	May	14.2748	0.5925	1.0232
183	1	May	13.6652	0.6141	0.9875
184	0	May	16.8402	0.4984	-1.1746
185	0	May	16.4338	0.5134	-1.2003
186	1	May	14.8844	0.5704	1.0596
187	1	May	15.1892	0.5593	1.0780
188	0	May	14.9098	0.5695	-1.2983
189	0	May	16.8656	0.4974	-1.1730
190	0	May	15.5702	0.5453	-1.2556
191	0	May	16.7640	0.5012	-1.1794
192	1	May	17.1196	0.4880	1.1979
193	0	May	15.0876	0.5630	-1.2868
194	1	May	16.7132	0.5031	1.1722
195	0	May	13.2842	0.6274	-1.4052
196	0	May	16.0528	0.5275	-1.2246
197	0	May	14.1986	0.5952	-1.3449
198	0	May	13.6144	0.6159	-1.3833
199	1	May	23.0632	0.2829	1.5891
200	1	May	21.5138	0.3318	1.4855
201	1	May	20.5232	0.3651	1.4195
202	0	May	19.4564	0.4026	-1.0150
203	0	May	18.2372	0.4467	-1.0880
204	1	May	20.8788	0.3530	1.4431
205	0	May	20.4470	0.3678	-0.9576
206	0	May	20.1168	0.3792	-0.9765
207	1	May	19.8882	0.3872	1.3775
208	0	May	22.8600	0.2891	-0.8260
209	0	May	21.2344	0.3410	-0.9133
210	1	May	21.5646	0.3301	1.4888
211	1	May	19.8374	0.3890	1.3741
212	0	May	20.6502	0.3608	-0.9460
213	0	May	24.6888	0.2366	-0.7348
214	0	May	20.9296	0.3513	-0.9303
215	0	May	19.8120	0.3899	-0.9942
216	0	May	19.7866	0.3908	-0.9956
217	1	May	21.0820	0.3461	1.4567
218	1	May	18.8976	0.4227	1.3124
219	1	May	19.5834	0.3980	1.3574

Table G-1. Calculation of Deviance Residuals of Cold Storage Treatment Data (continued).

220	1	May	22.7076	0.2937	1.5653
221	1	May	20.7518	0.3573	1.4347
222	0	May	20.4724	0.3669	-0.9561
223	0	May	19.4310	0.4035	-1.0165
224	1	May	20.7264	0.3582	1.4330
225	1	May	19.7358	0.3926	1.3674
226	0	May	19.6850	0.3944	-1.0016
227	0	May	18.7960	0.4263	-1.0542
228	0	May	21.1074	0.3453	-0.9204
229	1	May	19.3802	0.4053	1.3440
230	0	May	19.2278	0.4107	-1.0285
231	0	May	18.5928	0.4337	-1.0665
232	0	May	20.3962	0.3695	-0.9605
233	0	May	20.3708	0.3704	-0.9619
234	0	May	19.4564	0.4026	-1.0150
235	1	May	21.2852	0.3393	1.4702
236	0	May	21.4122	0.3351	-0.9035
237	0	May	17.6784	0.4673	-1.1223
238	0	May	20.5486	0.3643	-0.9518

APPENDIX H
RECOMMENDED SPECIAL SPECIFICATION FOR COLD STORAGE

SPECIAL SPECIFICATION
ITEM XXXX
COLD STORAGE

1. Description. This Item shall govern for the harvesting and handling of all plant materials (black willow [*Salix nigra]* cuttings) to be stored using cold storage for dormancy extension.

2. Equipment. Either of the two types cooling equipment can be used: (1) self-powered, self-contained trailers with cooling units or (2) walk-in refrigerators. Either type should be able to maintain 40 ^{o}F constantly.

3. Harvesting, Handling, and Storing. The live plant materials supplied shall be black willow (*Salix nigra*) cuttings with the species indicated on the plan. Plant names indicated shall comply with “Hortus Third by Liberty Hyde Bailey Hortorium.” The Contractor shall provide stock true to the botanical name. Appropriate stands of indigenous plants shall be found along stream banks, riparian corridors, and wetland areas or in approved nurseries. Harvest shall occur during the dormant season, after the plant has dropped its leaves. The Contractor shall provide the Engineer with the harvest schedule and the location of the source prior to harvesting. Select branches with a diameter measured at the base of the cuttings, between 0.5 inch and 2 inches. The length of the branches will vary but must be long enough to touch the undisturbed soil of the bank of the treated area. Always leave at least 50 percent of the selected stand for future regeneration.

All cuttings shall be cleanly made at a blunt angle. Initiate the cut 3-4 inches from the tree trunk when cutting branches and 8-10 inches from the ground when cutting basal shoots second growth. Live branch cuttings should be bound together securely at the collection site, in bundles, for easy loading, handling, and for protection during transport. All cut ends should point to the same direction and line together. Side branches and brushy limbs must be kept intact.

During transportation, the live cut branch bundles should be placed on the transport vehicles in an orderly fashion to prevent damage. Dump trucks, covered vans, or closed trailer-type vehicles can be used for transportation. The live cut materials must be covered with a tarpaulin during transportation to prevent drying.

Prior to placing cutting bundles in cooling trailers or walk-in refrigerators, contractors should use black plastics to wrap the bundles with the cut ends exposed. Place bundles vertically in buckets filled with water. Line buckets in the cooling space, and leave reachable access to each bucket for filling with water when necessary. Contractors should maintain buckets filled with water constantly.

Cold storage should not be applied to cuttings for more than 90 days.

4. Measurement. This Item will be measured by the "Lump Sum" of all cold storage in this project.

5. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Cold Storage." This price shall be full compensation for transporting live cuttings, leasing cooling equipment, fuel or electricity for running the cooling equipment, furnishing and hauling buckets, black plastics, twines, and water and for all labor, tools, equipment, and incidentals necessary to complete the work.