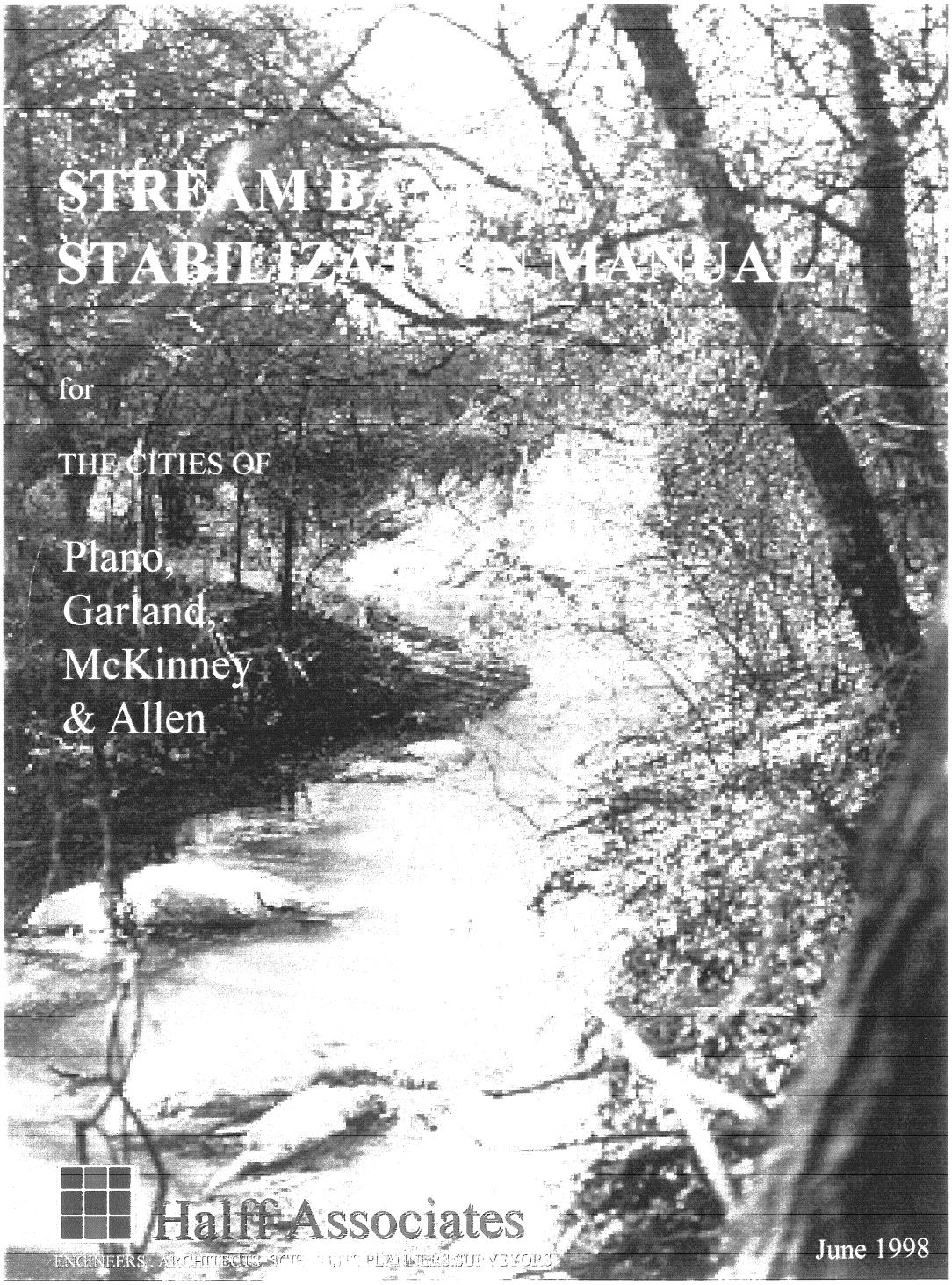


STREAM BA
STABILIZA MANUAL

for

THE CITIES OF

Plano,
Garland,
McKinney
& Allen

Halff Associates

ENGINEERS, ARCHITECTS, SCIE PLANNERS, SURVEYORS

June 1998

STREAM BANK STABILIZATION MANUAL

for

THE CITIES OF:

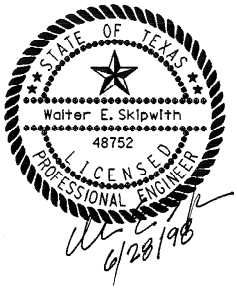
PLANO
GARLAND
McKINNEY
ALLEN

by

HALFF ASSOCIATES, INC.

in conjunction with

WEST Consultants, Inc.



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EXECUTIVE SUMMARY

Manual Purpose. This Stream Bank Stabilization Manual is intended to assist in the analysis, planning, design, and construction of stream bank erosion control measures. The goal of the manual is to provide procedures and design guidance for mitigation of severe erosion problems to reduce the potential for damage to public and private property and the environment. Generally speaking, the manual addresses streams in the White Rock Creek, Rowlett Creek, Wilson Creek or the East Fork of the Trinity River watersheds located in Plano, Allen, McKinney or Garland. The measures described in the manual are intended to be permanent. The procedures can be applied to problems related to existing development or incorporated into the planning process in developing watersheds. Ideally, the procedures presented here will be refined and applied city-wide in the form of watershed-based studies. This will enable a better understanding of bank stability and other stream features with the goal of developing permanent, economical solutions. This manual is not intended to provide, replace or supplement existing guidelines or regulations for construction site erosion control in any of the four communities.

Stream Bank Erosion And Failure. In **Chapter I**, the varied and complex causes of stream bank erosion are discussed. Bank failures can be massive and sudden or occur gradually over long periods of time. Of all the factors contributing to stream bank erosion in the project area, urbanization probably is the most important. Studies have shown that urbanization accelerates erosion and channels tend to roughly double their area over time as the stream attempts to reach a new state of relative stability. Therefore, it is important to establish some sort of stream bank stabilization program for newly developing areas so controls and/or mitigation of future problems can be achieved before homeowners or public facilities incur damage from stream bank failures due to erosion.

Stream Bank Protection and Erosion Damage Mitigation Measures. The manual presents structural and nonstructural methods of stream bank erosion mitigation for stream reaches in existing neighborhoods and for areas that are undergoing development pressures. **Chapter II** introduces the various methods and provides general guidance as to the applicability of each method. **Chapter IV** provides more specific design criteria and details. Of all the stream bank erosion mitigation methods examined in the manual, the establishment of an erosion hazard zone, or setback, offers the best solution for developing areas. A setback is a strip of land that separates one type of land use from another, usually for protection or aesthetic purposes. The resulting area, also referred to as a buffer, is established based on key physical or environmental features of streams and their adjoining flood plains. When used as an erosion control tool, setbacks protect adjoining developed land uses from damage due to stream bank slope failures, slides and settlement. Another effective flood plain management tool available to stream corridor planners today is the preservation of natural streams and flood plains. Preserving these areas as open space and greenbelt accomplishes the multiple goals of flood control, water quality enhancement, recreation and often economic development. Stream bank erosion can still be a problem particularly if the watershed is undergoing urbanizing influences. Therefore, erosion

hazard assessment and stabilization measures or tools such as setbacks will be needed, even along those streams whose channels remain undisturbed directly by development.

Selecting Protection For Stream Banks. The manual recommends a design frequency of the 2-year flood peak discharge for evaluation of typical erosion and stream bank stability problems. Design engineers should confirm this design criteria with the City Engineer of the community in which they are working.

Stream Evaluation. All streams should be physically inspected by a multidiscipline team of engineers and scientists in reaches affected by proposed development. Based on the field visit and best available maps, assessments can be made of such channel features as sinuosity, channel shape (depth, width, etc.) and vegetation. This assessment will assist the designer in the determination of the causes of stream erosion and the selection of appropriate stream bank stabilization method(s), if necessary.

Stream Hydraulic Analysis. Detailed stream hydraulic analysis is needed to provide an accurate portrayal of channel velocity and tractive force and to correctly assess stream bank erosion problems in the study reach. The hydrologic analysis should be based on discharges reflecting a fully urbanized watershed. Guidelines for hydrologic and hydraulic analysis are found in **Chapter III**.

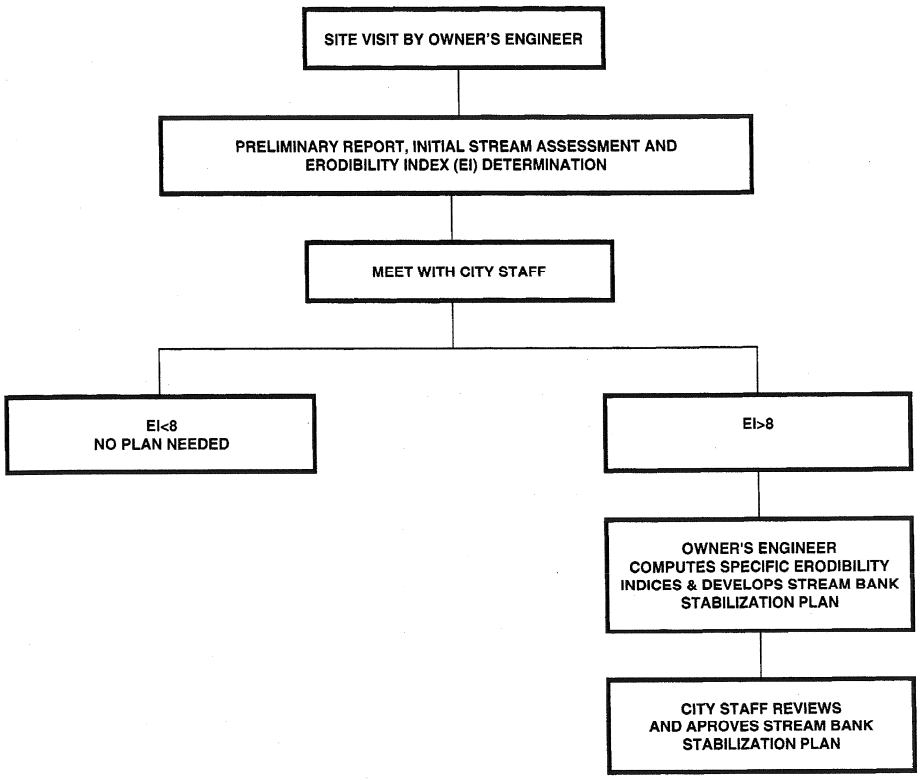
Setback Determination. Setbacks for the purpose of erosion damage mitigation shall also be established. This setback shall be permanently established by plat or recorded instrument. The erosion setback shall be required of all projects in which natural streams are to be preserved or where variations in the design recommendations of this manual are desired by the developer or land owner. The guidelines for establishing setback limits are found in **Chapter III**.

Erodibility Index. An erodibility index shall be computed as described in **Chapter III** for each potential erosion and stream bank stabilization problem area within the proposed project limits. Problem sites include areas of high velocity (greater than 5 feet per second), outside banks of meanders, steep banks (greater than 3:1) and areas designated by the city as erosion-prone. The erodibility index shall be a function of urbanization, stream velocities, sinuosity, and channel bank material. The procedure is as follows:

- Watersheds that have been or have the potential to be impacted by urbanization shall be weighted by a factor of 2.
- The degree of sinuosity or meandering of the subject stream shall be assessed and assigned a factor ranging from 1 for relatively straight streams to 3 for streams with pronounced meanders.
- The effect of channel bank soils on erosion potential is quantified based on a rating ranging from 1 for rock to 4 for sands and silts.
- Channel velocity, and indirectly, tractive force is included in the erodibility index as a range from one (velocity less than 5 ft/sec) to three(more than 8 ft/sec).
- To compute the Erodibility Index, sum the individual indices for channel velocity, sinuosity and bank materials.
- Multiply this total by the urbanization factor.

The resulting erodibility index will range from 3 to 20. Areas with stream bank erodibilty indices of 3 to 8 should exhibit mild erosion, 8-12 moderate erosion and 12-20 would indicate severe erosion potential. If the project contains any sites with an erodibilty index of 8 or greater, the applicant should develop a stream bank stability plan for submittal to and approval by the city engineering staff prior to platting as a part of the project design.

Summary of Procedures for Stream Bank Stabilization. All projects that involve streams to remain all or in part in their natural state or that have drainage basins larger than 130 acres shall be evaluated for stream bank stability problems according to the procedures outlined in this manual. A summary of those procedures is shown below. An important part of the initial stream assessment is a determination of the causes of the stream bank stability problems.

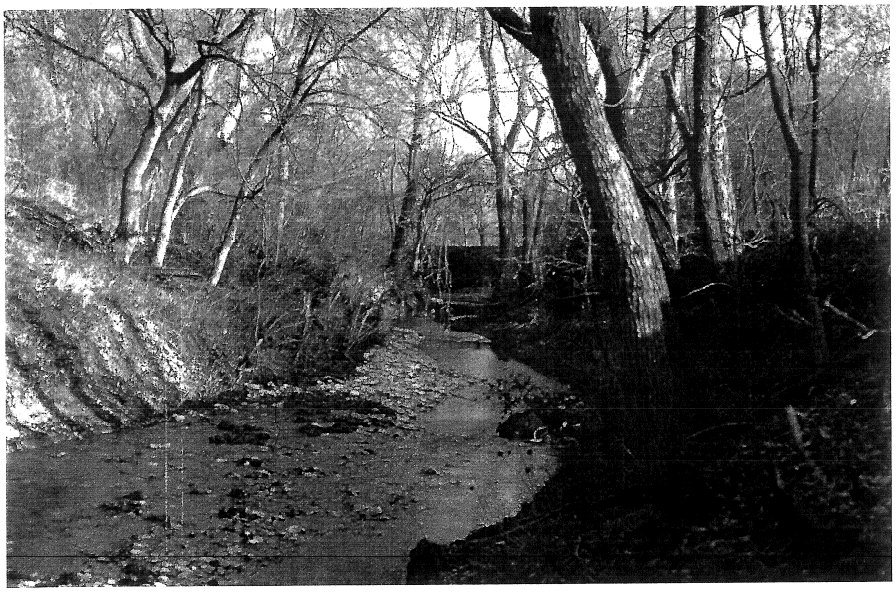


CHAPTER I

INTRODUCTION

A. Purpose of the Manual

This Stream Bank Stabilization Manual has been prepared to assist those involved in analyzing, planning, designing, and constructing bank stabilization measures or related activities in erosion hazard zones. The manual focuses on the North Central Texas area, specifically the communities of Plano, Garland, Allen and McKinney. It reviews available literature on bank erosion, describes existing bank erosion control programs and projects, defines the mechanics of the bank erosion process, presents methods to quantify bank erosion potential, and identifies design guidelines and typical construction details for bank stabilization. The manual is intended to define a systematic approach to understand and effectively address stream bank erosion problems with the goal of preventing or avoiding severe problems and their potential for damage to public improvements, private property and the environment.



WEST FORK- ROWLETT CREEK UPSTREAM OF ALMA ROAD IN ALLEN, TEXAS

DEVELOPMENT ADJACENT TO SMALL TRIBUTARY OF ROWLETT CREEK IN ALLEN, TEXAS

The measures described in the manual are intended to be permanent. The procedures can be applied to problems related to existing development or incorporated into the planning process in developing watersheds. Ideally, the procedures presented here will be refined and applied city-wide in the form of watershed-based studies. This will enable a better understanding of bank stability and other stream features with the goal of developing permanent, economical solutions. This manual is not intended to replace or supplement existing guidelines or regulations for construction site erosion control in any of the four communities.

B. Features of North Central Texas Affecting Streams

Natural channels are formed by the concentration of storm water runoff. The flowing water has the energy to scour the earth, which continues throughout the life of the stream. Sediment is deposited in the channel bottom at the same time that the channel is eroding. The channel bottoms and banks will gradually erode, naturally forming a larger channel. Initially the volume of erosion from a particular reach will be far greater than the volume of deposition. As the stream matures, the rate of deposition approaches the rate of erosion. When the stream becomes stable, the rate of disposition equals the rate of erosion. This stable condition continues as long as there is not an alteration of the flow pattern. If the activities of man or nature alter the watershed or channel, the balance is broken and a period of restabilization follows. Urbanization of a watershed is a common activity which disturbs this balance. Developing watersheds with expanding impervious areas, reduced infiltration rates, increased runoff, increased flood peaks and increased flood frequencies often suffer severe erosion problems. The higher discharges and velocities increase channel erosion, thus creating a larger channel. Structures near the channel are often imperiled and, in some cases, damaged by the eroding banks. The stream environment itself is

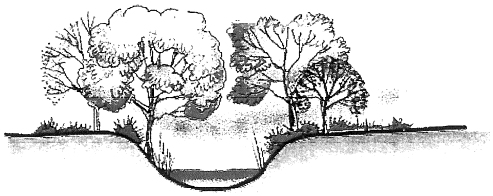
often degraded by the excessive deposition of the sediment laden runoff. The ultimate consequence of this process is shown graphically in Figure I-1.

1. Climate

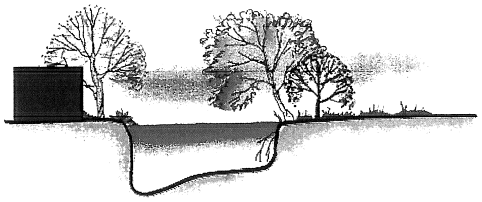
A region's climate can influence the need for stream bank stabilization and dictate which methods might be most successful in mitigating erosion damage. The study area for this Stream Bank Stabilization Manual lies in a region of temperate mean climatological conditions and experiences occasional, short duration extremes of temperature and rainfall. The climate is generally mild, with moderate winters and hot summers. The area has an average of 94 days with temperatures above 90°F and 37 days with temperatures below 32°F. The record temperature extremes range from a maximum of 113 degrees Fahrenheit in June, 1980 to a minimum of -8 degrees Fahrenheit in February, 1899. The maximum monthly and 24 hour rainfalls are 17.64 inches in April, 1922 and 9.57 inches in September, 1932, respectively. Mean annual rainfall is 33.3 inches with the heaviest precipitation usually occurring in April, May, and June. The study area lies approximately 250 miles inland from the Gulf of Mexico. Remnants of tropical storms generally occurring from August to October sometimes reach the study area and cause significant flooding. Intense thunderstorms usually occur in the spring and summer and are the most common cause of flooding on the small streams in the study area. Prevailing surface winds are southerly. Average wind velocity is 10.9 miles per hour (NWS, 1997).

Natural variations in landform and topography alter the climatic environment characteristics of localized areas, often dampening the effects of regional climatic extremes. When areas in close proximity to each other experience measurable climatic differences, the localized conditions constitute microclimates. North Central Texas creeks and their major tributaries create natural microclimates that differ somewhat from the region's overall climate. These areas typically experience lower temperatures, wind speeds, and solar-radiation intensities, and a higher relative humidity.

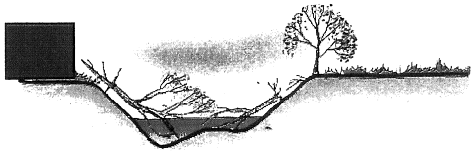
The primary factors that affect creek microclimates are trees, stream side slopes, and water. The orientation of a channel side slope, that is, the direction in which the slope faces has a significant effect on the microclimate. South facing slopes which receive more sunlight experience faster evaporation rates. This results in a noticeably hotter and drier microclimate than a north facing slope which is cooler and maintains a higher relative humidity. These distinct microclimates on the north and south channel slopes may support different types of vegetation, which may, in return, influence stream bank stability (Halff, 1989).



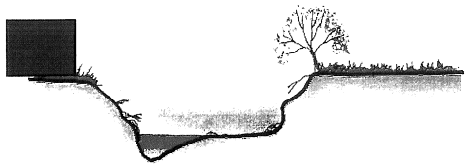
Pre-urbanization Condition



Bankful discharges increased by urbanization accelerate bank erosion



Channel banks fail



Bank erosion threatens structures and degrades stream environment

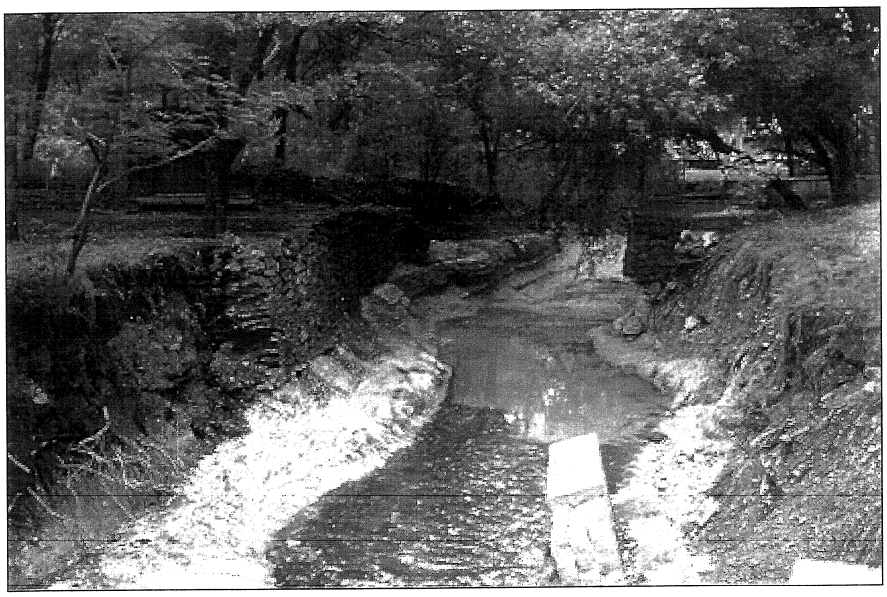
Figure I-1

The Channel Erosion Cycle in Urban Streams

2. Geology

River forms are a function of stream hydrology and geology. The geology of an area determines stream bed and bank materials and influences basin and valley relief. These hydrologic and geologic processes cause a stream to evolve to a natural state of stability as regards it's ability to convey flood waters and sediments from the watershed. Activities such as urban development and deforestation often upset this equilibrium and cause the stream to seek a new equilibrium, often at the expense of manmade features. Therefore, it is important to understand a stream's geology as a part of developing ways to correct or avoid damage due to stream bank erosion (Rosgen, 1996).

Dallas and Collin Counties are situated in the western part of the Gulf Coastal Plain in the Blackland Prairie Physiographic Province, a province characterized by little relief and dark, thick plastic clay soils. Three outcropping units are present through the area; the Eagle Ford Shale, the Austin Chalk and Ozan (lower Taylor Marl) formations. The Austin Chalk Formation is the surface bedrock of the White Rock Creek basin. This resistant formation provides much of the topographic relief throughout the area. The Eagle Ford Shale Formation surfaces to the west and the Ozan (Taylor Marl) Formation surfaces to the east of the watershed. The general limits of the outcrop of these formations in the study area is shown on Figure I-2 (Nordstrom, 1982).



SMALL, URBAN TRIBUTARY OF ROWLETT CREEK IN GARLAND, TEXAS

MAP SYMBOL	SOIL ASSOCIATION	FLOOD PLAIN SOIL TYPES
①	HOUSTON BLACK- HEIDEN: Deep, nearly level to strongly sloping, clayey soils;on uplands.	FRIO, SILTY CLAY TRINITY CLAY
②	EDDY-STEPHEN-AUSTIN:Very shallow, shallow, and moderately deep, gently sloping to moderately steep, loamy and clayey soils; on flood plains.	FRIO, SILTY CLAY, AUSTIN S CLAY DALCO CLAY, LEWISVI SILTY CLAY
③	TRINITY - FRIO: Deep, nearly level, clayey soils; on flood plains.	TRINITY CLAY, FRIO SILTY C GOWEN LOAM, OVAN CLAY, SEAGOVILLE CLAY
④	AUSTIN - HOUSTON BLACK: Moderately deep and deep, nearly level to sloping, clayey soils; on uplands.	HOUSTON BLACK CLAY, DALCO CLAY, GOWEN LOAM FRIO SILTY CLAY, TRINITY C
⑥	FERRRIS - HEIDEN: Deep, gently sloping to strongly sloping, clayey soils; on uplands.	HOUSTON BLACK CLAY, OVA CLAY, TRINITY CLAY, FERRIS CLAY
⑧	HOUSTON BLACK - AUSTIN ASSOCIATION: Gently sloping to sloping, clayey soils that are deep over marl and chalk; on uplands.	SEE 4
⑨	HOUSTON BLACK - HOUSTON ASSOCIATION: Gently sloping to sloping, clayey soils that are deep over compact clays; on uplands.	HOUSTON CLAY, LEWISVILLE CLAY, TRINITY CLAY, FERRIS HOUSTON CLAY
⑩	HOUSTON BLACK - BURLESON ASSOCIATION: Nearly level to gently sloping, deep, clayey soils on stream terraces.	TRINITY CLAY, ALTOGA SILT CLAY, LEWISVILLE SILTY CL

Geology

A Taylor Group

B Austin Group

C Eagle Ford Group

SOURCE

Soil Survey of Dallas County, USDA, 1980
Soil Survey of Collin County, USDA, 1969
Report 269 Cretaceous Aquifers of Nor

3. Soils

Residual soils weathered from the underlying formations produce the clay soils that are characteristic of the project area, as well as the Blackland Prairie Physiographic province. These soils have been classified and mapped in detailed soil surveys for Dallas and Collin Counties prepared by the U.S. Department of Agriculture Soil Conservation Service in cooperation with the Texas Agriculture Experiment Station.

The Natural Resource Conservation Service classifies soils by their profile or sequence of natural layers. Soils that have profiles which are almost identical make up a soil series. The soil series are then further classified into phases on the basis of differences in slope, stoniness, salinity, wetness, degree of erosion, and other characteristics that affect their use. Areas of two or more soil series which cannot be shown separately on the soil map are classified into phases called soil complexes.

Soils within a watershed are often grouped into three broad locational categories of bottomland, transitional and upland soils. Bottomland soils are found within "the normal flood plain of a stream, subject to flooding." Bottomland soils in the study area are comprised mainly of the Frio, Houston Black, and Trinity soil series. These are relatively deep sedimentary soils, laid down by repeated flood events over long periods. The Frio soil series is made up of friable, loamy soils with slopes of less than one percent. The Houston Black and Trinity soil series are comprised of deep, calcareous, clayey soils, with slopes that are nearly level to moderate. The Houston Black soil series also occurs on uplands and on old alluvial terraces along major streams. The Trinity soils are found mainly in the bottomland areas and are formed in recent alluvium on flood plains.

Upland is defined as "land at a higher elevation, in general, than the alluvial plain or stream terrace; land above the lowlands along streams." The transitional soils can be found between the bottomland and the upland soils on stream terraces. These soils often have greater inclines than the upland soils and tend to be eroded and gullied. The transitional and upland regions found within these communities are comprised of nine soil series, common to both areas. These are the Austin, Dalco, Eddy, Ferris, Heiden, Houston, Houston Black, Lewisville, Stephen and Trinity soils (Halff, 1989). Figure I-2 is a general soil map for the area showing the location of major soil associations and a list of the soils found within the project limits with a brief description of flood plain soil types and general erosion potential.

4. Vegetation

The project area lies in the Blackland Prairie vegetative zone of the Texas biotic province. A biotic province is defined as a continuous regional geographic area characterized by the occurrence of one or more ecological associations that differ significantly from the ecological associations of adjacent provinces. In general, the Texas biotic province is characterized by peculiarities of vegetation type, ecological

climax, climate, geology and soils, which distinguish it from the moist forest of East Texas and the dry grasslands of West Texas.

The Blackland Prairie vegetative zone within this province is characterized by gently rolling to nearly level topography, with dark-colored calcareous clay soils that support prairie grass-forb vegetation. The vegetative zone is further divided into three community classes distinguished by physiographic features: 1) the deep soil prairie, 2) the thin soil prairie, and 3) the limestone ravine. Within these categories, a complex combination of habitats exist: the upland and transitional region grasslands, the mature forest lands, the flood plain wetlands, and the water bodies. The deep soil prairie is composed of heavy calcerous clay, which originally supported tall and mid-height grasses. This area comprises the majority of the upland soil grasslands, which historically was prime farm land and has largely been developed. The thin soil prairie is underlain by Austin chalk or the Taylor Marl. The dominant vegetation of the thin soil prairie includes the mid-height and short grasses and a variety of dry site herbs. This category comprises the transitional soil grasslands. The limestone ravine category provides the best environment for trees in the Blackland Prairie zone. The shade, the concentration of runoff water, and a proximity to ground water are the major factors contributing to the growth of small hardwood forests in the limestone ravines (Halff, 1989).Vegetation is important to the bank stability of a stream because of the root systems which help to bind and protect the soil surface from the erosive forces of flowing water. This reinforces the need for involving a qualified landscape architect, environmental scientist and/or biologist as a part of the team analyzing stream bank stability problems.

5. Population Growth

A strong economy in North Central Texas has been responsible for sustained population growth throughout the region. New housing starts are at a ten year high. This growth is very evident in the four communities sponsoring the Stream Bank Stabilization Manual. These cities represent four of the eleven cities responsible for 50% of the area's growth in 1996, with Plano leading all North Central communities. Growth rates in Allen, McKinney, Plano and Garland were 8.3, 7.2, 6.2 and 1.4 percent, respectively. These cities have a combined estimated 1997 population of over 450,000. This growth translates to intense urbanization pressures on streams within the four cities.

C. The Nature Of Streams

Streamflow and channel variables interact over long periods of time to form the morphology of river systems. Induced changes in any of the physical processes create rapid and significant changes to the system. Often, channel morphology is influenced by streamflow and sediment regime, valley morphology, basin relief and the nature of stream bed and bank material (Rosgen, 1996).

1. General Stream Classifications

Streams have been classified many different ways. A simple system might define streams as either youthful, mature or old, depending on its stage of adjustment. Reasons why a stream classification system is important include:

- the ability to predict behavior from appearance
- the ability to relate specific hydraulic and sediment transport characteristics to a stream type
- provides a means of transferring site specific information to stream reaches of similar characteristics
- provides a consistent frame of reference(Rosgen, 1996)

Rosgen has developed a comprehensive stream classification that begins with very general geomorphic characteristics and progresses to very specific assessments and descriptions. Level I describes the geomorphic characteristics resulting from basin relief, land form and valley morphology. This includes such features as channel slope, channel shape and channel patterns. Level II assessments involve more specific descriptions of morphological features such as width/depth ratios, sinuosity and channel materials. Level III describes the stream condition in terms of vegetation, sediment transport, debris, bank erosion potential and alterations. A fourth level would consist of field measurements of sediment, streamflow, erosion and hydraulic characteristics. The descriptions of the many components of the classification system are complex and beyond the scope of this manual. The interested user is referred to *Applied River Morphology* (Rosgen, 1996) for a complete description of a stream classification program.

2. North Central Texas Streams

Generally speaking, the streams for which this manual is intended are those with a drainage area larger than 0.2 square miles that are tributary to White Rock Creek, Rowlett Creek, Wilson Creek or the East Fork of the Trinity River. Smaller streams generally tend to be replaced by manmade storm drainage systems. Channels are formed in either chalk or shale bedrock formations. Channels in the chalk are rectangular to trapezoid in shape, with bank slopes ranging from vertical to 2:1. Bank materials are composed of silty clay. Chalk streams generally have a greater drainage density (more channels per unit area) and are relatively steep. Shale based channels are trapezoidal in shape with 2.5 to 3:1 bank slopes, composed of weathered shale and clay alluvium. Shale channels are more sinuous but less steep than chalk channels (Allen, 1985). In general, these streams are relatively stable and resistant to erosion until disturbed by activities such as urbanization and channel alteration.

D. Stream Bank Erosion And Failure

Streams are dynamic systems which are continuously evolving, reacting to the various natural and man-induced influences placed on them. When a balance exists among the hydraulic and sediment transport characteristics of a stream reach and the hydrology and sediment delivery of its drainage area, it is said to be in equilibrium. Natural or man-induced influences can upset this equilibrium, causing a system response that commonly involves adjustments in flow hydraulics (velocity and depth), channel geometry (width, depth, and slope), and channel topography (sediment bars and meanders).

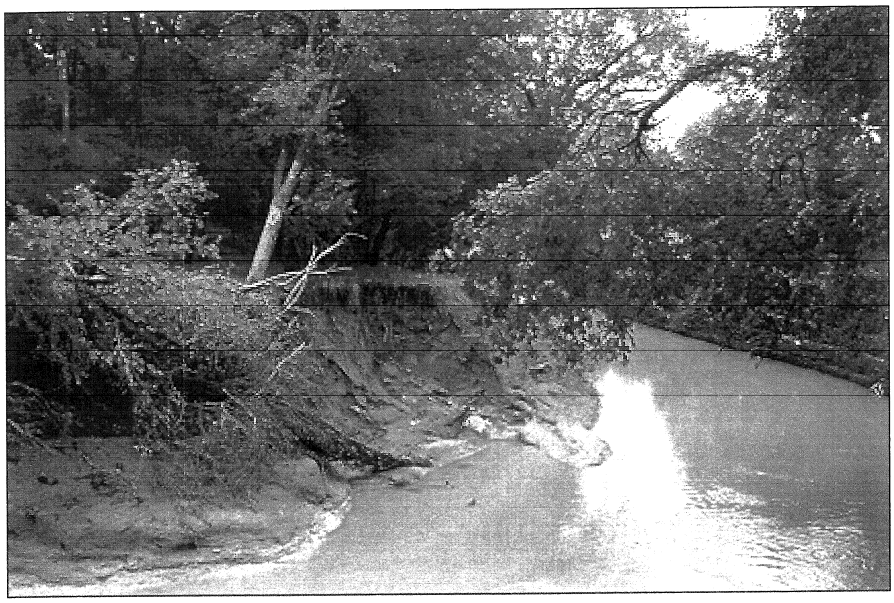
Although the causes of stream bank erosion are varied and complex, stream bank erosion can be classified into two types: 1) surface erosion of individual soil particles due to the action of water, and 2) mass wasting. Mass wasting can be characterized as a general structural failure of the bank and usually involves a relatively large section of the bank. Often, mass wasting results from surface erosion, such as when the toe of a bank is scoured away. A cycle of scour from surface erosion followed by mass failure may result in migration of the bank line.

In the following sections, basic definitions and methods of evaluating factors influencing bank stability will be presented. Important factors include channel velocity, tractive force (boundary shear stress), channel bends and land use changes.

1. Surface Erosion of Stream Banks

Individual soil particles are eroded from a bank by the tractive force of flowing water. Particle erosion occurs when the tractive force exerted by the water exceeds the particle's ability to resist movement. The strength of the tractive force increases proportionally to the velocity and depth of flow. Erosion is therefore more likely to occur during a flood event.

The ability of a soil particle to resist the tractive force is dependent on the particle's size and cohesive properties. Larger particles that weigh more are harder to move. Thus, gravel-sized materials resist erosion better than sand-sized materials. Cohesive particles, such as found in the clays found throughout the four communities covered by this manual, are more erosion resistant than non-cohesive silt-sized particles. In general, vegetative cover reduces flow velocity and the tractive force on soil particles, thereby increasing the stability of soil particles compared to bare soil conditions.



SPRING CREEK DOWNSTREAM OF JUPITER ROAD IN GARLAND, TEXAS

Major causes of the surface erosion of stream banks include:

- Flow Hydraulics
- Rainfall
- Groundwater Seepage
- Overbank drainage
- Wave attack
- Freeze-thaw and wet-dry cycles
- Land use

A discussion of the mechanics of surface erosion on stream banks is presented in the following sections.

a) Flow Hydraulics

Fundamentally, the erosion of individual soil particles on a bank is controlled by the physical characteristics of the particle, bank slope, and the hydraulics of flow (velocity and depth). The hydraulics of open channel flow can be classified as:

- Uniform, gradually varying, or rapidly varying flow
- Steady or unsteady flow
- Subcritical or supercritical flow

Descriptions of these flow states, and procedures for identifying them are presented in the hydraulic engineering literature.

Design procedures for erosion control are usually based on the assumption of uniform, steady, subcritical flow, which is more or less typical of streams in the study area. They are generally also applicable to gradually varying flow conditions. Rapidly varying, unsteady flow conditions are common in areas of flow expansion, flow contraction, and reverse flow, and are often associated with flow obstructions. Fully developed supercritical flow is rarely observed in natural channels, although flow in the transitional range between subcritical and supercritical often occurs in steep channels and through constrictions.

Bank erosion can be affected by both man-made or natural flow obstructions. Obstructions can cause complex hydraulic conditions such as flow impingement, increased turbulence and eddy action, and local flow acceleration. These hydraulic conditions may result in localized increases in shear stresses on the channel boundary. Common flow obstructions include bridges, woody debris, gravel bars, and revetments.

(1) Tractive Force

For cohesive soils, the boundary shear stress (tractive force) of the water against the soil particles measures the most important factor governing soil erosion. At a critical level, the water begins tearing loose the soil particles from the channel walls. Partheniades and Paaswell in "Erodibility of Channels with Cohesive Boundary" explain the process:

> "At any given instant in time, if there are no external forces acting on the surface of the clay, nor net forces acting on the clay mass, the system is in a state of temporary equilibrium for the given environmental conditions. Imposing an external force system, such as boundary shear, would create some deformation at the boundary, under the assumption that the clay particle system is not infinitely rigid. This deformation can be slight, and can occur as small translations or small rotations of individual particles, or particle groups. Movement of the particles then causes a readjustment in the force systems, which if no longer stressed, will come to some new position of equilibrium, but if still stressed will continue to undergo deviations in the force system. If the inter-particle bond is physically broke, and the particle is then entrained in the fluid, erosion has been initiated."(Partheniades, 1970)

Boundary shear stress, or tractive force, on a channel is the force exerted at the boundary between the soil and water by the force of the water. When the force is large enough, the particles of soil will move and erosion begins. The concept can be illustrated using a uniform flow, the flow depth and velocity remain unchanged from one section to another, as shown in Figure I-3.

Theoretically, the situation is one of zero acceleration. Combining this theory with Newton's second law of motion (Σ F=ma), then:

$$\Sigma F_i = 0$$

The sum of all forces in any one direction acting on the body of water must equal zero. Summing forces in the direction of the sloping channel bottom, as seen in Figure I-3, the hydrostatic forces, a_1 and a_2, at either end of the water element, are equal and opposite, and cancel. This suggests that the component of gravity force in the direction parallel to the channel bottom must be equal and opposite to the total boundary shear "force," b. The component of gravity force, W_s, parallel to the channel bottom is wAL sin Ø. For small slopes typical of streams in North Central Texas:

$$W_s = wALS$$

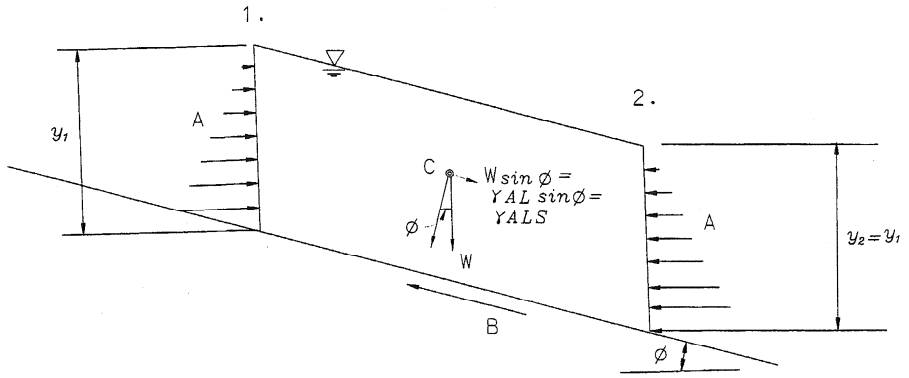
where: w = unit weight of water, pounds per cubic foot;
A = wetted area, square feet;
L = length of channel reach, feet; and
S = slope of channel bottom, feet per foot.

Thus, wALS gives the total boundary shear "force" exerted between Section 1 and Section 2. For boundary shear "stress", T_0, the shear "force," must be divided by the total wetted area, PL, assuming the shear stress distribution is uniform across the section; hence,

$$T_0 = wALS/PL = wRS$$

where: T_0 = boundary shear stress or tractive force;
P = wetted perimeter; and
R = hydraulic radius.

For relatively wide, open channels, the hydraulic radius, R, is equal to the depth of flow, y; therefore, T_0 = wyS, where y = depth of water in feet.



A. HYDROSTATIC FORCES
B. BOUNDARY SHEAR FORCES
C. GRAVITY FORCES

FIGURE I - 3

FORCES IN OPEN CHANNEL FLOW

Chow limits this derivation by stating that boundary shear stress is not uniformly distributed along the wetted perimeter. However, he concludes that the maximum shear stress on the bottom is close to wyS (Chow, 1959). Generally, S equals the slope of the energy gradient rather than the slope of the channel bottom. For uniform flow, the energy slope, or hydraulic gradient, and the channel bottom slope are equal. For non-uniform flow, the channel bottom is not smooth, but complicated with obstructions, such as weirs and dams. The slope of the energy gradient, or in this case hydraulic gradient, adjusts for obstructions and reflects the overall slope of the channel bottom. A dam would reduce the slope of the hydraulic gradient in relation to the slope of the channel bottom and thus decrease the boundary shear stress in the regions of decreased energy slope.

This concept uses the critical boundary shear criterion as the significant parameter affecting the onset of erosion. When the critical boundary shear stress is exceeded, erosion occurs. Values for area streams can range from 0.11 pounds per square foot (silt loam) to over 1.0 pounds per square foot (shale or limestone). The maximum permissible tractive force, or boundary shear stress, for stiff clays is 0.46 pounds per square foot, based on a straight channel of small slope according to Chow. For moderately sinuous channels, Chow recommends a twenty-five percent reduction, as shown in Table I-1. For very sinuous channels, Chow recommends a forty percent reduction of the maximum permissible tractive force (Halff, 1985). The boundary shear stress at a point on the bottom of a channel can be calculated using the equations derived by Chow or hydraulic computer models such as HEC-2 and HEC-RAS (USACE, 1997). Example tractive force calculations for area streams are shown in Table I-2.

Public works projects such as bridge replacement can accelerate stream bank erosion. The improvements to the bridge typically increase the capacity and lower the upstream flood levels especially for the shorter return period floods which are most critical to erosion control. The change in water surface elevation upstream of the crossing is often greater than before the new bridge was constructed. As a result, the slope of the hydraulic gradient is greater, increasing the boundary shear stress which contributes to increased erosion. An example of this can be seen in Figure I-4.

Stresses on the channel boundary associated with non-uniform, unsteady, and near supercritical flow conditions can have significantly different channel boundary stresses compared to uniform, steady, subcritical flow conditions. These stresses are difficult to assess quantitatively. Generally, increased factors of safety are utilized with uniform, steady flow design procedures to account for uncertainties associated with the more complex unsteady or supercritical flow conditions.

Table I-1
Maximum Permissible Velocities Recommended by Fortier and Scobey and the Corresponding Unit-Tractive-Force Values (Chow, 1959)[1]

MATERIALS	WATER TRANSPORTING COLLOIDAL SILTS			
	V, fps	T_0[2] lb/ft^2	25% Reduction Sinuous lb/ft^2	40% Reduction Very Sinuous lb/ft^2
Find sand, colloidal	2.50	0.075	0.06	0.05
Sandy loam, noncolloidal	2.50	0.075	0.06	0.05
Silt loam, noncolloidal	3.00	0.11	0.08	0.07
Alluvial silts, noncolloidal	3.50	0.15	0.11	0.09
Ordinary firm loam	3.50	0.15	0.11	0.09
Volcanic ash	3.50	0.15	0.11	0.09
Stiff clay, very colloidal	5.00	0.46	0.35	0.28
Alluvial silts, colloidal	5.00	0.46	0.35	0.28
Shales and hardpans	6.00	0.67	0.50	0.40
Fine gravel	5.00	0.32	0.24	0.19
Graded loam to cobbles	5.00	0.66	0.50	0.40
Graded silts to cobbles	5.50	0.80	0.60	0.48
Coarse gravel, noncolloidal	6.00	0.67	0.50	0.40
Cobbles and shingles	5.50	1.10	0.83	0.66

[1]-Well Established Channels, Mild Small Slopes and Flow Depths Less than 3 Feet
[2]-Corresponding Unit-Tractive-Force Values

Table I-2
Tractive Force at Various Locations in Study Area

Location & Flood	Depth feet	Velocity ft/sec	Tractive Force lb/ft^2
Stream IC-1A in Arbor Hills Nature Preserve, Plano			
• 10 year	4.1	5.2	1.2
• 100 year	4.6	5.8	1.3
Prairie Creek d/s of 15th St., Plano			
• 10 year	16.8	5.1	1.0
• 100 year	18.9	6.3	1.4
Spring Creek d/s of Jupiter Rd., Garland			
• 10 year	28.2	9.0	2.3
• 100 year	32.2	9.7	2.5
West Fork of Rowlett Creek d/s SH 121, Allen			
• 10 year	18.2	7.3	2.4
• 100 year	20.5	6.9	2.1
Wilson Creek d/s SPRR, McKinney			
• 2 year	15.4	3.4	0.5
• 100 year	20.	4.2	0.6

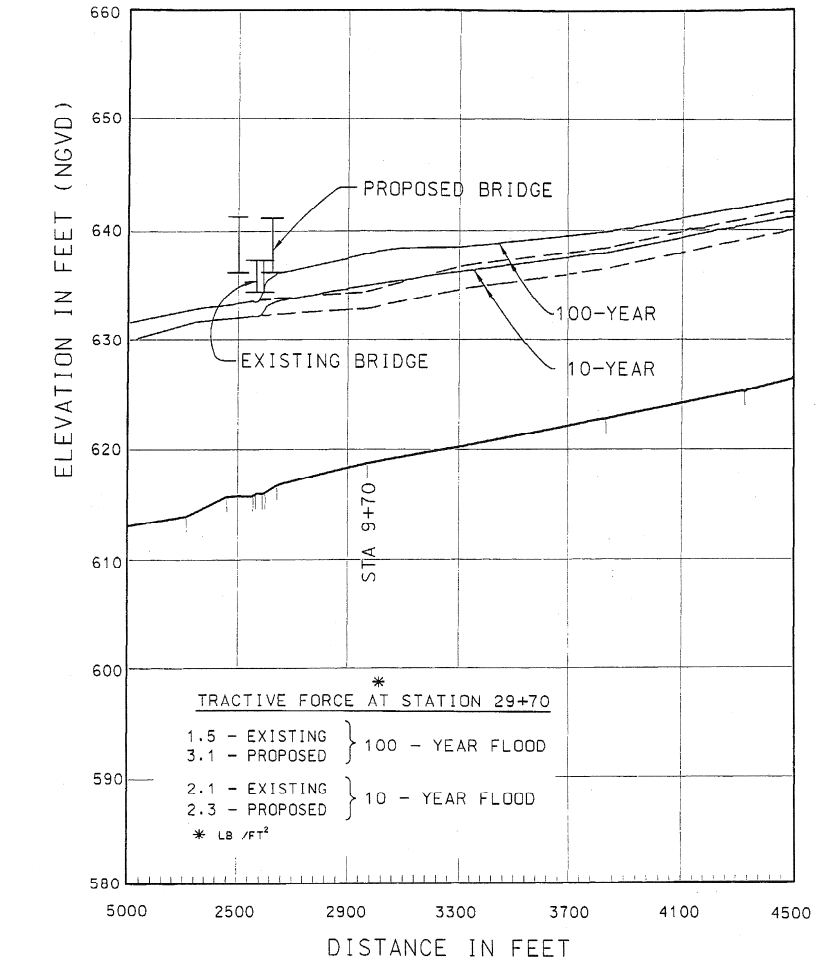


Figure I-4

Bridge Improvements Impacts on Tractive Force.

(2) Bend Hydraulics

As stream flow moves through a channel bend, centrifugal acceleration causes: 1) spiral motion in the flow, and 2) superelevation of the water surface. The velocity of flow increases toward the outside of the bend thereby increasing the tractive force to as much as twice that in a straight reach of the channel upstream or downstream from the bend. Figure I-5 shows the relationship between the ratio of shear on the outside of the bend to the mean channel shear stress versus the ratio of the bend radius of curvature to the channel width (Rc/W). The increase in shear stress along the outside of the bend often results in erosion in that area. The erosion often extends a distance downstream from the end of the bend. On the inside of the bend the flow velocity decreases, allowing sediments to deposit and build a point bar.

Sharp channel bends are more likely to experience erosion along the outside bank than gradually curved bends. However, it has been shown for channels with Rc/W ratios less than 2 that erosion rates on the outside of the bend are reduced sharply due to energy losses. During flood flows the path of maximum channel velocity generally moves across the channel against the point bar, often removing material deposited during normal flow conditions.

The superelevation of flow through a channel bend can be important for the identification of the bank area potentially affected by flow. It should be considered in establishing freeboard limits for bank protection on sharp channel bends. There are many methods for determining superelevation. For subcritical flow, superelevation at a channel bend may be estimated by (FHWA, 1989):

$$Z = C\,[(Va^2\,T) / (g\,Ro)]$$

where:

- Z = superelevation of the water surface (ft)
- C = coefficient that relates free vortex motion to velocity streamlines for unequal radius of curvature
- Va = mean channel velocity (ft/s)
- T = water-surface width at section (ft)
- g = gravitational acceleration (ft/s^2)
- Ro = the mean radius of the channel centerline at the bend (ft)

The coefficient C has been found to range between 0.5 and 3.0, with an average value of 1.5. A 20 foot bottom width channel with 2 to 1(v) side slopes flowing at 10 feet per second around a 100 foot radius bend will experience 0.7 feet of superelevation. Given the elevated tractive force through bends, Figure I-6 provides guidance as to where protection should begin and end.

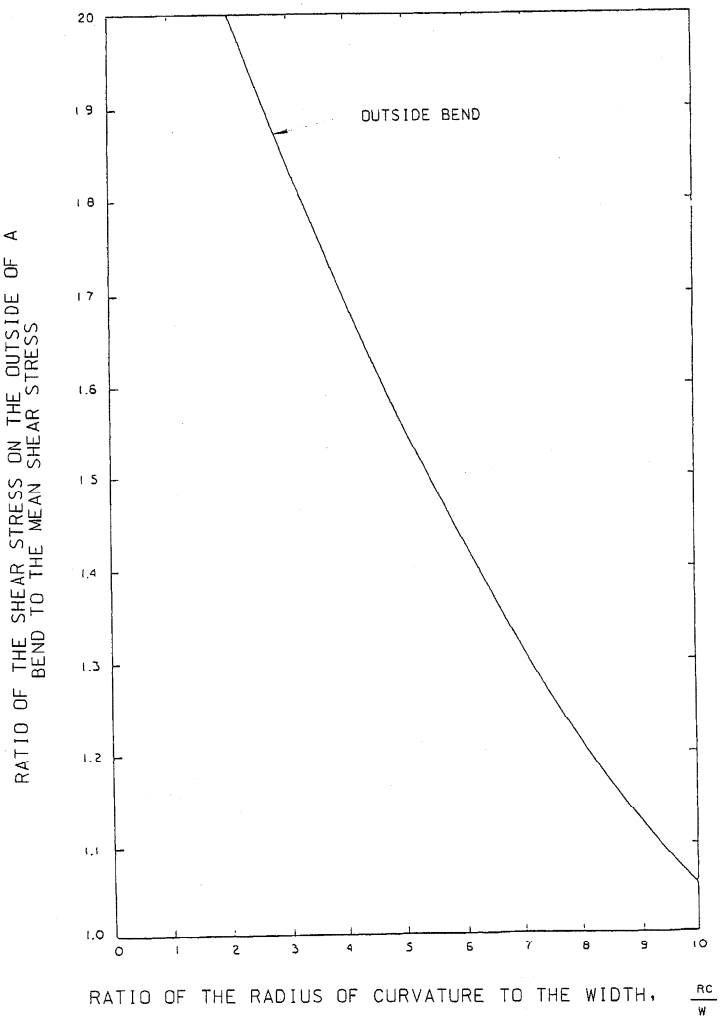
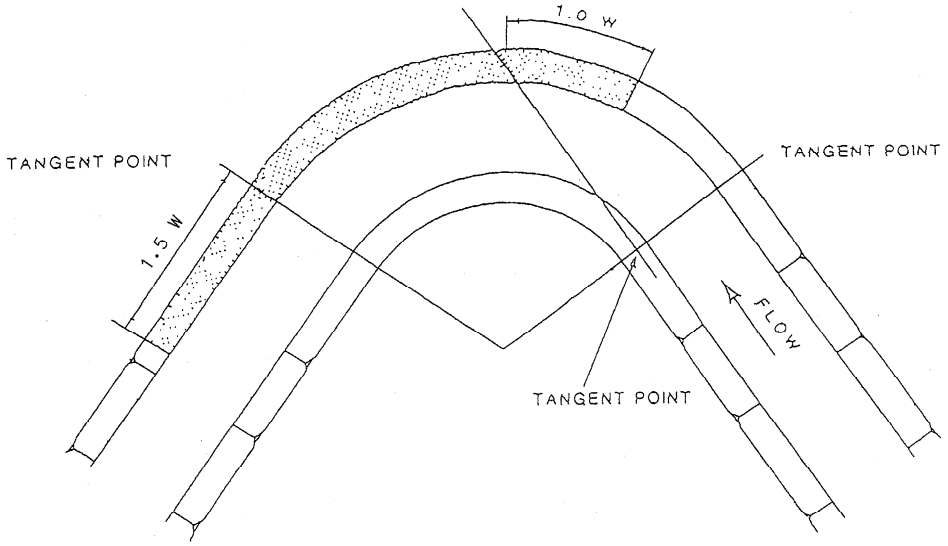


FIGURE I-5

BOUNDARY SHEAR STRESS
AT OUTSIDE OF BEND

(LANE, 1955)



W = STREAM BANK TOP WIDTH AT DESIGN FLOW

FIGURE I-6
EXTENT OF PROTECTION
REQUIRED AT A CHANNEL BEND.

(FHWA, 1991)

b) Rainfall

Rain can accumulate as overland flow or infiltrate into the soil. Raindrop impact on a stream bank can loosen soil particles and reduce infiltration capacity . The action of splashing rain drops and surface runoff removes soil particles in thin layers as sheet erosion. Runoff on the bank may form small channels as rill erosion. If the runoff is of sufficient magnitude, gullies will form on the bank. Sheet, rill, and gully erosion removes mineral nutrients and organic matter from soil. This action can leave stream banks coarse and less fertile, making the re-establishment of riparian vegetation difficult.

c) Groundwater Seepage

A portion of precipitation may infiltrate into the ground and become groundwater. Seepage along the face of a stream bank is an exposure of the groundwater table. The groundwater is forced to the face of the stream bank by piezometric pressure. Soil may be loosened and eroded by the seepage as it flows from the bank leading to rill and gully erosion similar to the effects of rainfall.

d) Overbank Drainage

Uncontrolled overbank drainage on the face of a stream bank can cause significant erosion. Left unchecked, large gullies can form within a bank due to overbank drainage. Overbank drainage problems are frequently associated with land clearing activities or developments adjacent to the stream channel, and a lack of adequate drainage outlets (ill-advised outfall location and/or elevation) and energy dissipation devices.

e) Wave Attack

Water craft or wind can set up waves that can erode a stream bank. Waves tend to dislodge bank materials. Commercial or recreational boat traffic may be a significant source of waves. Large areas of open water can present conditions for set-up of wind generated waves.

f) Freeze-Thaw and Wet-Dry Cycles

Occasionally in North Texas during winter months, stream banks may be subject to freeze-thaw cycles. The formation of ice within the soil matrix can heave and loosen bank materials, making them more erodible.

Drying of saturated clay deposits on a stream bank can cause shrinkage and cracking of the surface, forming a layer of loose soil that is easily eroded. Successive periods of wet and dry conditions may repeat the process.

g) Land Use

Land use changes that influence the sediment supply to or sediment transport capacity of a watercourse can result in stream bank erosion. Urbanization or land clearing can dramatically change stream hydrology, sediment supply, and sediment transport capacity of a water course. Reduced sediment supply or increased sediment transport capacity can result in channel incision (down cutting) and cause bank instability. Conversely, increased sediment supply or decreased sediment transport capacity can result in aggradation of the channel or the formation of bars which may cause flow impingement on channel banks and increased frequency of overbank flooding.

2. Stream Bank Failure

The general failure mechanisms associated with the mass wasting of banks are related to the characteristics of bank materials. Typical failure surfaces for various bank material types are shown in Figure I-7. Generally, a stream bank will remain stable for as long as the shear strength of the bank soil is greater than the shear stress placed on the bank. A decrease in the shear strength of the bank soil or an increase in the shear stress on the bank can individually or in combination lead to bank failure.

a) Decrease in Shear Strength

The major causes for a decrease in soil shear strength in banks are:

- Swelling clays
- Groundwater pressure
- Soil creep

Generally, neither swelling clays nor groundwater pressure in a bank can be directly observed. In certain cases, evidence of soil creep can be observed by the development of bank cracks that form parallel to the stream.

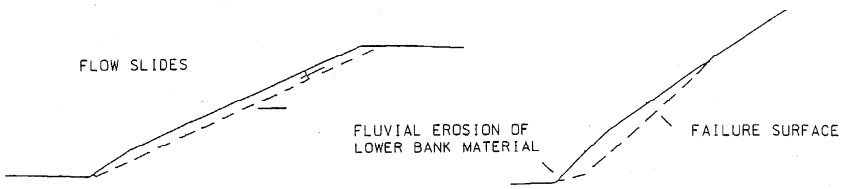
b) Increase in Shear Stress

Shear stress in a bank can increase by several means, but is most commonly associated with changes in channel bed elevation, undermining of the bank toe by surface erosion, increased loads on the bank, and rapid drawdown of stream flow.

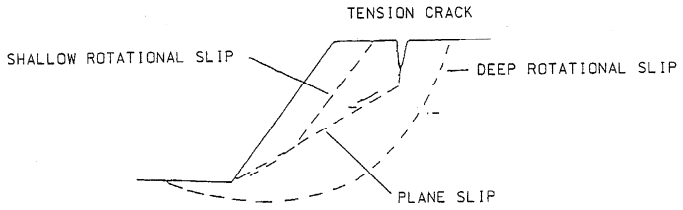
3. Erodibility

Of all these factors contributing to stream bank erosion in the project area, urbanization probably has the most impact. Studies have shown that urbanization of the drainage basin tends to roughly double the channel area as the stream attempts to reach a new state of relative stability (Allen, 1985). This phenomena is shown

graphically in Figure I-1. This adjustment process occurs over time, and many geomorphologists now think that it may take as long as 50 to 100 years for a stream to reach this new state of stability. Therefore, it is important to establish some sort of erodibility factor for newly developing areas so controls and/or correction of future problems can be achieved before homeowners and/or public facilities incur damage from stream bank failures due to erosion. Chapter III, Part D of this manual presents a procedure for establishing an erodibility index for stream reaches and locations as part of a stream bank stabilization program.



NONCOHESIVE



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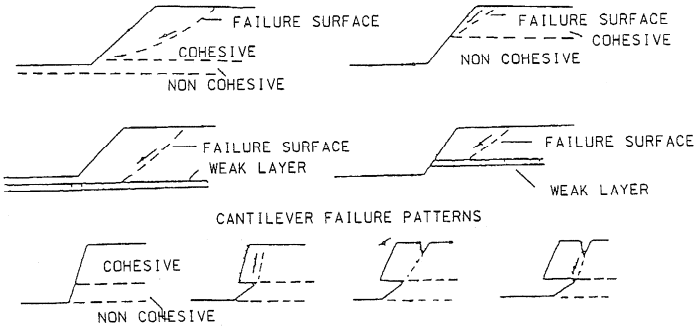


COMPOSITE

FIGURE I-7

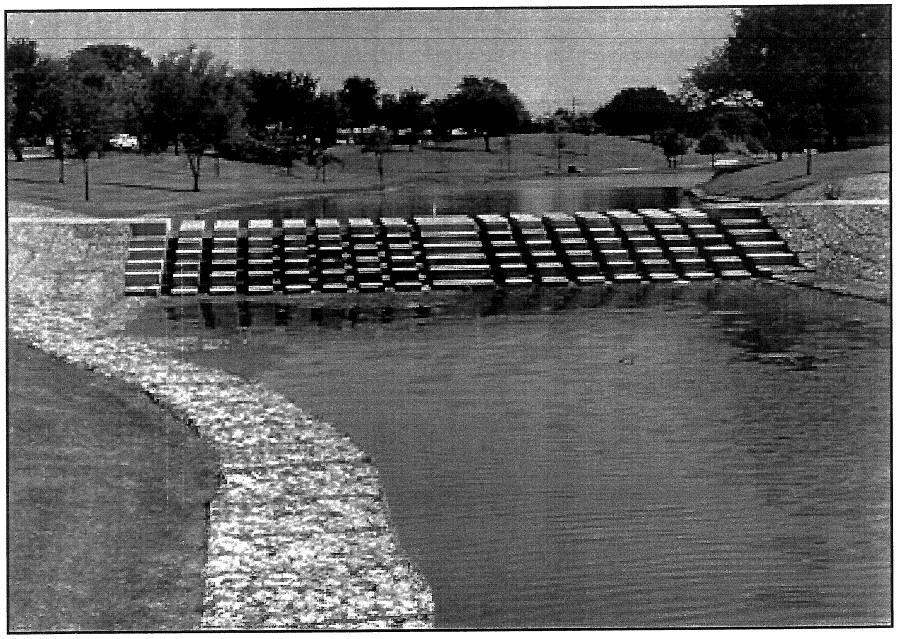
TYPICAL BANK FAILURE SURFACES
FOR VARIOUS SOIL TYPES.

(BROWN, 1985)

CHAPTER II

STREAM BANK PROTECTION AND EROSION DAMAGE MITIGATION MEASURES

Optimum erosion control and management of the flood plain should combine sound flood-control engineering with preservation and enhancement of the streams natural qualities. In order to insure the flood plain's utility, versatility, and compatibility with urban improvements, this manual has taken into account required flood conveyance, the safety of citizens and property, the visual impact of the land, and land uses to be derived from the area.

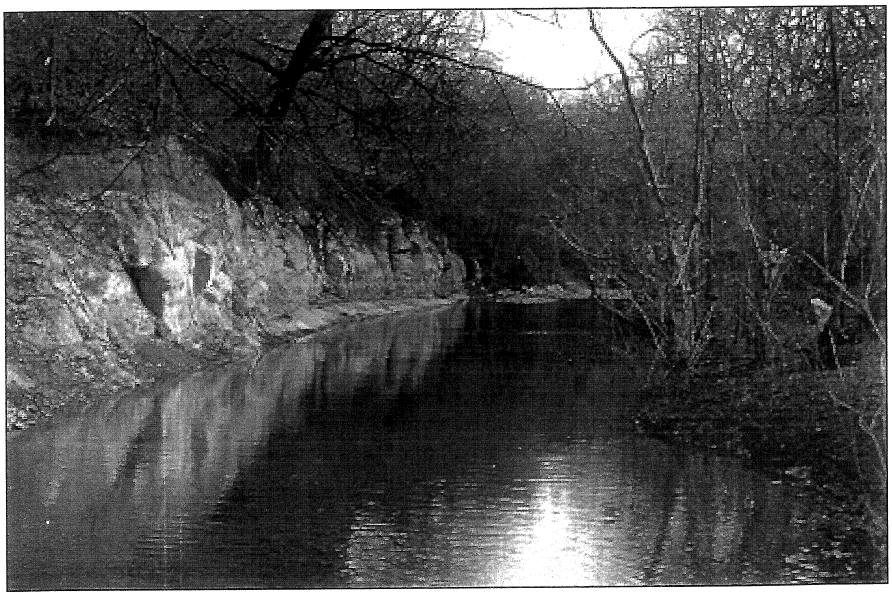


CHECK DAM IN RAWHIDE PARK, FARMERS BRANCH, TEXAS

All stream bank stability methods focus on the boundary between the water and its channel banks. Structural and non-structural methods can be employed to control erosion. Some methods will improve the channel's ability to withstand greater boundary shear stresses such as vegetation, gabions or other forms of channel armor, while others, such as detention basins, check dams, stilling basins and diversion channels, will reduce the boundary shear stress in critical areas altogether. Last, but not least,

stream preservation techniques such as the establishment of buffer zones, setbacks and erosion hazard zones prior to land development can reduce and even eliminate the economic damage that stream bank erosion can cause along urban streams.

Several design issues are common to many of the structural stream bank stabilization methods. In the selection and application of a particular erosion protection method, care must be taken to avoid merely transfering the erosion problem to another location. This requires the designer to not only understand the causes of stream bank erosion at the site in question, but to also take a comprehensive look at the entire stream reach, or even, basin. In addition, the transition of structural erosion controls to and from natural stream banks is critical, but often overlooked and should be carefully analyzed and designed. Special provisions, such as riprap and soil retention mats may be utilized to protect the termination of the proposed control and provide a smooth transition to the existing stream bank. In many cases, two or more of the methods presented can be combined to create effective, environmentally sensitive stream bank stabilization plans.



WEST FORK- ROWLETT CREEK, ALLEN, TEXAS

Stream bank stabilization is needed in areas where an existing structure is jeopardized, where the rate of and/or the potential for erosion could threaten future planned improvements, or where the actual or potential erosion puts significant environmental features at risk. The following summarizes the advantages and

disadvantages of methods that have been or could be used in the North Central Texas area. **Chapter III** provides guidance for the selection of methods and **Chapter IV** contains more detailed design guidelines.

A. Stream Preservation

One of the most effective flood plain management tools available to stream corridor planners today is the preservation of our natural streams and flood plains. Preserving these areas as open space and greenbelt accomplishes the multiple goals of flood control, water quality enhancement, habitat protection, recreation and often economic development. However, stream bank erosion in these areas can still be a problem particularly if the watershed is undergoing urbanizing influences. Therefore, stream bank stability assessments and possible erosion mitigation measures will be evaluated, even along those streams whose channels and flood plains remain natural.

B. Channel Bank Armoring

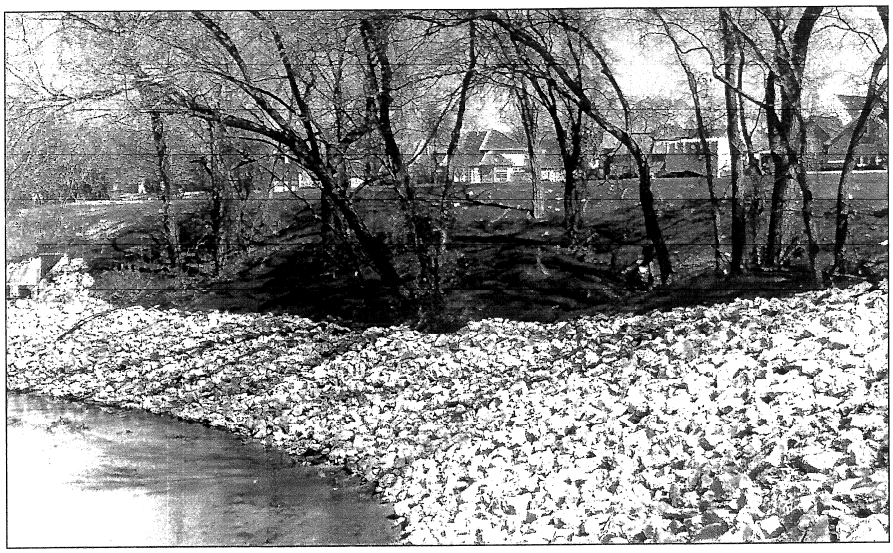
1. Concrete-Lined Channels

Concrete lined channels have historically been the choice of drainage designers for high velocity design flows. Typically they are more expensive than grass-lined channels. However, they can be placed in a narrower right-of-way and enable the use of steep side slopes in the presence of swiftly running water. Generally, this alternative can provide long life with a minimum of maintenance, but has negative impacts in terms of aesthetics and habitat along stream corridors. In addition, watersheds with significant amounts of channelization will experience more frequent flooding and higher flood peaks than will similar watersheds where natural channels and flood plains are preserved, due to the loss of valley storage in the stream (Halff, 1989). Therefore, concrete-lined channels should only be used where existing channel right-of-way is restricted or as a transition to bridges and culverts.

2. Rock Riprap

Riprap is an excellent channel liner and is less expensive than reinforced concrete channel liners. Riprap is loose rock or stone placed along the channel, sometimes strengthened by grouting with mortar. Sometimes immense rocks are required for shoreline protection at large lakes, while 9-inch to 12-inch rocks are adequate for channel protection in some applications. Since the durability of rip-rap is dependent on the stability of each individual rock to resist dislodgement, a conservative size rock is needed as a safety factor against extreme flow conditions. Rock riprap is effective in areas of high velocity and boundary shear stress. The rock riprap blanket has the ability to conform to irregularities in bank slopes. Usually, rock riprap is cheaper than concrete or gabion lining. The most common mistake in rock riprap applications is to provide rock that is too small for the tractive forces encountered. Rock riprap can be grouted to form monolithic armor. The result may be rigid but is usually not strong or long lasting. Often such applications begin to break apart after a

few years due to these forces of rushing water and expansive soils. Grouted rock riprap must be provided with weepholes to offset hydrostatic pressure buildup and toe protection to prevent undermining.



ROCK RIPRAP AT BEND ON FARMERS BRANCH CREEK, FARMERS BRANCH, TEXAS

3. Gabions

Gabions are wire baskets, filled with four to nine inch rock and bound together to form a structure. The advantages of gabions are that they conform to minimal shifts in the soil, and are adaptable to a wide variety of applications. Generally speaking, the appearance of gabion structures is considered less intrusive than similarly configured concrete structures. The disadvantage of gabions is that maintenance is necessary to preserve the integrity of the structure. Trees and branches carried by turbulent floodwaters can damage the wire baskets by either lodging themselves in the basket, or by pulling the wire and deforming the boxed configuration. If gabions are to be used in a structural application, this damage could lead to the loss of a large portion of the gabion structure during a single storm event. Special design considerations are needed for structures which are frequently inundated by turbulent floodwaters and subjected to bombardment of damaging debris.

GABION WALL ON TRIBUTARY OF ROWLETT CREEK IN PLANO, TAXAS

4. Landscaping and Vegetative Erosion Controls

a) Vegetation

Vegetation is the first defense against erosion. Grasses, ground covers, shrubs and trees can effectively protect the soil provided the slope is not steeper than 3(h) to 1(v) and the water velocity is not more than five feet per second. The plants must be compatible with the various habitats in the project area. In general, those selected for the channel must be able to withstand significant periods of inundation, have a rhizome-type of root network, and should not excessively restrict water flow. Plants for the overbank shall be both heat and drought tolerant. In difficult areas, such as steep slopes, a geotextile fabric should be placed and anchored to the soil before the vegetation is planted.

Typically, natural stream channels in the project area exhibit four vegetative zones as shown in Figure II-1. In the toe zone and splash zone, the plants listed can be inundated up to a week and can regenerate damaged top growth rapidly following river flood events. Species that commonly occur in similar environments are the submerged and emergent aquatic plants, such as Typha, Scripus, Polygonum, and Pharaqmites. These varieties offer resistance to low flows, but offer only minimal flow resistance

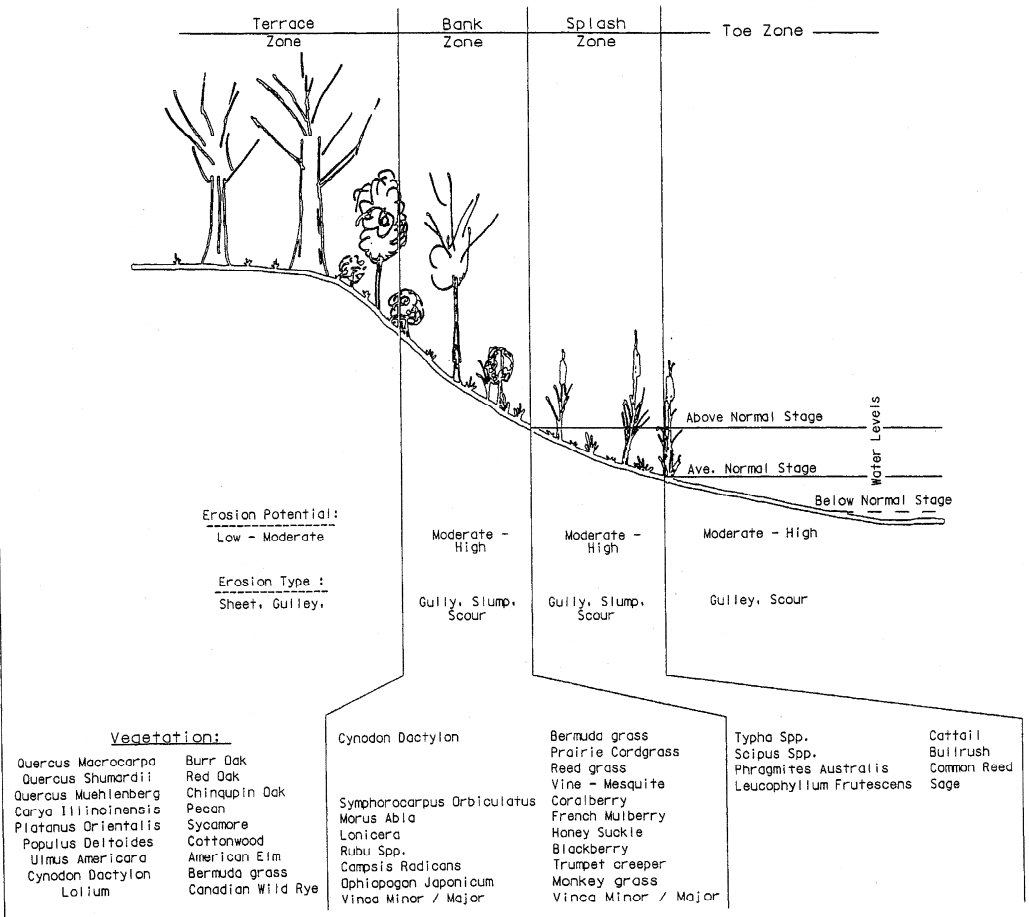


FIGURE II – 1
EROSION CONTROL
VEGETATION

(HALFF, 1985)

during high flows when the plants are flattened by the water. Therefore, planting a mixture of cattails, common reed, softstem, hardstem, and American bulrush along the channel would reduce its capacity for conveying small floods by increasing the roughness coefficient, n, from 0.035 to as high as 0.050 which is typical of natural channels with weeds (Chow, 1959).

The upper vegetative zones, bank zone, and terrace zone are normally dry. The vegetation selected for the bank and terrace zones should be tolerant of both the summer drought and the periodic flooding. Grass and trees suitable for the flood plain include Bermuda grass, buffalo grass, Canadian wild rye, and cottonwood, sycamore, pecan, American elm, burr oak, red cedar, and chinquapin oak. These trees add habitat and help other vegetation to survive, but must be carefully maintained. Their branches should be pruned high enough to avoid hindering flow and thinned so that sufficient sunlight will penetrate the ground to illuminate the shade-sensitive Bermuda grass and buffalo grass beneath.

b) Grass-Lined Channels

Grass-lined channels are common for several reasons. Grass- lined channels are inexpensive, can be visually attractive and are relatively easy to establish and maintain if properly designed and installed. Grassed channels can often repair themselves unless the erosion damage is very severe.

Grass-lined channels with relatively mild side slopes (3(h) to 1(v) or 4(h) to 1(v)) require additional protection at vulnerable points such as transitions and bends. The types of grasses preferred for a channel lining are those which have rhizomes (roots which sprout additional plants). Selected species should be compatible with local and/or native vegetation and should be capable of being established within a reasonable length of time.

The permissible velocity in a grass-lined channel is that which can be sustained for reasonable lengths of time without experiencing severe erosion. The permissible velocity will vary with type of grass, channel slope, and soil classification. Erosion-resistant soils would include **Houston Black** and similar clays. Easily-eroded soils would be sands, silts and clays with significant percentages of silt or silt seams, which are common along the streams in the project area. Permissible velocities are shown in Table II-1.

c) Cut or Filled Slopes

A 4(h):1(v) side slope in the soils of project area streams is generally stable and easily maintained by machine mowing. If the vertical height of the slope is greater than 15 feet, a 10 to 15 foot wide bench or shelf should be installed at mid slope and every 10 feet of vertical elevation change thereafter. Steeper side slopes of 3(h):1(v) may be

allowed in areas of restricted right of way, subject to approval by the City Engineer. These areas will experience more frequent slope failures.

d) Soil Retention Blankets

Soil retention blankets of natural or synthetic materials can be used to hold the seed and soil in place until new vegetation is established on channel banks or stream beds.

Table II-1
Permissible Velocities for Channels Lined with Grass*

Cover	Bed slope range, %	Permissible velocity, fps	
		Erosion-resistant soils	Easily eroded soils
Bermuda grass	0-5	8	6
	5-10	7	5
	>10	6	4
Buffalo grass, Kentucky bluegrass, smooth brome, blue grama	0-5	7	5
	5-10	6	4
	>10	5	3
Grass mixture	0-5	5	4
	5-10	4	3
	Do not use on slopes steeper than 10%		
Lespedeza sericea, weeping love grass, ischaemum (yellow blue-stem), kudzu, alfalfa, crabgrass	0-5	3.5	2.5
	Do not use on slopes steeper than 5%, except for side slopes in a combination channel		
Annuals-used on mild slopes or as temporary protection until permanent covers are established, common lespedeza, Sudan grass	0-5	3.5	2.5
	Use on slopes steeper than 5% is not recommended		

Remarks. The values apply to average, uniform stands of each type of cover. Use velocities exceeding 5 fps only where good covers and proper maintenance can be obtained.

*U.S. Soil Conservation Service , 1947.

5. Pilot Channels

Often grass-, gabion-, and stone riprap channels are combined with reinforced concrete pilot channels in the stream bed. Pilot channels can improve flood conveyance, especially for small, frequent flood events and provide an all weather surface for stream maintenance. Pilot channels should be designed to carry normal base flows and that of relatively small storm events to reduce as much as possible the frequency of erosive overflows. Often this results in channels with vertical sides 2 to 4 feet deep. In areas of heavy pedestrian traffic, the depth of the pilot channel wall may need to be limited for safety purposes.

GRASSED CHANNEL WITH CONCRETE PILOT CHANNEL ON COTTONWOOD CREEK, McKINNEY, TEXAS

6. Articulated and Interlocking Concrete Blocks

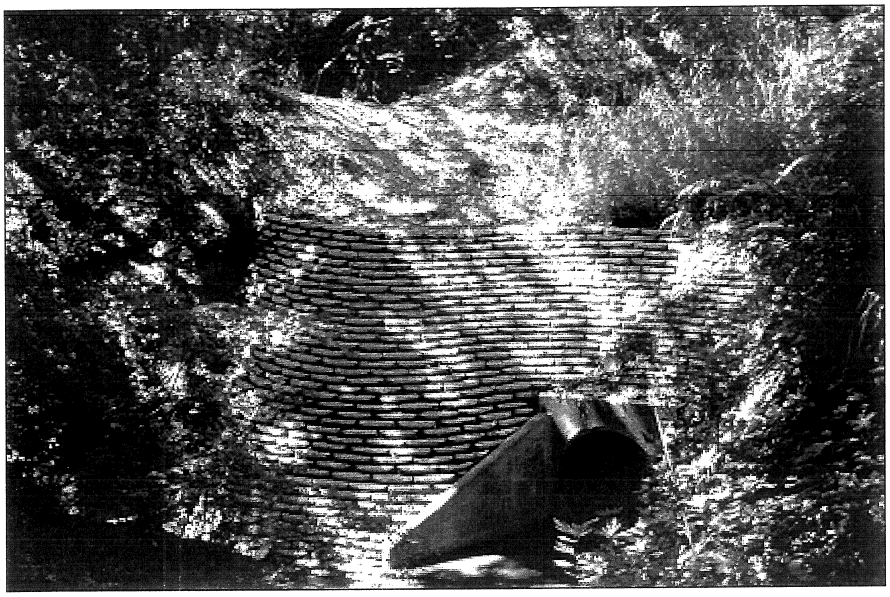
Concrete blocks cemented to a fabric liner or linked by cables form a flexible and porous mat that allows grasses and other plants to grow through the openings in the mat. The blocks are available from several manufacturers in numerous shapes, sizes, and colors. The block mats are limited to mild slopes and moderate velocities because the mats can be undermined by turbulent, debris-filled floodwaters.

Numerous hand-placed individual blocks are being marketed as erosion-control methods. Their effectiveness is dependent on their mass and their ability to resist being dislocated and transported by flowing water. The same limitations that apply to rip rap apply to these systems.

7. Sand- Cement Bag Revetments

Many types of systems, including several into which mortar, gravel or concrete are pumped into fabric liners are available. Locally, a system of individual paper bags filled with aggregate and cement has been used in public and private stream bank stabilization projects. Installation and maintenance complexity are minimal, since vegetation does not grow through the fabric. Floating debris can damage sacks although some fabrics are more resistant to these types of forces. Proper installation

must include adequate foundations and anchoring of the liners and bags. Applications of these systems are limited in terms of their height, steepness of slope and ability to withstand high levels of boundary shear stress.



SAND- CEMENT BAG WALL ON HERNDON BRANCH IN McKINNEY, TEXAS

8. Poured-In-Place Concrete Grid Mats

Poured-in-place concrete grid mats have had success in their limited applications. In England, the reinforced grid has been successfully used on the face of a dam or spillway. Successful establishment of grass can require significant amounts of irrigation, especially in areas of significant vehicular or pedestrian traffic.

C. Walls

1. General.

Sometimes walls are constructed to function as channel banks in areas of limited right-of-way. Walls are typically formed out of reinforced concrete, gabions, steel pilings or stone. Reinforced concrete and gabion walls have some of the same advantages and disadvantages as described in their use as lined channels. Grouted

and dry-stack stone walls are attractive but should be restricted in height to less than four feet unless used in combination with anchoring systems and accompanied by structural analysis prepared by a licensed engineer.

2. Reinforced Earth

This system consists of layers of reinforcing strips attached to a precast reinforced concrete facing. The reinforcing strips are extend into the backfill zone behind the wall. The wall is backfilled in lifts separating the strips. The structure is made stable through the transfer of stress created by earth pressure to the reinforcing strips, by friction created between the soil and the strips. This type of reinforcing system can also be used with gabion walls, sand-cement bag revetments and other precast retaining wall systems. Typically, the installation requires a large area at the back of the wall and may not be practical in areas where space is limited. Design elements of reinforced earth walls such as the limits of the backfill zone should be specified by a licensed and qualified engineer.

3. Bulkheads.

A bulkhead is a vertical wall used to support a slope and/or protect it from erosion. As such, it must be designed to resist the forces of overturning, bending and sliding. Bulkheads can be constructed out of sheet pile, sheet metal or timber and are most useful at the following locations:

- braided (many parallel channels crisscrossing) streams with erodible sandy banks
- where stream banks have failed by sliding
- at lake and pond edges to provide depth at the edge and protect against erosion by wave action

4. Precast Retaining Wall Systems

This system consists of a gravity retaining wall, utilizing precast, interlocking, reinforced concrete modules. Typically, these modules are filled with select backfill and compacted. Generally speaking, these systems should be installed as per manufacturers recommendations.

D. Control Structures

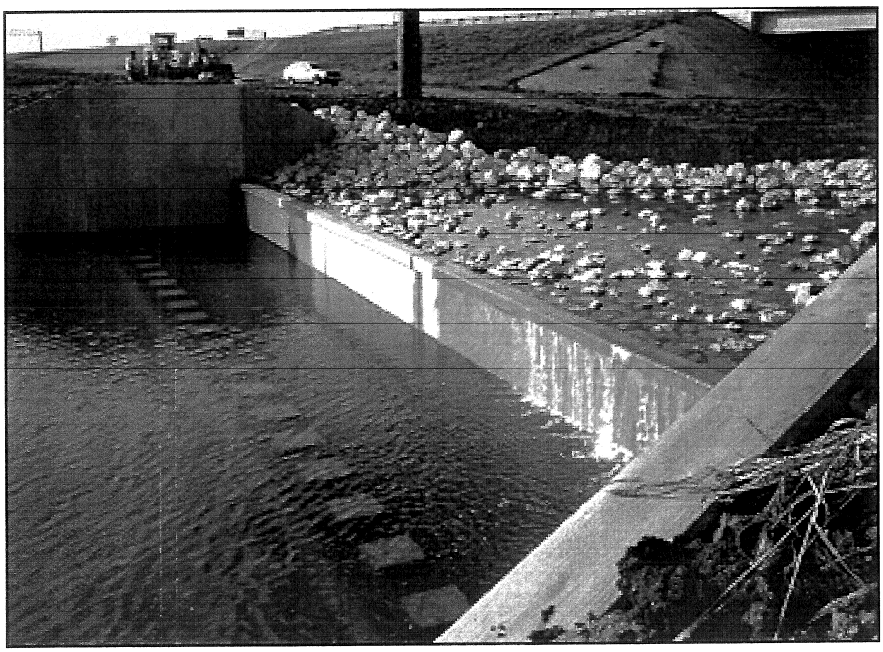
In contrast to the preceding methods that improve a channel's ability to resist erosion, the following structures focus on reducing the erosive power of the water. Energy dissipating structures force the water to yield its kinetic energy. Since kinetic energy can be expressed as being proportional to the flow mass (m) and the square of the velocity (v), water with less kinetic energy has a slower velocity and is less erosive

than that which has high kinetic energy. For example, in a stilling basin or plunge pool, turbulence consumes the water's kinetic energy. The desired result of energy dissipating structures is slower water and less channel erosion.

SMALL CHECK DAMS IN PARK, McKINNEY, TEXAS

1. Check Dams

Check dams are effective in reducing channel or stream erosion. The dam ponds water and increases the cross-sectional area of the stream and hence, reduces the velocity. The decrease in the slope of the hydraulic gradient lowers the shear stress, thereby reducing the erosive forces. The creek will deposit sediment behind the check dam, which should be periodically removed. Since check dams will be frequently inundated, they are constructed of concrete, gabions, or other durable materials capable of withstanding high-water velocities. The dam should be anchored into bedrock material and designed to prevent undermining and overturning. The area immediately downstream of the structure should be protected unless the formation of a scour pool is desired.



GRAPEVINE CREEK DROP STRUCTURE DOWNSTREAM OF IH 35, COPPELL, TEXAS

2. Drop Structures

Channel drop structures can be used to maintain stable, nonerosive conditions in upstream and downstream reaches or to arrest head cutting. Like check dams, local scour can occur downstream of the drop structure and undermining must be prevented usually by constructing the drop structure foundation deeper than computed scour depths. As an option, the change in grade can be achieved along a sloping apron as opposed to a vertical drop. In this case , the apron must be able to withstand the high velocities and turbulence at its downstream end. In some cases, a series of drop structures may be used to minimize drop height and structure cost.

In some cases, it may be acceptable to allow a plunge pool to form downstream of a check dam or drop structure. The scour depth downstream of the structure must be determined and can be predicted by Veronese:

$$d = (1/32)\, H^{O.225}\, q^{O.54}$$

where: d = depth of scour below the water level in feet;

H = difference in elevation between the reservoir level and the tailwater elevation in feet; and
q = discharge in cubic feet per second per foot of width.

The depth of scour is dependent more on the energy of the stream (i.e. weight of water and velocity of flow) than on the durability of the armoring material.

> "Depths of scour are influenced initially by the erodibility of the stream material or the bedrock and by the size or the gradation of sizes of any armoring material in the pool. However, the armoring or protective surfaces of the pool will be progressively reduced by the abrading action of the churning material to a size which will be scoured out and the ultimate scour depth will, for all practical considerations, stabilize at a limiting depth irrespective of the material size."(USBR, 1987)

3. Stilling Basins

Stilling basins are effective in reducing downstream erosion at the downstream ends of check dams, drop structures and larger dams. They are designed to increase turbulence, reduce the total energy, and increase the downstream depth of flow (Peterka,1984).

4. Durable Obstructions.

Baffles, chute blocks and other kinds of durable obstructions increase the turbulence and are useful in dissipating the energy of low flows. These are often incorporated into stilling basin design and at storm drain outfalls (Peterka, 1984).

E. Other

Channels and swales increase the cross-sectional area of the floodway and thereby lower velocities.

1. Diversion Channel.

Construction of a diversion channel can eliminate the need for total rehabilitation of the natural creek bed. The diversion channel becomes the primary conveyance; only the amount of flow necessary to prevent stagnation is permitted in the natural channel.

2. Swales.

High-water swales are shallow channels excavated parallel to the natural channel. During low-flow conditions, the swale will remain dry and all the water will flow through the natural course. During high-flow conditions flood water will be conveyed via the swale. An example of this type of erosion mitigation feature is found in Dallas' Tennison Memorial Golf Course. A diversion swale along the west side of the course

conveys approximately twice as much flow as the natural channel. This reduces the amount and frequency of bankful flows in the natural channel.

F. Soil Bioengineering Practices

The practice of soil bioengineering (SBP) is gaining recognition as a viable tool for controlling erosion and stabilizing slopes. In soil bioengineering, plants provide both a living component and a structural component (roots and stems) in a slope protection system. Using common cuttings, such as willows, the treatment attempts to provide sufficient stability until native vegetation can be established. Some suggest the following advantages for SBP's:

- Economy - SBPs are often less expensive to install than conventional methods.
- Environmental compatibility - SBPs offer benefits of habitat improvement, aesthetic value, ecological utility, and use of native and natural materials.
- Maintenance - Once established, SBPs typically require minimal maintenance and can be self repairing.
- Improved strength over time - Growth of the vegetative components of SBPs increases structural stability.
- Access - Access is often critical to the installation of conventional erosion control and stabilization techniques. Many SBPs require minimal equipment usage and are not restricted by access considerations.

SBPs can fill a need in stabilizing lands susceptible to erosion and instability where traditional or structural methods would be inappropriate or prohibitively expensive. These techniques can also be useful for lands that require reconstruction for environmental restoration purposes. However, there are several limitations to SBPs which should be emphasized and can impact their usefulness by design professionals:

- Installation season - SBPs are most effective when installed during the dormant season of late fall through early spring, depending on the plant material. This season may coincide with poor weather conditions which may discourage or prohibit the use of SBPs.
- Safety or risk factor - Because of ever present liability concerns and difficulties in quantifying the performance of SBPs, engineers may be reluctant to approve their use.
- Availability of plant material - Sufficient quantities of locally adapted plant species may be difficult to obtain.
- Labor considerations - Some SBPs can be labor intensive. Availability of affordable competent labor may be a limiting factor.
- Time - SBP installations may take several seasons to become fully established. This introduces problems with contractor warranty and maintenance practices.
- Installation procedures - While the use of SBPs is increasing, local installers may be unfamiliar with correct procedures. In public works projects, contractors may often bid such work with little or no training in proper installation techniques. As

with all constructed projects, quality assurance must be achieved to ensure that the SBP has a good chance of success.

- Competition from other products - A growing market of other erosion control products, with well developed marketing efforts, may overshadow the existence or application of SBPs.

Chapter IV has specific design details for soil bioengineering practices. Appendix A shows design details. In the following section, several common SBP's will be discussed.

1. Live Staking

Live staking is the insertion by tamping of live rooted vegetaive cuttings into the ground. This is a relatively simple procedure that may be used as a primary treatment or as a means of securing fascines, mattresses or other soil bioengineering components. Typical uses of live stakes are for stream banks near the waterline, for small earth slides and slump areas created by groundwater seepage. Live stakes can also be incorporated into boulder walls or riprap installation. The stakes are tamped into the underlying soil between boulders or through a riprap layer. Subsequent growth strengthens slope and improves aesthetic value (Gray, 1996).

Live Staking is economical and fast to install. Stakes can be installed in wet conditions. However, applications are subject to availability of suitable plant material and restricted to installation in the dormant season.

2. Wattles

This technique, also called live fascines, uses bundles of branch cuttings which are placed and secured into shallow trenches. The bundles are tied together with twine anchored in the trench with wooden stakes. The trenches are typically excavated by hand and follow the contour of the slope or stream bank. Once the wattle has been placed and secured in the trench, the trench is back-filled with soil to a point where just the top of the wattle bundle is exposed. Wattles may have uses for stream bank protection in combination with other SBPs. One variation of wattle use for stream bank protection is the construction of wattle flow deflectors. Wattles are anchored in a streamside trench which is angled downstream. The trench is shorter than the wattle bundle, allowing the wattle to extend out into the moving water. As the vegetation grows, the stems extend the deflector mechanism upward, providing flow control during high water and protecting the stream bank. Care must be taken to ensure that channel flood conveyance is not reduced (IECA, 1995).

3. Brush Layering

Brush Layering involves placing live branches in excavated terraces, covered with soil and compacted to form a series of reinforced benches. The brush layer, with the tips of the branches protruding through the surface, reinforces the slopes in several

ways. The physical properties of the branches, even before rooting and growth, add stability to the slope. The protruding tips serve to capture debris and reduce surface erosion. Infiltration properties of the slope may be improved, thereby creating a more favorable environment for vegetation. Once the branches grow, roots add considerable strength to the soil. This technique works best with fill slope construction.

Depending on the size of the slope to be treated, this treatment may lend itself better to equipment use than wattling. It can be, therefore, a very cost effective alternative for slope stabilization when compared to other conventional methods such as retaining walls (IECA, 1995).

4. Brush Mattressing

In this soil bioengineering technique also called brush matting, a mattress-like branch layer is placed on a stream bank and is secured to the bank slope using a variety of anchoring techniques such as live or dead stakes, wire, twine, or other live branches. Brush mattressing is typically used in conjunction with other techniques such as live staking and wattles. As with brush layering, this technique requires large quantities of branch material (IECA, 1995).

5. Live Cribwall

This technique combines a structural element of logs or timbers with live branch cuttings to form a reinforced wall. Live cribwalls are used for slope stabilization, usually at the toe of slopes, or for stream bank protection applications. Vegetation improves the strength of the wall and improves the overall aesthetics by screening the structural components (IECA, 1995).

6. New Soil Bioengineering Technologies

Variations on the techniques described above are being utilized more and more as SBPs integrate the use of a variety of natural and synthetic products. Stream bank protection SBPs can be substantially improved with the use of strong natural or synthetic geotextiles. The added strength can be particularly valuable in the early stages of treatment, prior to rooting and establishment of vegetation. One method described by the King County Dept. of Public Works, Surface Water Management Division (Seattle, Washington) utilizes a strong natural geotextile such as coir to wrap individual lifts of soil which are separated by a brush layer (Johnson and Stypula 1993). The geotextile helps to protect the newly constructed system by protecting against

higher stream flows and may also be used, in conjunction with riprap, for structural toe protection. This technique may also allow for steeper slope faces and, therefore, is valuable for sites which cannot be sloped back. This method has been called "vegetated geogrid".

In a similar fashion, plastic geogrids are often used to add structural integrity to SBPs. Geogrids have been used as a component of brush layering systems and of vegetated dikes, a SBP used to prevent bank scour. The grids help primarily to confine small stone, but also add a structural component which continues to strengthen as roots grow throughout the structure (IECA, 1995.)

Tubes of coconut fiber are used to support plant growth along the edges of streams, rivers, lakes and reservoirs (Goldsmith and Bestmann 1992). When used in conjunction with pre-planted pallets of aquatic plant species, this technique is very successful in creating wetland and riparian habitats. The coconut fiber tubes are also an effective shoreline protection against erosion due to small waves.

7. Future Trends

Many SBP procedures are labor intensive. Labor, particularly for public projects, can often be expensive and locally, available workers are unskilled in SBPs. Therefore, SBPs must evolve to a point where labor is minimized and/or equipment use is maximized before widespread acceptance and significant applications occur in North Central Texas.

One way to achieve wider application is to develop modular systems of soil bioengineering components. Nursery grown and prepared wattles; pre-assembled brush layers; sandwich-style modules of plant material, soil, and geotextiles; wave attenuation barriers; prefabricated crib walls and floating islands; and assembled habitat structures such as submerged ledges and platforms for fish - all are potential modules which could make SBPs easier to implement.

Soil Bioengineering Practices have not seen widespread use in North Central Texas. Applications are needed to gain local experience with the practices. The techniques may be useful to local parks departments for inexpensive erosion control in golf courses or nature preserves and to local landowners who cannot afford expensive structural solutions or desire a more natural setting.

G. Setbacks and Buffer Zones

A setback is a strip of land that separates one type of land use from another, usually for protection or aesthetic purposes. The resulting separation, also referred to as a buffer, is usually established by systematic programs involving the location of key physical or environmental components of streams and their adjoining flood plains.

When used as a stream bank erosion control tool, setbacks protect adjoining developed land uses from damage due to potential slope failures, slides and settlement. Many other benefits can be realized in a setback or buffer zone program. Buffer zones can reduce pollutant loadings in storm runoff, reduce storm runoff volumes, provide critical habitats for urban wildlife, protect stream banks from randomly located outfalls originating from adjoining residential and commercial development and protect riparian areas along natural streams and wetlands. However, setback programs designed for these purposes usually result in much wider buffer zones than those needed for stream bank erosion control. Setbacks for erosion hazard purposes are discussed in Chapter III.

H. Stream Restoration

As discussed in Part A of this chapter, stream and flood plain preservation can be one of the most effective flood plain management tools available to stream corridor planners. However, many streams in the urban areas of North Texas have already been altered for drainage or flood control purposes, yet continue to experience stream bank stability problems along and downstream of the channel and flood plain modifications.

In some parts of the country, streams altered by man in the past are being restored to a natural state. This enhances habitat for fish and wildlife and provides a more pleasant setting for surrounding neighborhoods. One possible tool that can be used to help achieve restoration of disturbed streams is storm water detention. Detention can return the watershed's hydrologic response to a state more typical of it's pre-urban condition. Another tool involves reforestation of all or parts of the streams watershed. Reforestation is especially beneficial along riparian areas and achieves multiple goals of water quality enhancement, increased biological diversity and improved habitat.

If located in an urban setting, restored streams may still need erosion protection or mitigation and should be evaluated with appropriate techniques including the use of setbacks. Methods to achieve restoration of urban streams are still in the beginning stages of development and are worthy of future investigation.

CHAPTER III

SELECTING PROTECTION FOR STREAM BANKS

A. Design Criteria

Design frequency for stream bank stabilization and erosion control should be established as a function of risk. Normally, stream bank protection projects should be designed to withstand much more frequent flood events than flood control projects as long as the consequences of failure do not result in extensive damage to public or private facilities or severe environmental damage.

WEST FORK- ROWLETT CREEK DOWNSTREAM OF NEW CUSTER ROAD, ALLEN, TEXAS

Recommended design frequencies for typical erosion control and stream bank stabilization analysis range from the 2-year to the 100-year flood peak discharge and shall be determined by each individual city's erosion control policies. The 100-year flood has a 1 percent chance of occurrence in any given year and is the base or regulatory flood in the National Flood Insurance Program. The 2-year flood has a 50 percent chance of occurrence in any given year. This design level will typically provide protection against 60 to 70 % of the 100 year storm depth based on an analysis of streams ranging from 0.1 to 10 square miles in a community near the project area. If the 2-year flood is not known or calculated for the stream in question, the 10-year flood from the most current

flood insurance study results could be used. In any case, proposed stream bank stabilization projects should be evaluated for impacts on the regulatory 100-year flood plain in addition to other impacts as directed by the city engineer. No adverse impacts on upstream or downstream land owners will be allowed.

Setbacks or erosion hazard zones shall be permanently established for the purpose of erosion damage mitigation by plat or recorded instrument according to guidelines presented in Part D of this chapter. The erosion setback shall be required of all projects in which natural streams are to be preserved or where variations in the design recommendations of this manual are desired by the developer or land owner.

Projects designed within these guidelines should have a reasonably low risk of damage due to stream bank erosion. If developers or landowners propose projects with higher risk, those projects should be protected against failure due to erosion based on the 100-year flood. For example, if a developer desires to locate fill or structures within the erosion hazard zone, those channel banks should be evaluated for stream bank stability based on the 100-year flood. Since all of the study area's stream banks erode at some rate, this will require the developer to construct permanent stabilization measures such as walls or other measures as described in this manual.

B. Site Analysis

1. Site Inspection

All streams with drainage basins larger than 130 acres, or any stream that is earmarked for preservation in its natural state or exhibits stream stability problems requiring correction should be physically inspected by the Design Engineer for the purpose of stream bank stability assessment. The engineer should be accompanied by a Geotechnical Engineer or geologist, landscape architect and environmental scientist if at all possible.

a) Geology

The inspection team should examine the stream's bed and bank material and classify it as to soil and strata. Areas of existing erosion should be closely inspected and preliminary assessments of cause should be made.

b) Vegetation

Native and existing vegetation should be noted as to type, location and condition.

c) Documentation

A complete documentation of the field inspection should be compiled and made a part of the engineering study for the stream. This should include photographs and map locations of critical features such as existing vertical banks and significant trees. Features such as these can be located relatively easily using existing maps or with handheld GPS units.

2. Channel Morphology

Based on the field visit and best available maps, assessments should be made of such channel features as sinuosity, channel shape (depth, width, etc.) and vegetation. The causes of existing channel bank instability or anticipated future problems shall be determined.

C. Stream Hydraulic Analysis

Detailed stream hydraulic analysis is needed to correctly assess stream bank erosion problems. Typically, the analysis can begin with Flood Insurance Study computer models. However, these models will probably require updating due to their age and supplemental cross sections to provide an accurate portrayal of channel velocity in the study reach. As a general rule, additional cross sections should be inserted be sections with velocity changes greater than 20 percent. If supplemental cross sections are necessary, those sections shall be based on field surveys or detailed topographic mapping. Interpolated cross sections shall not be allowed. The hydrologic basis of the analysis should be based on discharges reflecting a fully urbanized watershed. The analysis should be performed or supervised by an experienced hydraulic engineer or hydrologist.

1. Velocity Determinations.

Velocity determinations come directly from the hydraulic computer model. In some cases, more detailed velocity distributions should be developed across the section to accurately reflect conditions in wide flood plains or complex channels. HEC-RAS, the USACE's replacement for HEC-2, provides an excellent graphical presentation of velocity variations across the cross section as seen in the example Figure III-1(USACE, 1997).

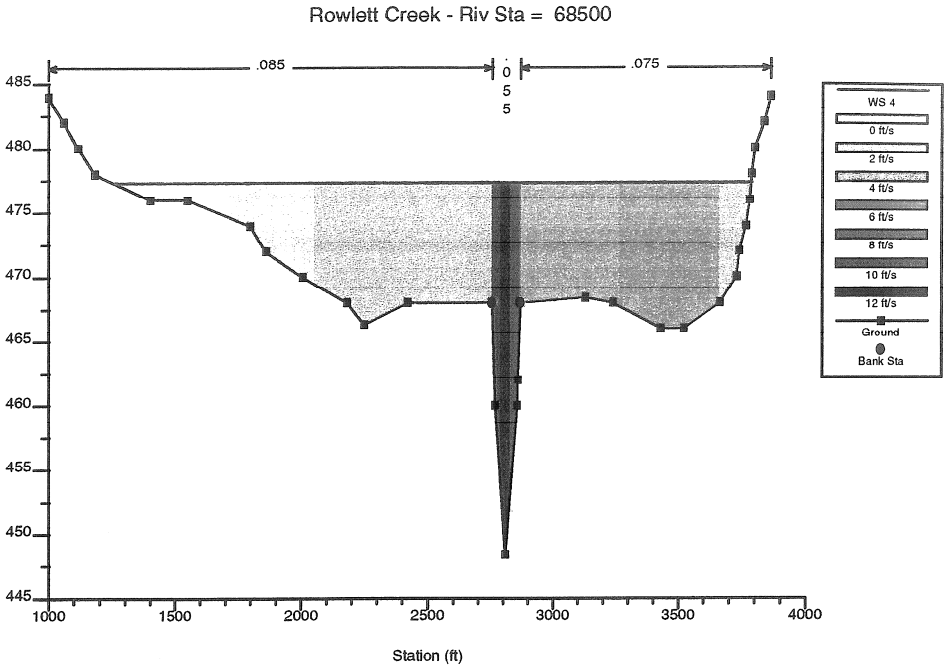


Figure III-1

HEC-RAS Velocity Distribution Plot

2. Tractive Force Calculations.

Tractive Force computations can be determined as described in Chapter I. Tractive force is a better means of assessing erosion potential than velocity. Both HEC-RAS and HEC-2 will compute tractive force (boundary shear stress). However, velocity guidelines will be used in this manual until more design experience is gained in North Central Texas using tractive force. Appendix C contains sample stream hydraulic analyses using HEC-RAS.

D. Erodibility Index

An erodibility index shall be computed for each erosion site within the proposed project. Erosion hazard sites shall be defined as follows:

- Areas of high velocity (greater than 5 feet per second based on design flows)
- outside banks of meanders
- steep banks (greater than 3:1)
- areas exhibiting existing stream bank erosion based on visual observation.

The erodibility index shall be a function of urbanization, stream velocities, sinuosity, and channel bank material.

1. Urbanization.

The watershed upstream of the project area in question shall be evaluated for urbanization influences on hydrology based on it's ultimate or fully developed land use. Watersheds that are undergoing urbanization influences (including redevelopment) shall be assigned a factor of 2 unless the entire watershed is stable having been urban for at least 50 years. This determination shall be made by the City Engineer. Watersheds that will remain in open space or natural conditions are assigned a factor of 1. This factor may be weighted to reflect the presence of parks and permanent open spaces. Urban watersheds that have significant storm water detention facilities and hydrologic analysis demonstrating that post development design flows will not exceed predevelopment design flows for stream bank stabilization evaluation shall be assigned an urbanization factor of 1.

2. Sinuosity.

Sinuosity is related to meander geometry and is defined as the ratio of stream length to valley length (Rosgen, 1996). Chapter I of this manual discussed how actual tractive force could exceed allowable values in meanders. even when average values are within acceptable limits. The degree of sinuosity

or meandering of the subject stream shall be assessed and assigned an index as follows:

- Pronounced meanders (sinuosity > 1.5)- 3
- Moderate meanders (1.26 - 1.5)- 2
- Relatively straight (1.0 -1.25) 1

A minimum stream length of 500 feet shall be used, centered on the project or site in question for the purposes of determining the degree of sinuosity.

3. Channel Bank Soils

The effect of channel bank soils on erosion potential is quantified based on the following soils index:

- Rock- 1
- Predominately clay- 2
- Clay interspersed with sandy and/or silty seams- 3
- Sands and silts- 4

4. Channel Velocity.

Channel velocity, and indirectly tractive force, is reflected in the erodibility index as follows:

- less than 5 ft/sec- 1
- 5 to 8 ft/sec- 2
- greater than 8 ft/sec- 3

5. Erodibility Index Computation.

To compute the Erodibility Index, sum the individual indices for channel velocity, sinuosity and bank materials. Multiply this total by the urbanization factor. The resulting erodibility index will range from 3 to 20. Areas with stream bank erodibilty indices of 3 to 8 should exhibit mild erosion, 8-12 moderate erosion and 12-20 would indicate severe erosion potential. If the erodibilty index is 8 or greater, the applicant should develop a stream bank protection plan as a part of the flood plain evaluation study for the project.

E. Erosion Hazard Setback Determination

Erosion setbacks or hazard zones shall be determined for every stream in which natural channels are intended to be preserved. The setback should be determined as described in this chapter. If variations to the setback policy are intended, adjusted setback limits should also be clearly shown on site plans, plats and the erosion control exhibit. Technical backup supporting the request

for a variance should be included in the engineering report. Technical backup can be in the form of detailed slope stability analysis.

The following is a suggested setback program designed for use in the preservation of natural streams in North Central Texas. It is based on the philosophy of maintainable slopes and allows the natural erosion processes to continue without threatening structures. The stream bank erosion setback zone would be established as follows:

- locate the toe of the natural stream bank
- from this toe, construct a 4(H) to 1(V) line away from the stream and intersect natural ground
- continue past the intersection an additional 15 feet to the edge of the setback.

A typical setback established by this technique is shown in Figure III-2a. Setbacks established for the purposes of stream bank erosion hazard protection may extend beyond the limits of the regulatory flood plain.

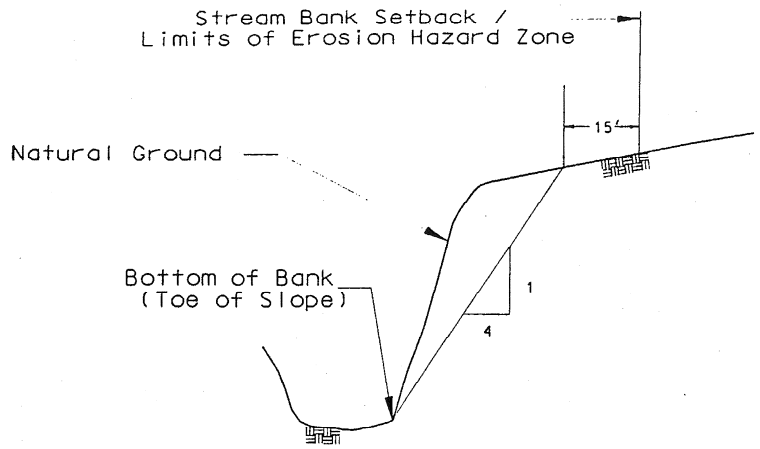
It may be desirable to reduce the stream bank erosion hazard setback line in areas where stream banks consist entirely or partly of rock. In these areas, the interface of the stream bank with the top of the unweathered rock strata should be located with the assistance of a qualified geotechnical engineer or geologist. This point on the surface of the slope will be the toe of a 3:1 slope intersecting natural ground. The actual setback line should then be located 15 feet beyond this intersection. This is illustrated in Figure III-2b.

When natural channel banks are protected in this manner, no building, fence, wall, deck, swimming pool or other structure, should be located, constructed or maintained within the area encompassing the setback.

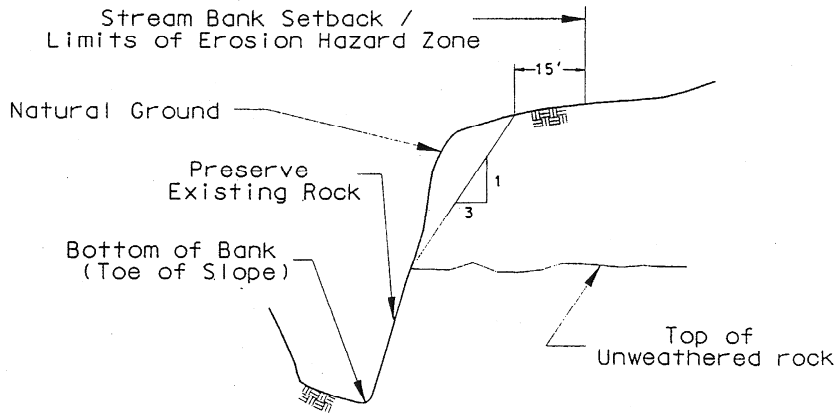
As an alternative to the setback, the developer or landowner may submit to the City Engineer a plan to stabilize and protect stream banks threatened by erosion. Stabilization shall be of a permanent nature, consistent with the guidelines of this manual, and shall be designed and sealed by a licensed professional engineer.

F. Matrix of Allowable Stream Bank Erosion Control Methods

Table III-1 is a summary of stream stabilization techniques and their suitability for solving mild, moderate and severe erosion problems.



A) EARTH OR SHALE CHANNEL BOTTOM



B) Rock Channel Bottom and Banks

Figure III-2

EROSION HAZARD
SETBACKS

(ALLEN, 1985)

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G. Stream Bank Stabilization Plan Requirements

Stream bank stabilization plans shall be comprehensive and shall include the following information:

- detailed topography of the site at a scale of 1"=100' or better.
- location of all hydraulic model cross sections both pre- and post-project
- hydraulic models reflecting both the erosion hazard design discharge and the 100-year flood reflecting pre- and post-project conditions.
- cross section plots reflecting pre- and post-project conditions showing velocity distribution
- profile plots of pre- and post-project conditions
- tabulation of pre- and post-project velocities
- photographs covering the stream in general and all erosion problem areas with locations referenced on the site plan
- geologists or geotechnical engineers report on stream channel bank conditions
- drainage area map with permanent open space and/or park land uses shown
- tabulated Erodibility Indices at each cross section and erosion hazard site with special attention at channel meanders
- proposed site plan showing erosion hazard setback line along stream, proposed erosion mitigation measures and regulatory flood plain and floodway
- construction phases for the overall project and erosion control features should be clearly indicated on the site plan
- details of proposed stream bank stabilization measures
- details of proposed erosion control measures at storm sewer and drainage outfalls to the stream channel
- supporting design computations as necessary for proposed stream bank stabilization and erosion control methods
- construction schedules
- temporary erosion control plan for construction phase
- hydrologic summary report including model and data if performed
- hard copy of computer model output
- electronic copy of computer model input
- copies of all required permits
- Stream bank stabilization plans shall be prepared under the supervision of a professional engineer licensed in the State of Texas. This will be witnessed by the engineer affixing his seal and signature to each erosion hazard site plan and details and any reports or calculations submitted to support the plan

H. Summary of Procedures

Figure III-3 summarizes the stream bank stabilization plan and approval process. Existing stream hydraulic models can be used to assist in the initial determination of the erodibility index. The preliminary report should also include photographs, a summary geology/geotechnical report and other findings.

I. Ranking of Stream Bank Stabilization Projects

The erodibility index allows the determination of erosion hazard. Given the hazards, a procedure is necessary for ranking the multiple problems so that needed corrective measures can be implemented prudently in light of budget limitations. The following is a modification of the procedures currently used by the City of Plano. The ranking is based on a summation of the scores from the following six evaluation criteria:

1. Threat to Major Structure

- Residences- 20
- Existing Drainage Facilities- 20
- Roadways- 15
- Water and Sanitary Sewer Lines- 10

2. Threat To Minor Structures

- Pools- 20
- Decks- 15
- Retaining Walls- 15
- Fences- 10
- Headwalls- 10

3. Threat To Environment

- Major (large trees, etc)- 10
- Minor- 5
-

4. Erosion Outside of Easement

- Known- 20
- Highly Likely- 15
- Probable- 10

5. **Potential to Erode Outside of Easement(estimated distance from top of stream bank to edge of easement)**

- Less Than 5 Feet- 10
- 5 to 10 Feet- 7
- 10 to 15 Feet- 5
- 20 Feet +- 0

6. **Erodibility Index**

- Ranges from 3 to 20
- Use as computed in Section III.D

The maximum possible score is 100.

Table III-1

Application of Stream Bank Stabilization and Erosion Control Methods

Method	Mild Erosion EI < 8	Moderate Erosion 8 ≤ EI < 12	Severe Erosion EI ≥ 12
A. Structural and Armor Methods			
1. Concrete Lined Channel	x	x	x
2. Rock Riprap Revetment	x	x	x
3. Gabion Lined Channel	x	x	x
4. Pilot Channels			
a.. w/ Grassed-lined Channel	x	x	
b. w/ Gabion-lined Channel	x	x	x
c. w/ Rock Riprap	x	x	x
5. Articulated Blocks	x	x	
6. Walls and U-shaped Channels			
a. Reinforced Concrete	x	x	x
b. Gabion	x	x	x
c. Stone	x	x	
d. Crib Wall	x	x	
e. Bulkheads	x	x	
f. Precast Systems	x		
6. Sand-Cement Bag Revetment	x		
7. Fabric Formed Concrete Systems	x		
8. Vane Dike/Debris Fin (see note 1)			
9. Soil Cement	x	x	
10. Bendway Weirs	x	x	
B. Control Structures			
1. Check Dams	x	x	x
2. Drop Structures	x	x	x
3. Stilling Basins	x	x	x
4. Transitions	x	x	x
5. Durable Obstructions	x	x	x
C. Soil Bioengineering Practices	x		
D. Other Nonstructural Methods			
1. Grass-lined Channels	x	x(see note 2)	
2. Geogrids/geotextiles/Cellular Confinement	x		
3. Blankets, Mats, Netting	x	x	
4. Removal of Obstructions	x		
E. Setbacks and Buffer Zones	x	x	x
F. Stream Restoration	x(see note 3)		
G. Diversion Channels (see note 4)			
H. Swales (see note 4)			
I. Detention (see note 4)			

NOTES:

1. Used for sediment and debris deposition control
2. When used with approved flexible channel liner
3. Restored streams in urban settings may still require supplemental erosion hazard mitigation measures
4. Effectiveness is a function of specific application and application may itself require use of one or more of erosion control methods listed above

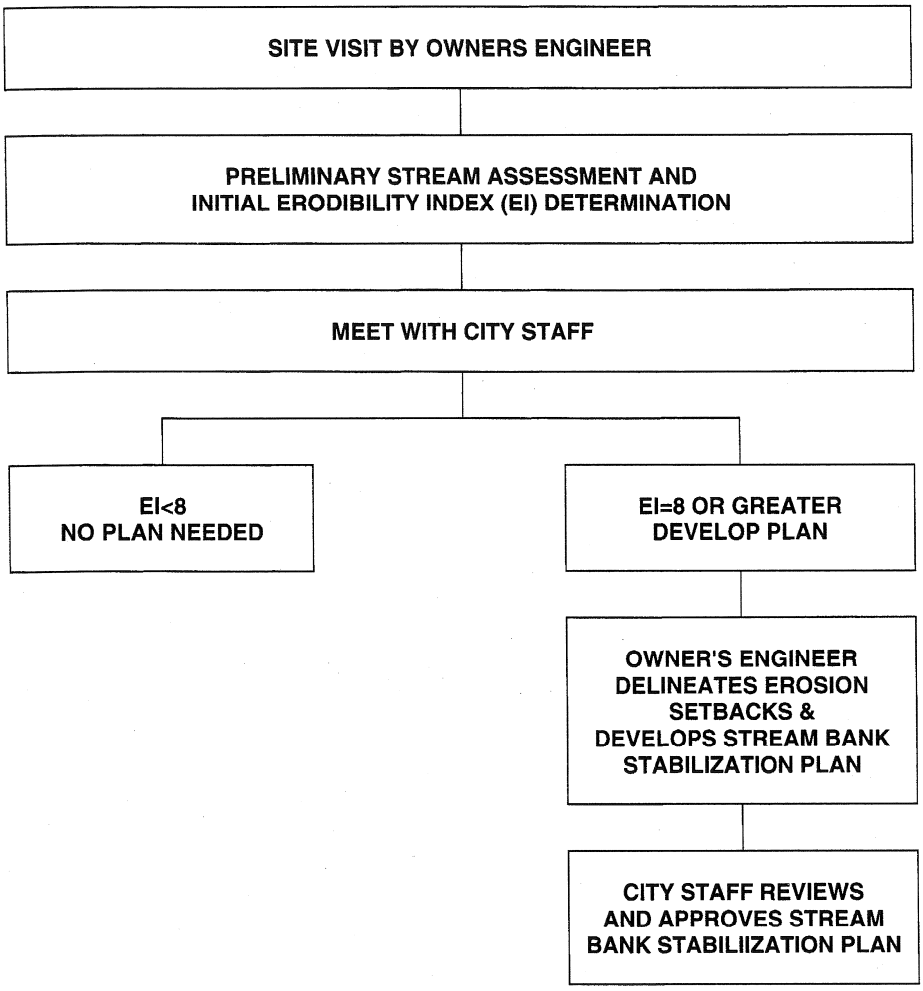


FIGURE III-3

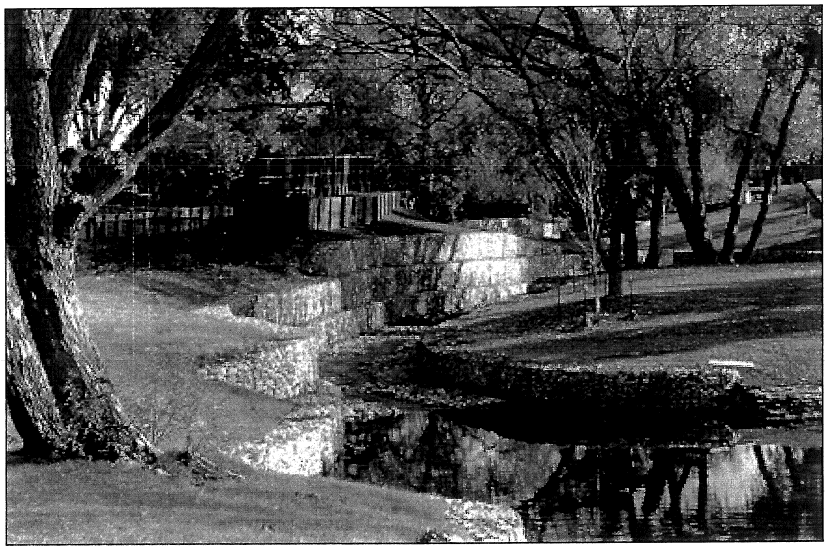
STREAM BANK STABILIZATION PLAN AND APPROVAL PROCESS

CHAPTER IV

DESIGN GUIDELINES AND DETAILS

A. General

In this chapter, general design guidelines are provided for various bank stabilization methodologies introduced in Chapter II. Selection criteria for any of these erosion control methods is outlined in Chapter III. Details for the stabilization and erosion control methods discussed in this chapter are found in Appendix A.



WEST PITTMAN CREEK DOWNSTREAM OF DIAMONDHEAD DRIVE, PLANO, TEXAS

B. Structural and Armor Methods

1. Concrete-Lined Channel.

Concrete-lined channels are a common drainage feature of small, urban streams in North Central Texas, especially in areas where right-of-way for drainage purposes is minimal. In addition to flood flow capacity, concrete lined channels should be designed to maintain scour velocities (>2 fps) throughout the expected flow regime. Supercritical flow will not be allowed. Minimum bottom width shall be 10 feet. Channel intersections shall be at an angle not exceeding

15 degrees. The minimum radius of centerline curvature shall be three times the top width of the channel unless superelevation computations are submitted for review. Subsurface drainage should be provided to prevent scour under the slabs and relieve pressures behind protected slopes. Uplift forces on the slabs should be evaluated. Joint location and frequency should be carefully considered by the design engineer (USACE, 1991). A typical concrete lined channel section is shown in Plate 1 of Appendix A. The designer is also referred to the standard details of the community in which they are working.

2. Rock Riprap Revetment.

Rock or stone can be an effective erosion control measure if properly designed. Extensive research by such organizations as the Corps of Engineers has resulted in good design procedures. These design features have been incorporated into commercially available software packages to assist the design engineer (WEST, 1996). Usually, the design procedure selects a representative stone size, $D_{\%,}$, where % denotes the percentage of the total weight of the graded material that contains stones of less weight. Other issues to consider in the design of rock riprap include:

- limit slopes to 2h to 1v
- provide a well-graded layer of rock
- provide filter material underneath the riprap to prevent washout
- provide a riprap blanket thickness of at least 1.5 times D_{50}.
- properly terminate all ends of riprap blankets.

A typical riprap blanket section is shown in Plate 2 of Appendix A.

3. Gabion Lined Channel.

Gabions are a popular erosion control method because of their flexibility. Gabion lined channels can adjust to conform to minor changes in stream bed and bank conditions. Any gabion basket that is in frequent contact with water should be PVC coated. Gabion baskets that are exposed to high velocity flows with large debris such as trees should be protected with a surface layer of grout. Aids such as design manuals and computer programs are available from gabion basket manufacturers. A typical section for a gabion lined channel is shown in Plate 3.

4. Concrete Pilot Channels.

Design guidelines for concrete pilot channels are similar to those for concrete-lined channels. If the pilot channel's side slopes are vertical, access ramps must be provided at regular intervals for channel maintenance. If concrete pilot channels are used in conjunction with grass-lined side slopes, supplemental measures such as rock riprap or a soil retention blanket may be necessary at the concrete-grass transition to prevent erosion and undermining of the pilot channel. An example combination pilot channel is shown in Plate 4.

5. Articulated Concrete Blocks.

Use of this method is normally not economically justified for small streams locally because of the specialized construction equipment required. Utilization of any product of this nature should be as per manufacturer's direction.

6. Walls and U-shaped Channels.

Walls must often be used to form channel banks because of right-of-way or other bank geometry restrictions. This usually results in special engineering issues which should be evaluated by a licensed professional engineer experienced in structural design.

a) Reinforced concrete.

Channel walls can be formed by reinforced concrete retaining walls. Design guidelines for such walls are beyond the scope of this manual. Some guidance can be found in the Standard Details published by each city. Reinforced concrete walls should be designed by a licensed professional engineer experienced in structural design.

b) Gabion Tiebacks.

Gabion walls can be constructed to function as channel banks. In this application, the structural walls can either be gravity (Plate 5) or incorporate an anchoring system for minimal right-of-way and bank disturbance (Plate 6).

c) Stone.

Stone masonry walls can be used for low channel banks. Stone walls should not exceed 4 feet in height and should be provided with adequate weepholes for subsurface drainage. Mortar strengths should be a minimum of 2500 psi (28 days). Walls greater than four feet should be designed, signed and sealed by a licensed professional engineer. An example stone wall is shown in Plate 7.

d) Crib Walls.

Structurally, crib walls are gravity walls, constructed of timber, precast concrete or steel beams. In addition to overturning, crib walls should be analyzed for internal stability. The front face should be battered for economy and appearance. Designs should be supervised by a licensed professional engineer experienced in structural design. The Federal Highway Administration has published standards for log cribbing (Gray, 1996).

e) Bulkheads.

Bulkheads should be constructed of durable materials such as treated lumber, metal or concrete. Sections above normal pool or adjacent to variable level ponds must provide for seepage through the wall. Tieback systems designed by qualified structural engineers should be provided. Plate 8 shows a typical bulkhead installation.

7. Sand-Cement Bag Revetment.

Sand-cement bag revetments are not uncommon in North Central Texas. Design considerations are similar as those for concrete and other types of revetments. Designers should provide against undermining of the toe and erosion at ends of the revetment. Sand-cement bag revetments are best suited to mild (2h to 1v or flatter) slopes and/or short walls in areas of low velocity. Steeper and/or taller walls must include supplemental measures such as tiebacks to withstand structural forces. Design guidelines can be seen in Plate 9.

8. Fabric Formed Concrete Systems.

Fabric Formed Concrete Systems are similar in application to sand-cement bag revetments and are usually proprietary systems. Installation should be in accordance with manufacturer's recommendations.

9. Dikes, Jetties and Jacks.

Dikes, jetties and jack systems are typically for control of large river systems and will not be presented in detail in this manual. One possible exception are vane dikes. Vane dikes are low elevation structures designed to guide flows away from eroding banks. They can also be used to evenly distribute flood flows through bridges and culverts when the upstream stream channel may be meandering or skewed to the crossing. An example of this application of vane dikes is shown on Plate 10A. Vane dikes can also be used with debris fins to reduce potential blockage of culverts (Plate 10B).

10. Soil Cement.

Use of in-place soil combined with cement provides a practical alternative to rock and concrete riprap. The resulting mixture, soil cement, has been successfully used as bank protection in many areas of the Southwest. Soil cement in a stair-step construction can be used on slopes as steep as 1:1. If properly constructed, soil cement can provide an aesthetically pleasing erosion control solution. A variation of this technical, Roller Compacted Concrete (RCC), has been used successfully on relatively large dam spillways. Most stream bank stability problems are too small in scope to be candidates for cost effective applications of RCC. As with all erosion control methods, soil cement applications should be designed by an experienced engineer. See Plate 11.

11. Bendway Weirs

Bendway weirs were developed by the engineers of the US Army Engineer Waterways Experiment Station to protect stream banks along the Mississippi River. These low weirs redirect the force of the river away from the outer bank toward the inner part of the bend and can be used to direct flow towards bridge structures. Most design criteria is based on field experience supplemented by model testing. A conceptual layout is shown on Plate 11A.

C. Grade Control Structures

Often, it is necessary to make abrupt changes in channel grade for the purpose of maintaining non-erosive flow conditions. This can be accomplished through the use of check dams, drop structures, and channel transition structures. Generally speaking, design of these structures should be performed by an experienced hydraulic engineer.

1. Check Dams.

The positioning of check dams along a stream course is an effective means of arresting the incising and downcutting that can occur as an urban stream attempts to achieve stability. Check dams should be made of durable materials such as concrete or gabions. Designs should extend sufficiently upstream and downstream to prevent undercutting. Normally, protection should extend up the adjoining slope to protect against any locally elevated velocity created by the structure. Stream hydraulics should be tested to ensure that design flood levels are not increased. Plate 12 shows a typical check dam in section.

2. Drop Structures.

Drop structures are utilized to check erosion by controlling energy gradients and to provide for large changes in flowline elevation over short distances. The changes in flowline elevation can be accomplished by means of a vertical drop or by constructing a fairly steep chute. A stilling basin is usually part of the drop structure design (Peterka,1984). To be effective, drop structures must be located so as to create stable channel conditions upstream and downstream from the structure. Details and design charts for a typical drop structure are shown on Plate 13.

3. Channel Transitions.

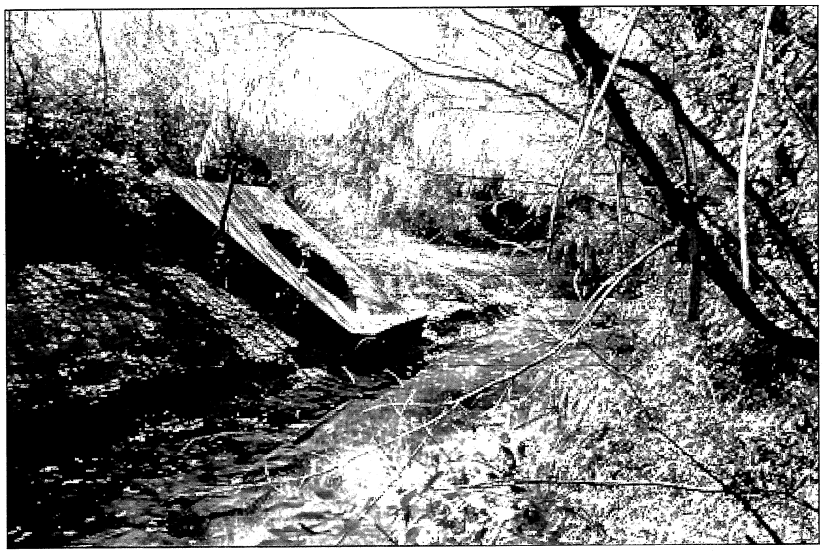
Channel transitions should be designed to accomplish the necessary change in cross section with as little flow disturbance as possible within the limits of ROW and economy. There is little guidance for transitions from improved, regular channel sections to natural stream sections. In general, detailed water surface profiles should be computed throughout the transition and velocity changes from section to section should not exceed 20 percent. Changes in flow line elevation should be minimized. The transition itself can take the general forms shown on Plate 14. The resulting water surface profile should be as smooth and straight as possible. Transitions involving high velocity (supercritical) flows should follow the rules of thumb as shown on Plate 14(USACE, 1991).

D. Storm Sewer Outfalls

Storm sewer outfalls are a chronic erosion problem in urban drainage systems. Often, the storm sewer system is terminated well short of the stream bank itself and at an elevation well above the receiving stream's flowline. The usual result of this practice is a headcut which eventually reaches the storm sewer headwall. Sometimes, the headwall itself is undermined to the point of failure. Even if the storm sewer outfall is extended to the stream bank, erosion can occur as a result of storm sewer flows between the headwall and the stream channel itself or even as a result of stream bank erosion due to urbanization.

There are three general types of storm sewer outfalls:

- the traditional Type A and B headwall found in most municipal standard drainage details
- the sloped end section headwall (sometimes called Type C)
- the impact type stilling basin outfall .



STORM SEWER OUTFALL ON RUSSELL CREEK UPSTREAM OF ALMA ROAD, PLANO, TEXAS

Generally speaking, the Type A, Type B and sloped end section headwalls will provide adequate protection for outfall velocities (in the pipe or box) of 8 ft/sec or less. This is provided that the outfall extends fully to the stream channel and adequate erosion protection is provided in the form of rock riprap and/or a reinforced concrete flume to prevent erosion around the headwall and between the headwall and the stream channel. Plate 15 shows suggested protection for standard headwalls. A good detail for sloped end sections is found in the City of Plano's standard details, sheet SD-14.

If the intervening area between the last inlet and the top of stream bank is more than one acre, surface erosion of the bank at the outfall often occurs. A wye or grate inlet should be situated at the top of bank to prevent this erosion. This can also serve as a vent to relieve capacity-robbing pressure fluctuations which can occur when the upstream pipe is flowing full and the downstream end is submerged.

The impact-type stilling basin outfall should be used when outfall velocities (in the pipe or box) are in excess of 8 ft/sec. The basic dimensions of the basin (Plate 16) are a function of the design discharge (Plate 17). Columns 1 and 2 of Plate 17 give pipe sizes used in field installations and assume a maximum velocity for the design flow of 12 ft/sec. Other pipe sizes may be used,

but the relationship between structure size and discharge should remain as shown in the table. Conduit slope at the outlet should be limited to 3%. If the conduit slope must exceed 3%, use a mild(less than 2%) slope for at least two diameters upstream of the basin (Peterka, 1984).

E. Soil Bioengineering Practices

Soil Bioengineering Practices (SBP) are thoroughly covered in *Biotechnical Slope Protection and Erosion Control* (Gray and Leiser, 1982). Excerpts and summaries of the various methods from that text are presented here for general guidance to those considering SBP's for stream bank stabilization.

1. Live Stakes.

Live staking, the planting or driving of unrooted cuttings to control soil erosion and shallow sliding, should be from plant species that will root easily and grow with minimal maintenance. Species should have long straight stems for ease of driving. Willow and desert aphyll can be used in our region for live staking. Stakes should be cut and planted when the species is dormant.

2. Wattles.

Wattle spacing should range from 3 feet on severely eroded slopes to 20 feet on slopes subject to moderate uniform sheet erosion. Wattling bundles should be composed of plant materials that root easily, are long, straight and flexible and are in plentiful supply near the project site. If easily rooted plant material is in short supply, bundles should be live staked. Placement should occur in late October or in the month of November after the fall rains . Wattle details and installation guidance is shown in Plates 18 and 19.

3. Brush Layering.

Branches should be 3-4 feet long, ¾-2 inches in diameter, and spaced 8-12 inches apart. Vertical spacing can range from 3 to 10 feet depending on the erosion potential of the slope. Spacing should be closer at the bottom of long slopes and increase as one moves up the slope. Brush Layering details and installation guidance is shown in Plates 20 through 22.

4. Brush Matting.

Brush matting or mattressing, mulches of hardwood, should be placed after planting in a shingle fashion with the butt ends pointed upstream. Mats should be a minimum of 4 inches thick constructed of 1 inch thick stems. Stakes should be 3 feet long and placed at 3-ft centers. Brush matting details and installation guidance is shown in Plates 23 through 26.

5. Coir.

This product is a very strong organic geotextile in mats or rolls, used to confine and stabilize soil until vegetation can be established. Coir is often used in conjunction with other SBP's and is commercially available.

6. Live Cribwalls.

Crib walls are hollow box -like interlocking arrangement of logs, timbers or concrete beams filled with soil or rock. These function as gravity walls as far as design is concerned. Typically, timber is rough cut, structural grade Douglas Fir. Heights should be limited to 4 feet unless designed by a Professional Engineer experienced in structures of this nature. Backfill should be free-draining, granular material. A typical crib wall design is shown in Plate 27.

7. Stream Bank Toe Protection

Type III- Pre-Vegetated Blankets, shown in Plate 28, are useful in establishing vegetation at stream and lake edges.

8. Combinations.

Various Soil Bioengineering Practices can be combined to solve problems such as gully and rill erosion as shown in Plate 29.

F. Other Nonstructural Methods

1. Grassed-Lined Channels

Key parameters in grass-lined channel design include permissible velocity, roughness coefficient, side slope, curvature, bottom width, and freeboard. The roughness coefficient for bare earth should only be used for checking maximum permissible velocity. Since bare earth channels will normally collect sediment and encourage undesirable vegetative growth, they will not be permitted for proposed improvements, unless written approval is obtained from the City Engineer. Design for grass-lined channels must include adequate temporary erosion controls for the construction period and final acceptance is conditional upon full vegetation coverage. If a variance is granted, the capacity of proposed bare earth channels will be determined using the grass-lined Manning's coefficient.

Small roadside-type ditches may be designed using normal depth, uniform flow methods as long as the flow rate does not exceed 100 cubic feet per second and the flow area does not exceed 20 square feet. Ditches and channels which exceed these limits must be designed with the standard-step method and will require the submittal of a HEC-2 (or equivalent) hydraulic model.

The maximum permissible velocity for grass-lined channels is as shown in Table II-1. To verify the channel velocities, the designer shall use uniform depth (for small channels) and a HEC-2 (or equivalent) hydraulic model (for large channels). Flow velocities shall not exceed allowable limits for the design storm when exiting a riprap section or culvert apron back onto grass-lined or bare earth channels. Appropriate energy dissipater designs shall be used if these velocities are exceeded.

Side slopes for earthen or grass-lined channels shall be four (4) horizontal to one (1) vertical side slopes or flatter if the slopes are to be maintained by the City. Steeper side slopes will be allowed only upon the approval of the City Engineer. The channel side slopes, along with the channel invert (to be approved by the City Engineer and Parks Department), must otherwise be stabilized in a manner approved by the City Engineer.

Channel intersections and minimum curvature criteria are the same for Grass-lined channels as for concrete-lined channels

If a greenbelt is incorporated into the overall plan for development, as a channel or as a buffer zone around a channel, then the greenbelt shall be landscaped, yet still retain the required hydraulic capacity. Landscaping requirements and maintenance responsibilities will be determined at the plat stage.

In North Central Texas, the Texas Department of Transportation uses the following grasses:

- Bermuda grass
- Buffalo grass
- Green Spangletop
- Little Bluestem
- Indian grass
- Switchgrass
- Sideoats Grama
- Sand Dropseed

The chances of establishment of newly seeded channels can be improved through the use of hydraulic mulch, synthetic blankets, emulsifiers and tackifiers. All channels must include the use of an approved soil retention blanket (see section D.3 of this chapter) for the lower two feet of the channel. Channels with erosion design velocities exceeding 5 feet per second but less than 8 feet per second shall include use of an approved soil retention blanket throughout the channel section. Channels with erosion design velocities equal to or greater than 8 feet per second must be armored (see IV.B)

2. Geogrids/Geotextiles/Cellular Confinement.

Most of these systems are proprietary and should be installed per the manufacturer's recommendations.

3. Blankets, Mats, Netting.

Excellent guidance is provided by the Texas Department of Transportation concerning synthetic blankets and mats for use as slope protection and flexible channel liners. Annually, these products are tested and a list of acceptable products is published (TXDOT, 1997). It is recommended that applications in the project area be limited to those products on TxDOT's approved list. The current list is included in Appendix B.

A soil retention blanket is used for short and/or long-term protection of seeded and sodded slopes, ditches, and channels. Soil retention blankets can be manufactured out of wood, straw or coconut fiber mat, synthetic mat, paper mat, jute mesh or other material. The soil retention blanket shall be one of the following classes and types:

- TXDOT Class 1. "Slope Protection"
  - Type A. Slopes 3(h):1(v) or flatter - Clay soils
  - Type B. Slopes 3(h):1(v) or flatter - Sandy soils
  - Type C. Slopes steeper than 3(h):1(v) - Clay soils
  - Type D. Slopes steeper than 3(h):1(v) - Sandy soils
- TXDOT Class 2. "Flexible Channel Liner"
  - Type E. Short-term duration (Up to 2 years) Shear Stress (t_d) < 48 Pa
  - Type F. Short-term duration (Up to 2 years) Shear Stress (t_d) 48 to 96 Pa
  - Type G. Long-term duration (Longer than 2 years) Shear Stress (t_d) > 96 to <239 Pa
  - Type H. Long-term duration (Longer than 2 years) Shear Stress (t_d) $\geq$ 239 Pa

4. Removal of Obstructions

Obstructions in a stream channel can alter flow characteristics and contribute to bank instability. Logs and other debris can block bridges and culverts worsening flood levels. Common obstructions in urban areas include fallen trees and sediment deposition.

Streams should be inspected at least annually, prior to spring rains to locate obstructions and schedule their removal. Removal typically involves cutting the tree into manageable pieces for removal and safe disposal. Sediment removal is more difficult and may involve dredging and/or mechanical removal. Sometimes, point bars at stream meanders can be removed by excavating a pilot channel across the bar and allowing the stream flow to erode the accumulated sediments. This practice should not be undertaken without the approval of the City Engineer.

CHAPTER V

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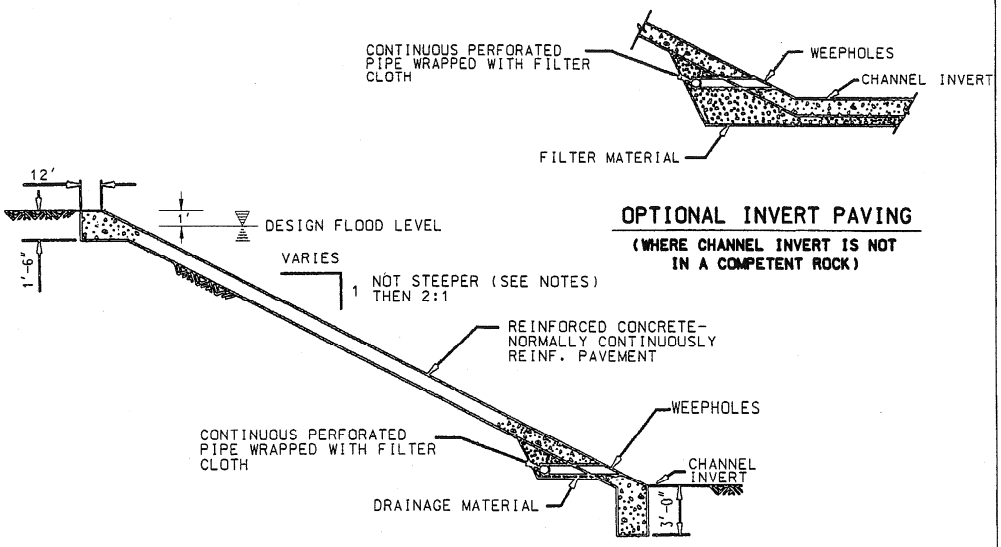
APPENDIX A

STREAM BANK STABILIZATION DETAILS



OPTIONAL INVERT PAVING

(WHERE CHANNEL INVERT IS NOT IN A COMPETENT ROCK)

TYPICAL SECTION PAVED CONCRETE CHANNEL BANK

N.T.S.

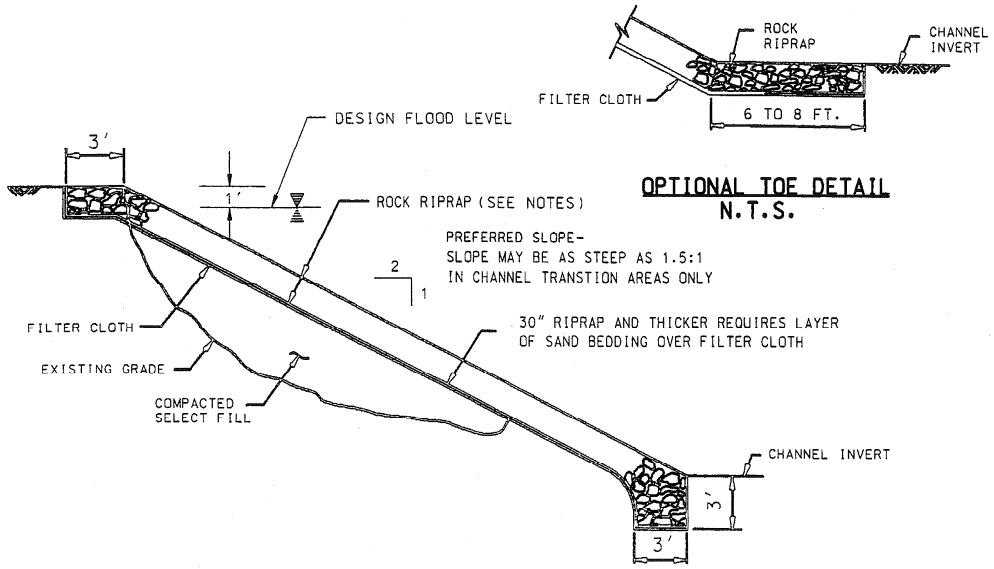
NOTES:

1. RECOMMENDED MAXIMUM SLOPE IS 2:1. SLOPES MAY BE STEEPENED TO 1.5(H):1(V) IN TRANSITIONS TO OR FROM NATURAL, UNALTERED STREAM BANKS.

2. HEADERS AT LEAST 3' IN DEPTH AND CAREFULLY DESIGNED TRANSITIONS SHALL BE CONSTRUCTED AT THE UPSTREAM AND DOWNSTREAM ENDS OF CHANNEL LINING.

(HALFF - 1990)

McKINNEY	city of plano	**REINFORCED CONCRETE CHANNEL LINING**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 1



OPTIONAL TOE DETAIL
N.T.S.

TYPICAL ROCK RIPRAP SECTION
N.T.S

NOTES:

1. RIPRAP SHALL BE DESIGNED BY THE USACE METHOD AS OUTLINED IN "HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS" USACE, ENGINEER MANUAL 1110-2-1601, CHANGE 1

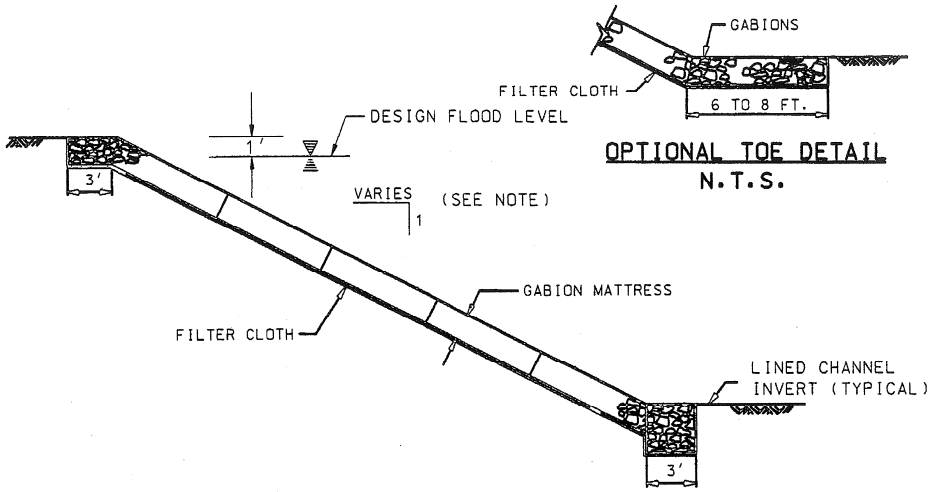
2. THICKNESS OF RIPRAP LAYER SHALL BE EQUAL TO THE LARGEST STONE SIZE OR 1.5 TIMES THE MEDIAN STONE SIZE, D50, WHICH EVER IS GREATER.

3. DESIGN FACTOR OF SAFETY SHALL BE 1.2

4. HEADERS AND APPROPRIATE TRANSITIONS AT UPSTREAM AND DOWNSTREAM ENDS OF REVETMENT SHOULD BE INCLUDED.

(HALFF - 1990)

McKINNEY	city of plano	**ROCK RIPRAP CHANNEL LINING**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 2



OPTIONAL TOE DETAIL
N.T.S.

TYPICAL GABION MATTRESS SECTION
N.T.S.

NOTES:

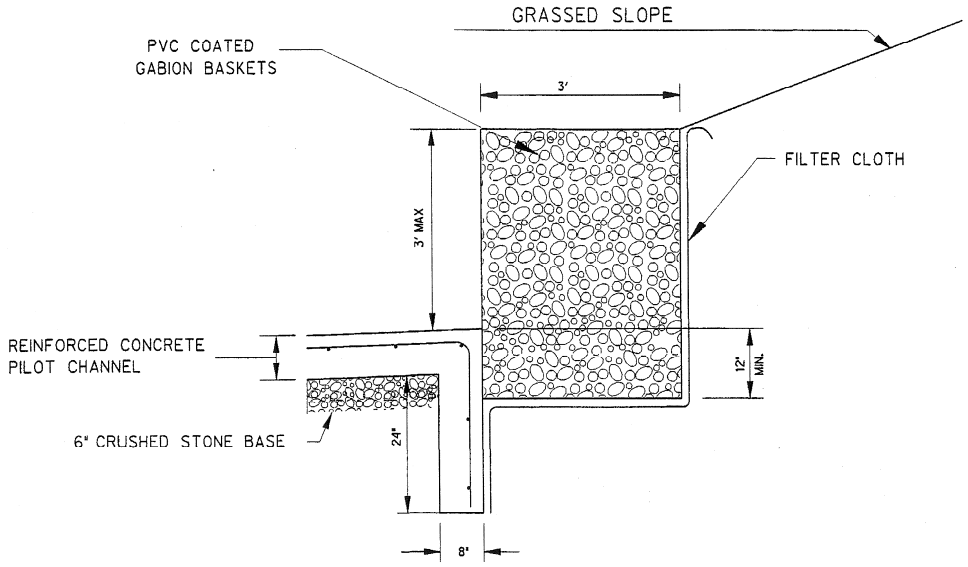
1. RECOMMENDED MAXIMUM SLOPE IS 2(H):1(V). SLOPES MAY BE STEEPENED TO 1.5(H):1(V) IN TRANSITIONS TO OR FROM NATURAL, UNALTERED STREAM BANKS.

2. HEADERS OF AT LEAST 3' IN DEPTH AND CAREFULLY DESIGNED TRANSITIONS SHOULD BE CONSTRUCTED AT UPSTREAM AND DOWNSTREAM ENDS OF GABION MATTRESS SLOPE PROTECTION.

3. GABION BASKETS SUBJECT TO FREQUENT INUNDATION SHALL BE PVC COATED.

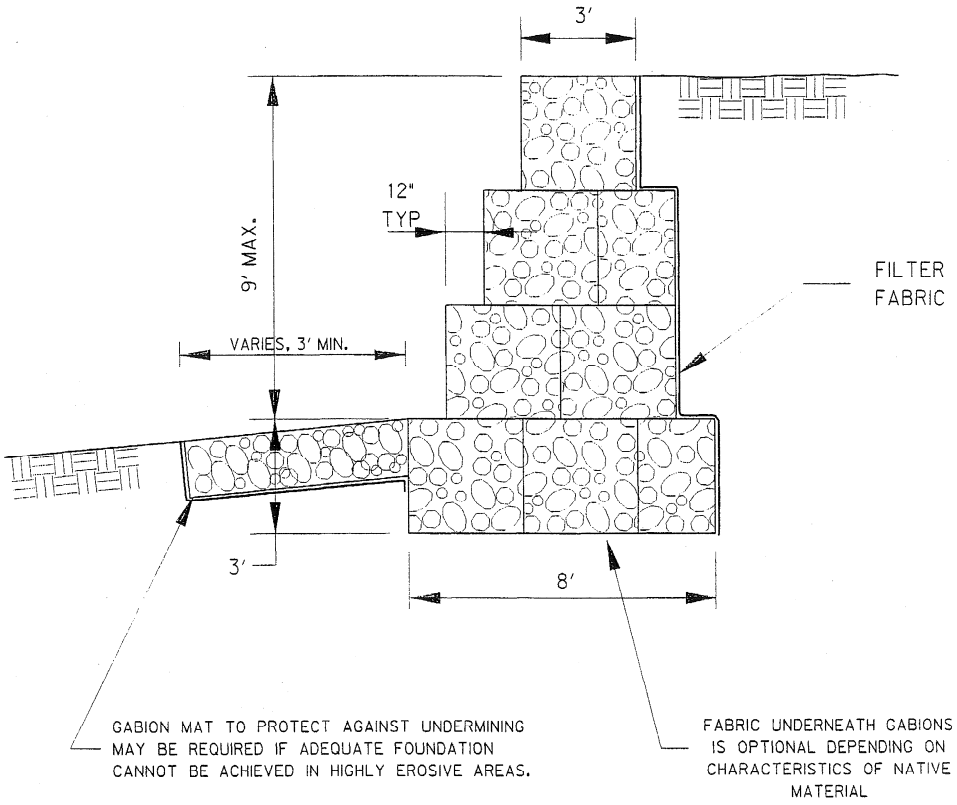
(HALFF - 1990)

McKINNEY	city of plano	GABION MATTRESS SLOPE PROTECTION	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 3



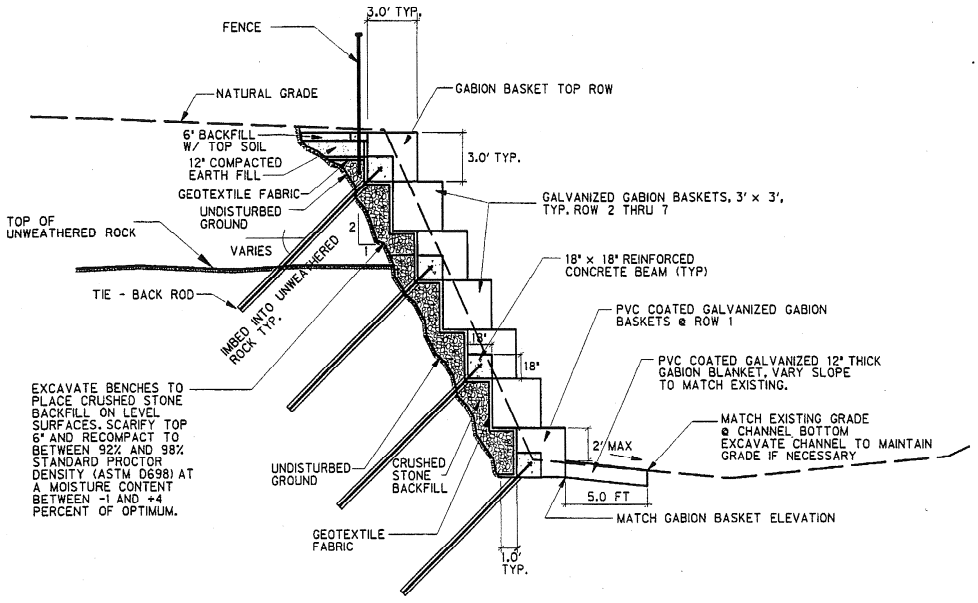
(HALFF, 1996)

McKinney	city of plano	**GABION WALL @ CONCRETE PILOT CHANNEL**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 4



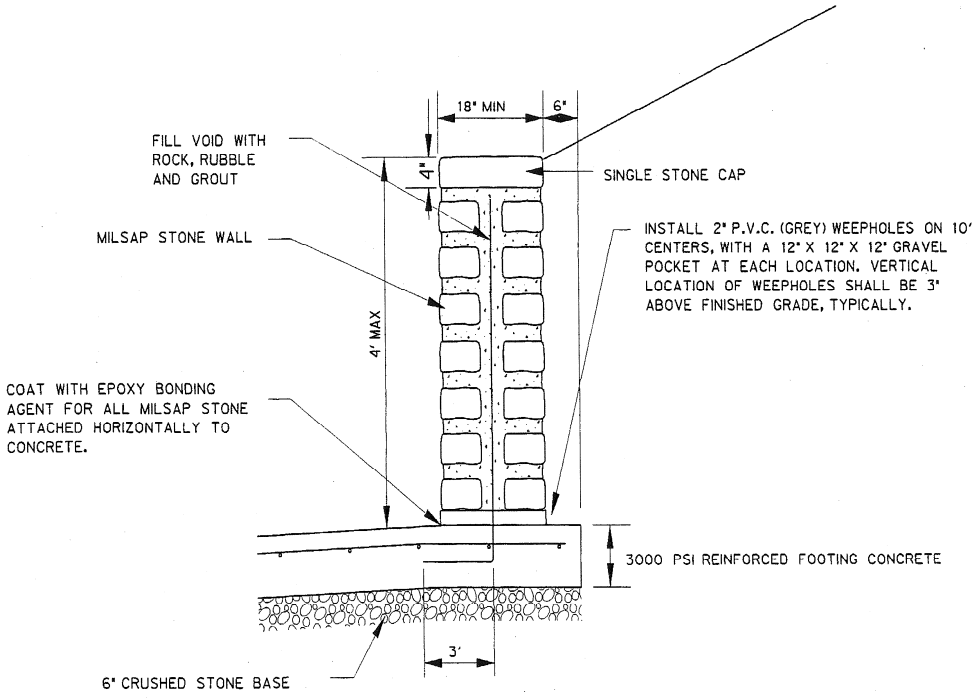
(HALFF, 1996)

McKINNEY	city of plano	**TYPICAL GABION WALL DETAIL**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 5



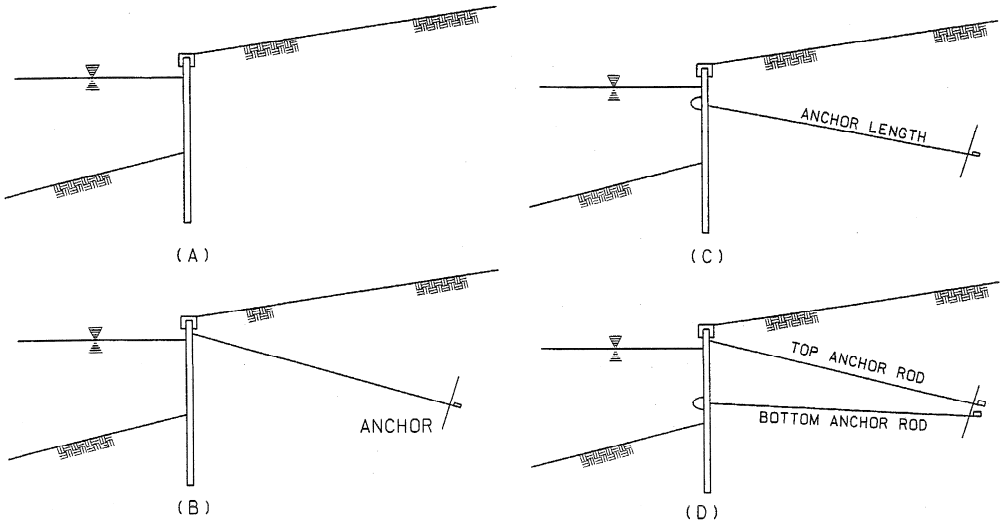
(HALFF, 1997)

McKINNEY	city of plano	**MULTI- TIER GABION TIE-BACK WALL**	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN	GARLAND	Halff Associates	PLATE 6



(HALFF, 1996)

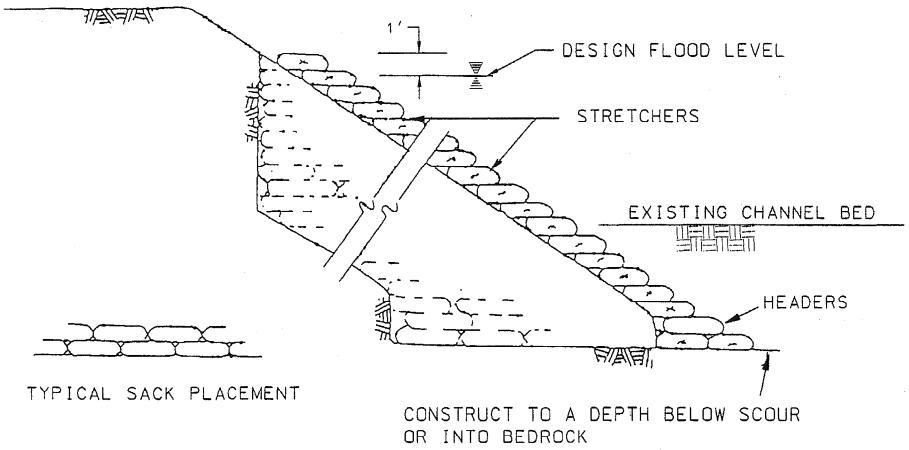
McKinney / city of plano		MILSAP STONE WALL DETAIL	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN / GARLAND			Halff Associates / PLATE 7



ANCHORAGE SCHEMES FOR A SHEETPILE BULKHEAD.

(FHWA, 1991)

McKINNEY	city of plano	BULKHEAD	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 8



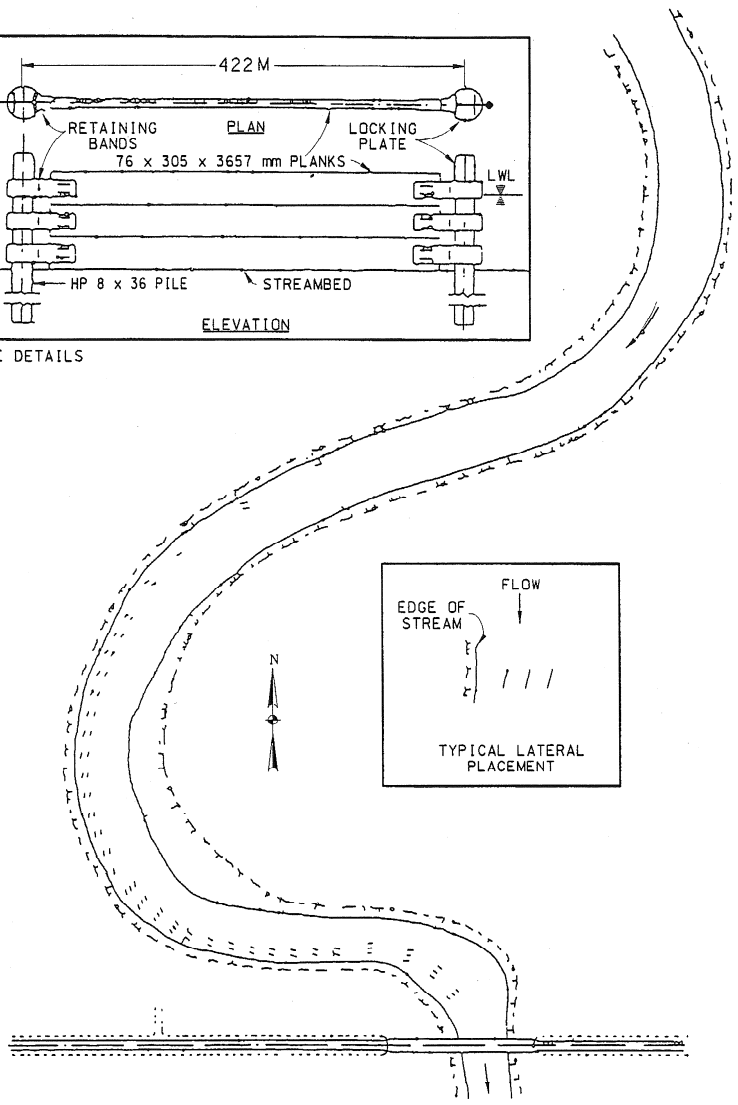
NOTES:

1. SACKS SHOULD CONTAIN 15% CEMENT (MINIMUM) BY WIEGHT THOROUGHLY MIXED WITH THE SAND.
2. MAXIMUM REVETMENT SLOPE NOT TO EXCEED 1(H) TO 1(V).
3. DESIGN SHOULD INCLUDE WEEPHOLES.
4. DESIGN SHOULD INCLUDE TOE PROTECTION.
5. DESIGN SHOULD INCLUDE HEADERS AND APPROPRIATE TRANSITIONS AT UPSTREAM AND DOWNSTREAM ENDS OF REVETMENT.
6. USE ONLY IN AREAS OF LOW VELOCITY AND ERODIBILITY.

(FHWA, 1991)

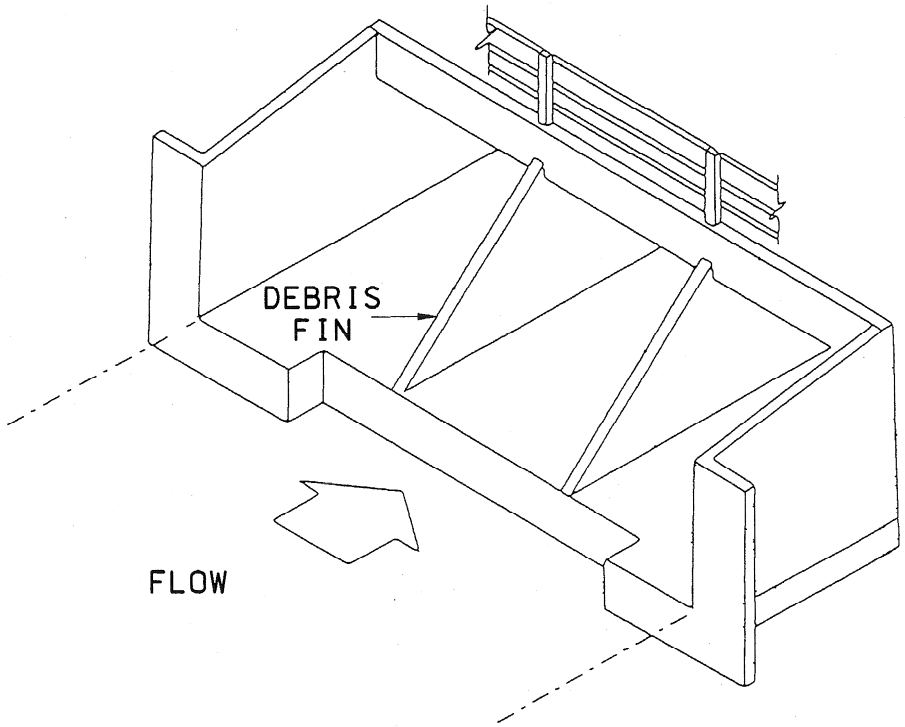
McKINNEY	city of plano	**TYPICAL SAND CEMENT BAG REVETMENT**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 9

VANE DETAILS



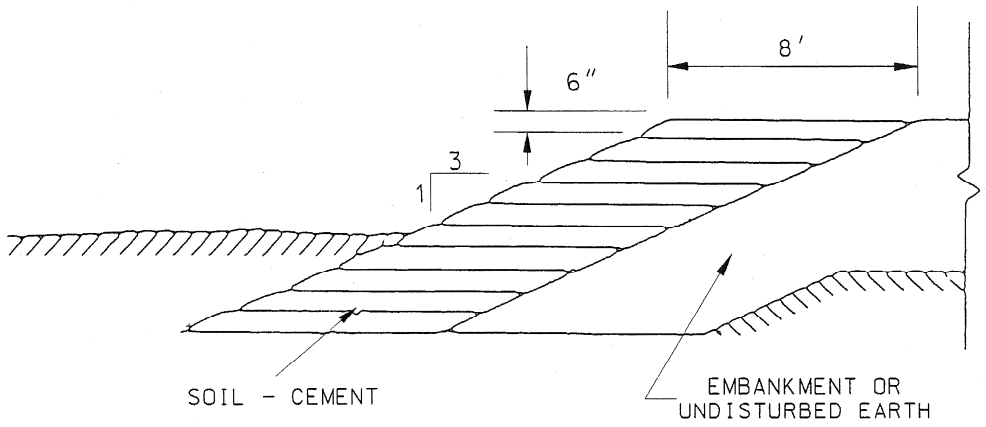
(FHWA - 1991)

McKinney	city of plano	IOWA VANE SYSTEM	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 10A



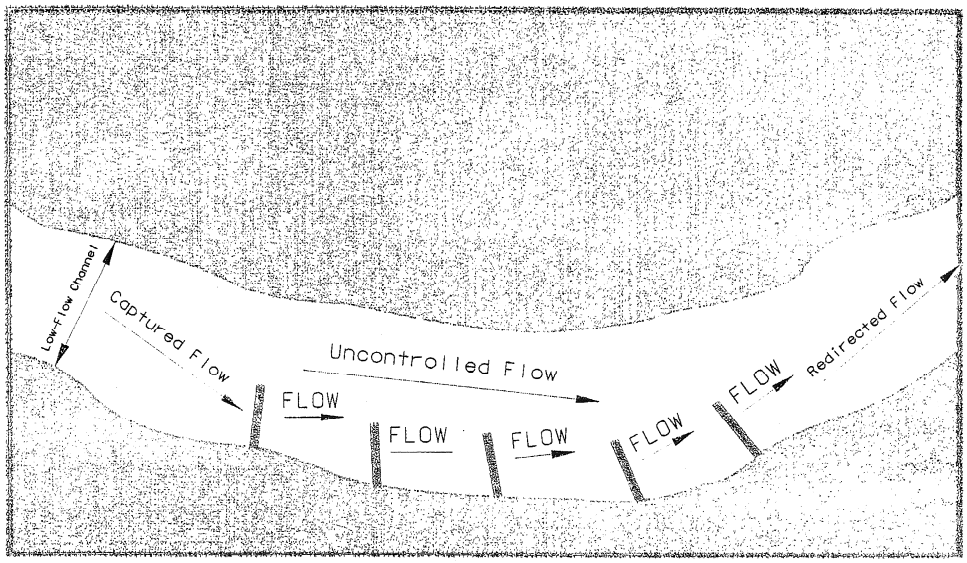
(AUSTIN, 1996)

McKinney	city of plano	CONCEPTUAL LAYOUT OF DEBRIS FINS	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates ENGINEERS : ARCHITECTS : SCIENTISTS : PLANNERS : SURVEYORS	PLATE 10B



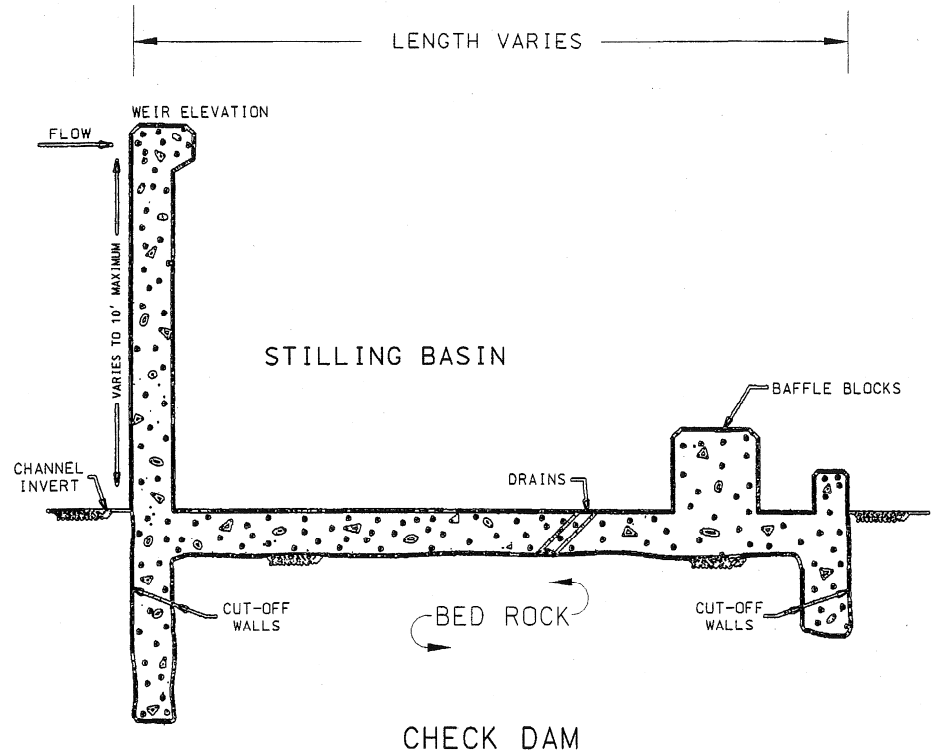
(FHWA - 1991)

	city of plano	SOIL CEMENT BANK PROTECTION	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 11



(EROSION CONTROL, 1996)

McKINNEY	city of plano	BENDWAY WEIR LAYOUT	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 11A



CHECK DAM
TYPICAL SECTION

N.T.S.

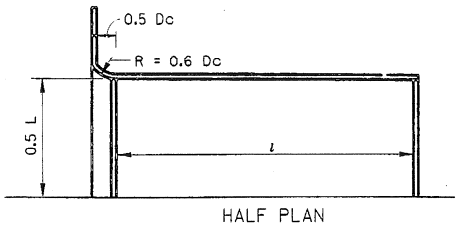
NOTES:

1. WEIR HEIGHTS SHOULD BE SET AT AN ELEVATION THAT PROVIDES MAXIMUM VELOCITY REDUCTION UPSTREAM BUT DOES NOT INCREASE REGULATORY FLOOD PLAIN DESIGN ELEVATION.

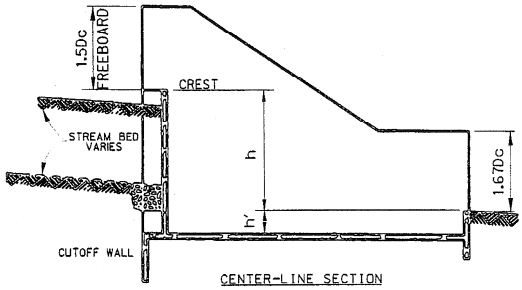
2. STILLING BASIN DESIGN GUIDANCE CAN BE FOUND IN THE USBR PUBLICATION "HYDRAULIC DESIGN OF STILLING BASINS AND ENERGY DISSIPATORS"

(HALFF - 1990)

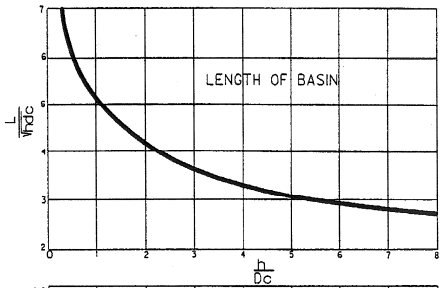
McKINNEY	city of plano	**CHANNEL CHECK DAM**	**STREAM BANK STABILIZATION MANUAL**	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 12

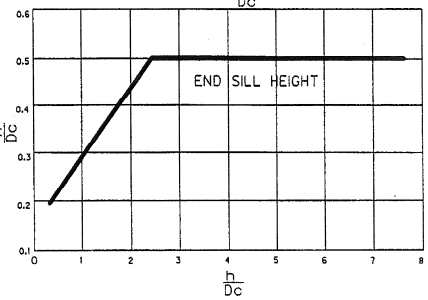


HALF PLAN



CENTER-LINE SECTION





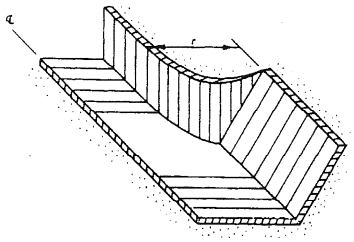
C = WEIR DISCHARGE = 3.0
Dc = CRITICAL DEPTH OVER CREST
h = HEIGHT OF DROP
h' = HEIGHT OF END SILL
H = HEAD ON WEIR = 3/2(Dc)

l = LENGTH OF BASIN
L = LENGTH OF WEIR CREST
Q = DISCHARGE, CLH*3/2

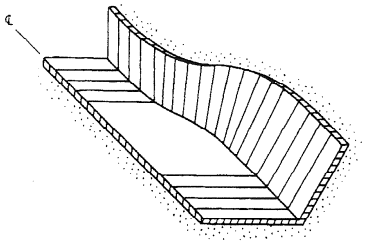
DETAILS AND DESIGN CHART FOR TYPICAL DROP STRUCTURE

(USACE -1991)

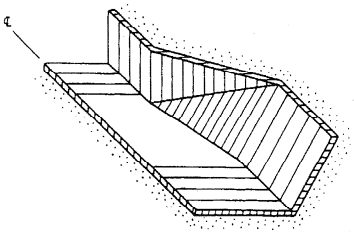
McKINNEY	city of plano	**DROP STRUCTURE**	**STREAM BANK STABILIZATION MANUAL**	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 13



CYLINDRICAL QUADRANT



WARPED



WEDGE

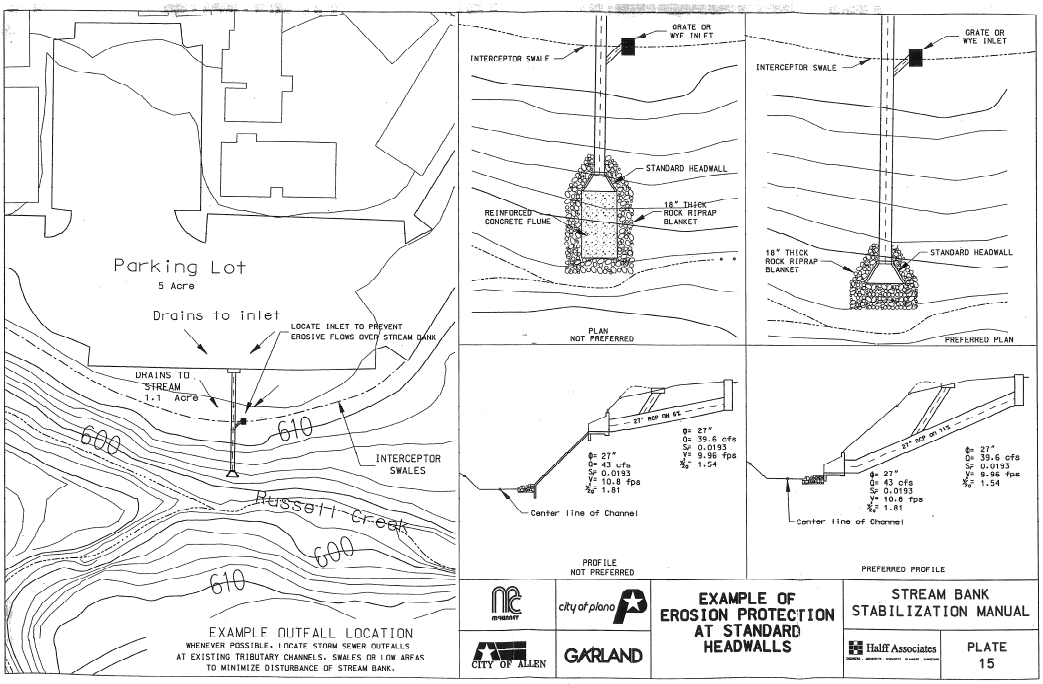
High Velocity (Supercritical)

Recommended Convergence and Divergence Transition Rates

Mean Channel Velocity fps	Wall Flare for Each Wall (Horizontal to Longitudinal)
10-15	1:10
15-30	1:15
30-40	1:20

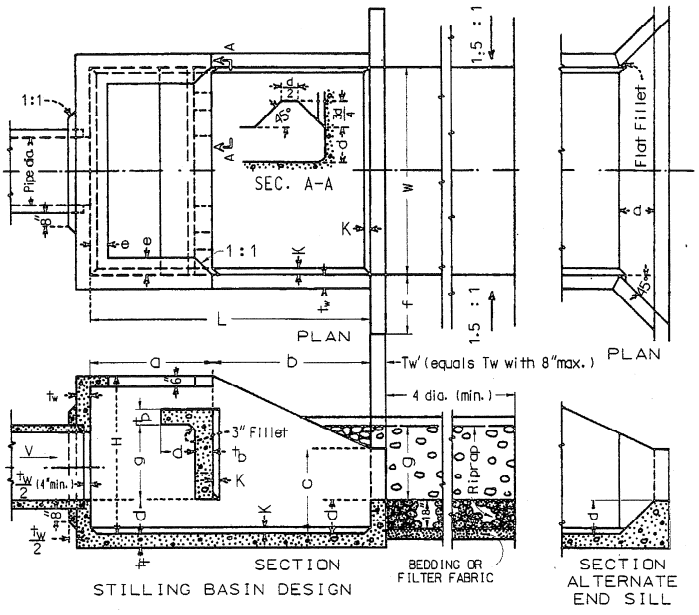
USACE, 1991

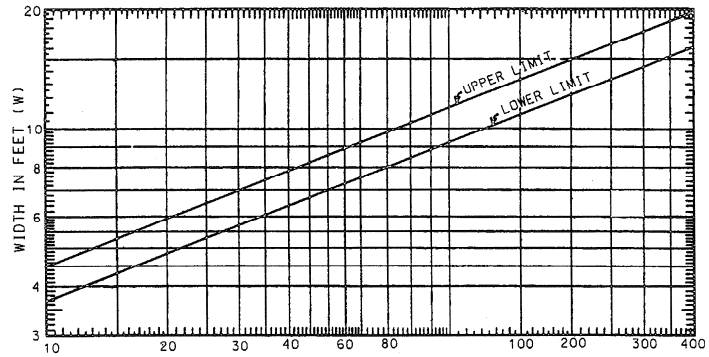
McKINNEY	city of plano	CHANNEL TRANSITION TYPES	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN	GARLAND		Halff Associates — PLATE 14



		EXAMPLE OF EROSION PROTECTION AT STANDARD HEADWALLS	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN	GARLAND		Halff Associates / PLATE 15

STILLING BASIN FOR PIPE OR OPEN CHANNEL OUTLETS





Impact type energy dissipator (Basin VI). (PETERKA, 1984)

McKINNEY / CITY OF ALLEN	city of plano / GARLAND	**IMPACT – TYPE STORM SEWER OUTFALL BASIN**	STREAM BANK STABILIZATION MANUAL Halff Associates PLATE 16

Suggested pipe size[1]		Max Discharge Q	Feet and inches											Inches					
Dia In.	Area (sq.ft.)		W	N	L	a	b	c	d	c	f	g	t_w	t_f	t_b	l_p	K	Suggested riprap sc. (18)[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	
18	1.77	21	5-6	4-3	7-4	3-5	4-1	2-4	0-11	0-6	1-6	2-1	6	6 1/2	6	6	3	4.0
24	3.14	38	6-9	5-3	9-0	3-11	5-1	2-10	1-2	0-6	2-0	2-6	6	6 1/2	6	6	3	7.0
30	4.91	59	8-0	6-3	10-8	4-7	6-1	3-4	1-4	0-8	2-6	3-0	6	6 1/2	7	7	3	8.5
36	7.07	85	9-3	7-3	12-4	5-5	7-1	3-10	1-7	0-8	3-0	3-6	7	7 1/2	8	8	3	9.0
42	9.62	115	10-6	8-0	14-0	6-0	8-0	4-5	1-9	0-10	3-0	3-11	8	8 1/2	9	8	4	9.5
48	12.57	151	11-9	9-0	15-8	6-9	8-11	4-11	2-0	0-10	3-0	4-5	9	9 1/2	10	8	4	10.5
54	15.90	191	13-0	9-9	17-4	7-4	10-0	5-5	2-2	1-0	3-0	4-11	10	10 1/2	10	8	4	12.0
60	19.65	236	14-3	10-9	19-0	8-0	11-0	5-11	2-5	1-0	3-0	5-4	11	11 1/2	11	8	6	13.0
72	28.27	339	16-6	12-3	22-0	9-3	12-9	6-11	2-9	1-3	3-0	6-2	12	12 1/2	12	8	6	14.0

[1] Suggested pipe will run full when velocity is 12 feet per second or half full when velocity is 24 feet per second. Size may be modified for other velocities by Q=AV, but relation between Q and basin dimensions shown must be maintained.

[2] For discharges less than 21 second-feet, obtain basin width from curve of Fig. VI-13B. Other dimensions proportional to W:H=3W/4, L=4W/3, d=W/6, etc.

[3] Determination of riprap size explained in paragraph VI.A.2.

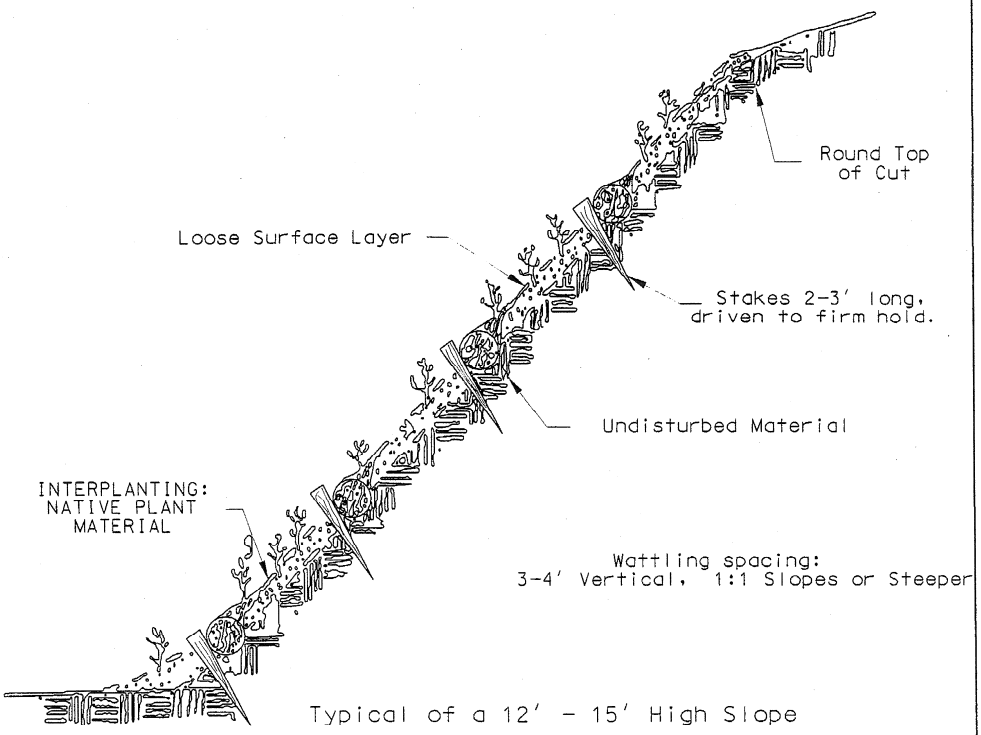
McKINNEY | city of plano | CITY OF ALLEN | GARLAND

STILLING BASIN OUTLET DIMENSIONS

STREAM BANK STABILIZATION MANUAL

Halff Associates

PLATE 17

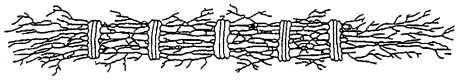


Typical of a 12' - 15' High Slope

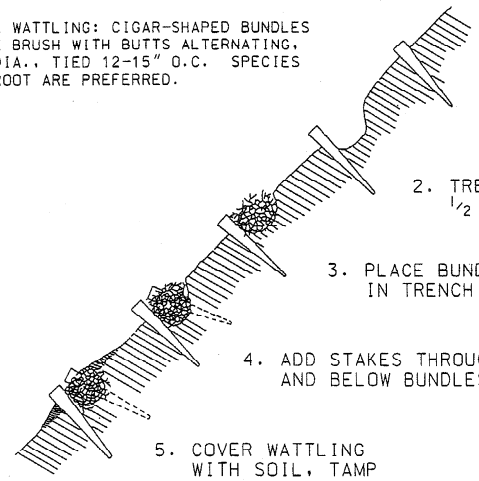
Slope or Cut Treatment - Wattling
Use for loose surface soils with sheet, rill or small gully erosion

(LEISER IN IECA, 1995)

McKINNEY	city of plano	**CONTOUR WATTLING FOR SLOPE PROTECTION**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 18



PREPARE WATTLING: CIGAR-SHAPED BUNDLES OF LIVE BRUSH WITH BUTTS ALTERNATING, 8-10" DIA., TIED 12-15" O.C. SPECIES WHICH ROOT ARE PREFERRED.



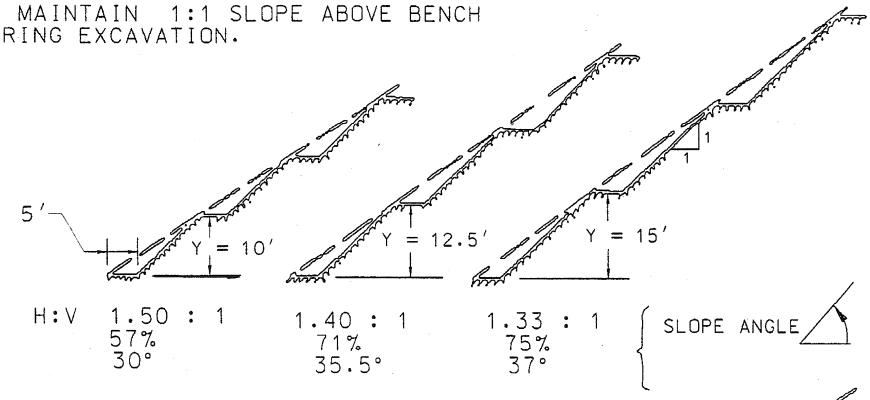
NOTE: WORK STARTS AT BOTTOM OF CUT OR FILL AND PROCEEDS FROM STEP 1 THROUGH STEP 5

PREPARATION OF WATTLING AND INSTALLATION PROCEDURE. SEQUENCE OF OPERATIONS IS SHOWN SCHEMATICALLY IN THE DIAGRAM.

(GRAY, LEISER - 1982)

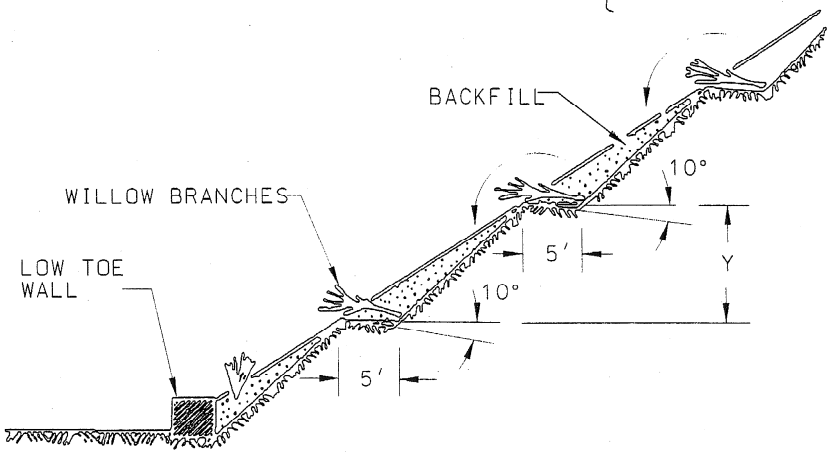
McKINNEY	city of plano	**CONTOUR WATTLING PROCEDURE**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 19

REQUIRED VERTICAL BENCH SPACING (Y)
TO MAINTAIN 1:1 SLOPE ABOVE BENCH
DURING EXCAVATION.



H:V	1.50 : 1	1.40 : 1	1.33 : 1
	57%	71%	75%
	30°	35.5°	37°

SLOPE ANGLE

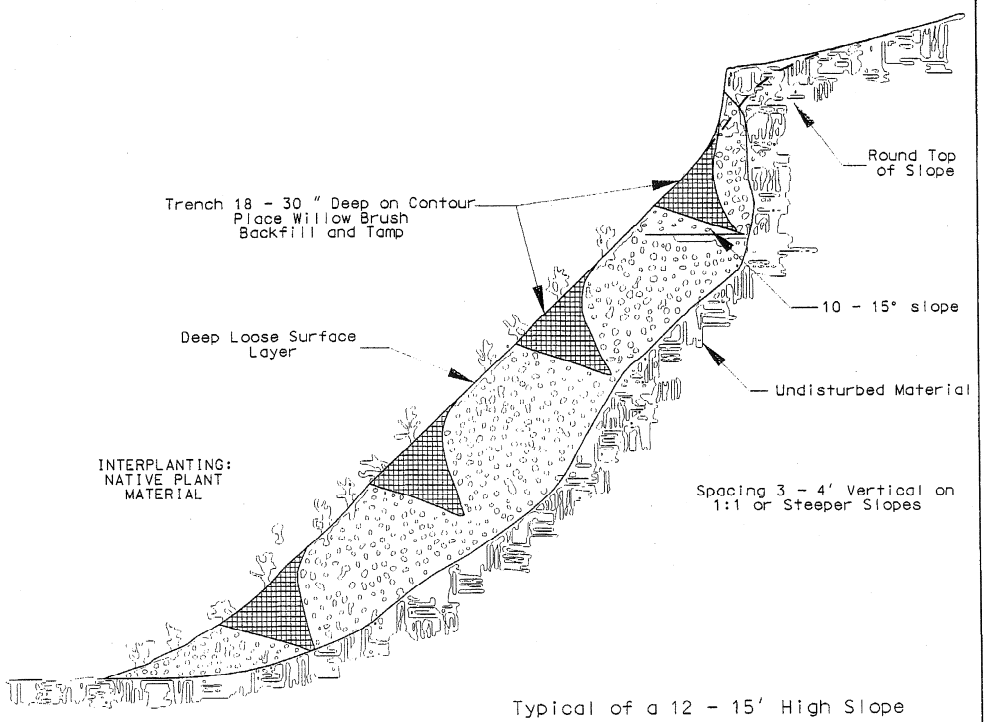


CONTOUR BRUSH LAYERING

SCHEMATIC DIAGRAM OF CONTOUR BRUSH LAYERING, SHOWING SEQUENCE OF OPERATIONS AND VERTICAL SPACING BETWEEN BENCHES FOR DIFFERENT SLOPE ANGLES.

(GRAY, LEISER - 1982)

McKINNEY	city of plano	**CONTOUR - BRUSH LAYERING**	**STREAM BANK STABILIZATION MANUAL**	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 20

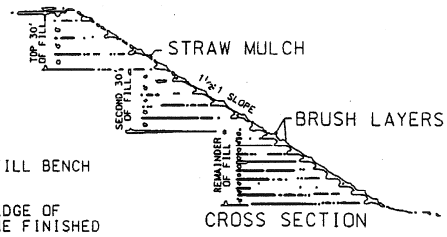


Typical of a 12 - 15' High Slope

Slope or Cut Treatment - Brush Layering
Use for deep, loose surface soils, deep gullies, seep areas, etc.

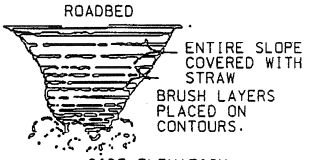
(LEISER)

McKINNEY / city of plano		BRUSH LAYER DETAILS	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN / GARLAND			Halff Associates / PLATE 21

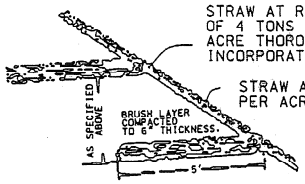


CROSS SECTION

1. AT REQUIRED FILL ELEVATION SMOOTH EDGE OF FILL BENCH ON CONTOUR TO WIDTH OF MAT.
2. LAY BRUSH, LEAFY ENDS OUTWARD, FLUSH WITH EDGE OF FILL TO SUCH DEPTH THAT AFTER COMPACTION THE FINISHED MAT WILL BE APPROXIMATELY 6" THICK.
3. PLACE ADDITIONAL FILL MATERIAL ON TOP OF BRUSH AND COMPACT AS FOR REMAINDER OF FILL.
4. AT CONVENIENT STAGES OF FILL CONSTRUCTION SPREAD STRAW EVENLY OVER SLOPE AT RATE OF 4 TONS PER ACRE. ROLL WITH A SHEEPSFOOT ROLLER OPERATED VERTICAL TO THE PLANE OF THE SLOPE UNTIL STRAW IS THOROUGHLY INCORPORATED INTO THE SOIL. AT LEAST 4 ROUND TRIPS OF THE ROLLER WILL BE REQUIRED.
5. SOW EVENLY OVER THE SLOPE A MIXTURE OF 50% BARLEY. 45% RYE GRAIN AND 5% ALFALFA SEED BY WEIGHT AT RATE OF 200 LBS. PER ACRE.
6. SPREAD SECOND APPLICATION OF STRAW AT RATE OF 4 TONS PER ACRE. REPEAT ROLLING OPERATION UNTIL STRAW IS FIRMLY IMBEDDED IN SOIL.
7. PLANT LIVE CUTTINGS OF HARDY VARIETIES OF PLANTS INDIGENOUS TO THE LOCALITY, BETWEEN MATS FOR PERMANENT VEGETATIVE PROTECTION.



SIDE ELEVATION

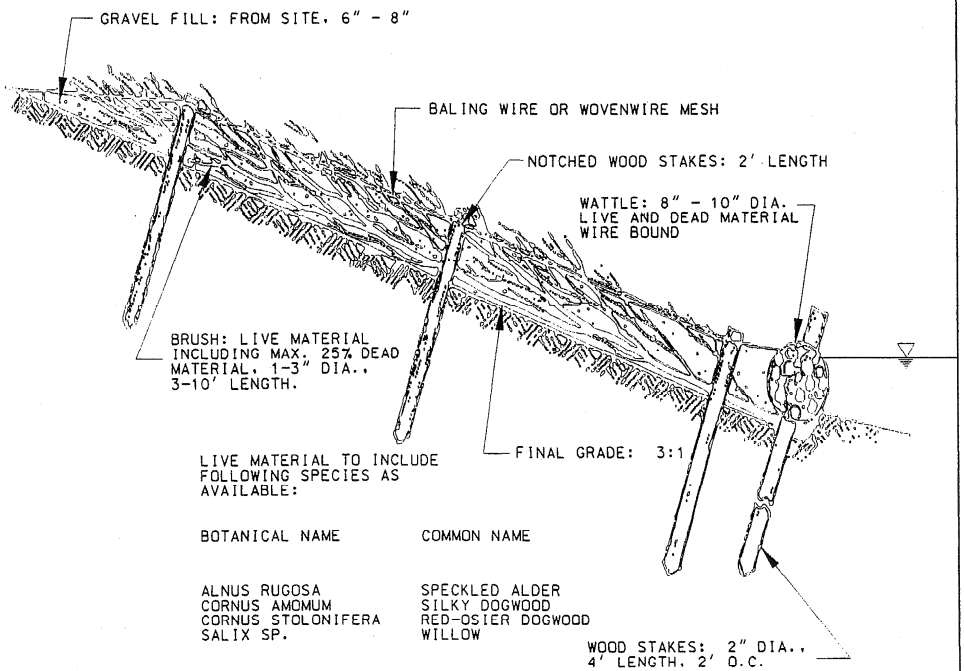


* THE TOTAL QUANTITY OF STRAW APPLIED PER ACRE WILL VARY ACCORDING TO THE CHARACTER OF THE FILL MATERIAL. LOOSE, GRANULAR, DISINTEGRATED ROCKY SOIL USUALLY REQUIRES MORE STRWA PER ACRE FOR AN ADEQUATE COVER (6 TO 10 TONS PER ACRE) THAN DOES SOIL OF A LOAMY CHARACTER (4 TO 8 TONS PER ACRE).

SPECIFICATIONS FOR FILL SLOPE STABILIZATION USING BRUSH-LAYER METHOD. (FROM BOWERS, 1950).

(BOWERS, 1950)

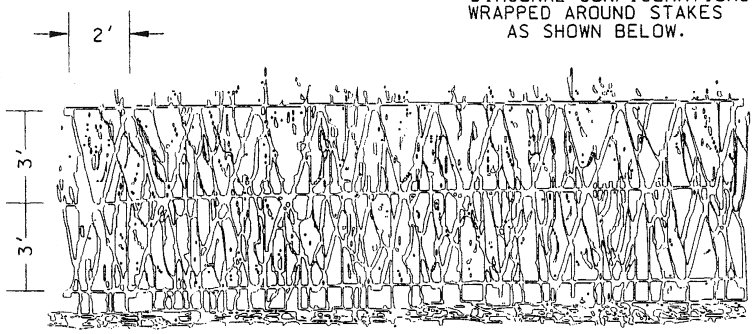
McKINNEY	city of plano	**BRUSH LAYER METHOD FOR FILL SLOPE STABILIZATION DURING CONSTRUCTION**	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN	GARLAND		Halff Associates — PLATE 22



(BESTMANN - 1992)

McKinney	city of plano	BRUSH MATTRESS	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 23

LASHED WITH WIRE
IN PARALLEL AND
DIAGONAL CONFIGURATIONS,
WRAPPED AROUND STAKES
AS SHOWN BELOW.

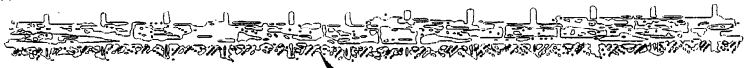


PLAN

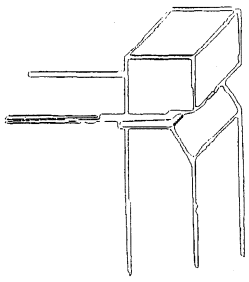
DIRECTION OF FLOW

OVERLAPPED SHINGLE STYLE
UPSTREAM WATTLE ON TOP.

LONGITUDINAL
SECTION



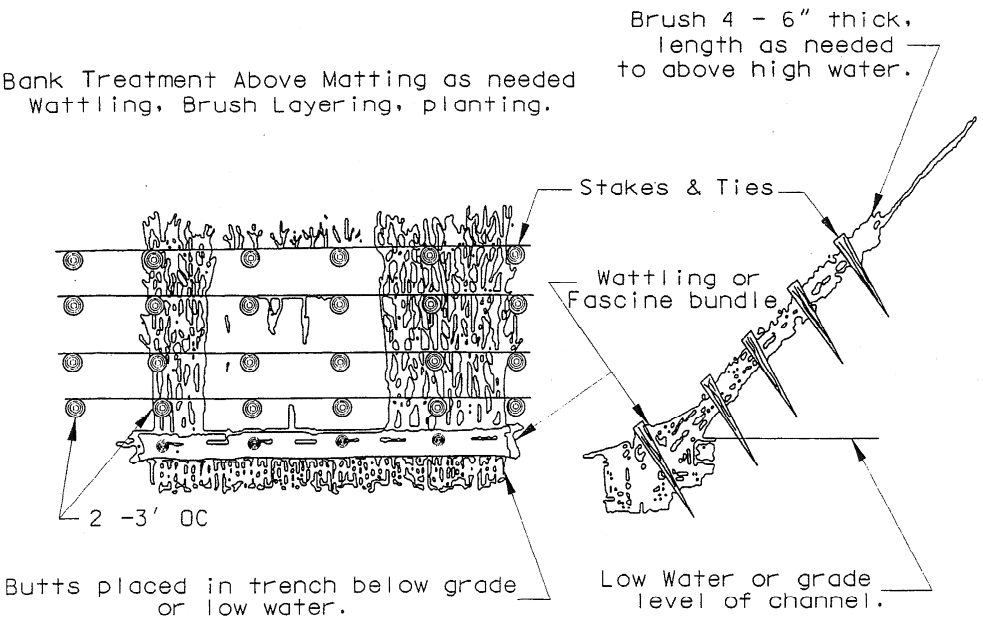
STAKED INSIDE END WIRE
BINDINGS OF UPPER AND
LOWER WATTLES.



WIRE WRAPPED TWICE
AND FIRMLY SEATED
IN NOTCH.

(BESTMANN - 1992)

McKINNEY	city of plano	**BRUSH MATTRESS**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 24

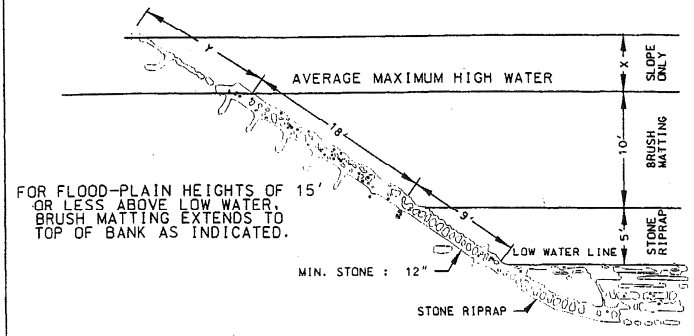


Diagonal ties may be required.

(IECA - 1995)

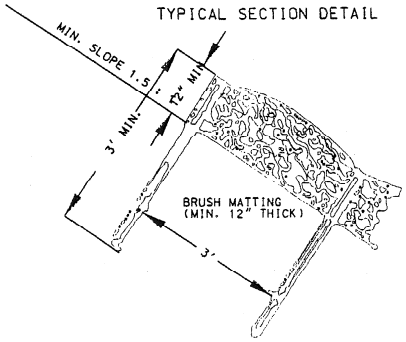
McKinney	city of plano	**CHANNEL PROTECTION BRUSH MATTING**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 25

TYPICAL SECTION DETAIL

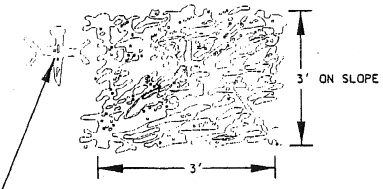


FOR FLOOD-PLAIN HEIGHTS OF 15' OR LESS ABOVE LOW WATER, BRUSH MATTING EXTENDS TO TOP OF BANK AS INDICATED.

TYPICAL SECTION DETAIL



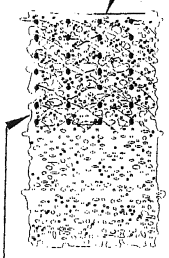
ELEVATION DETAIL



STEEL SPIKE MAY BE USED TO TWIST WIRES TIGHT

TYPICAL ELEVATION

STAKES DRIVEN ON 3' CENTERS EACH WAY, WITH NO. 9 GALV. WIRE OVER BRUSH AS INDICATED.



DIRECTION OF CURRENT

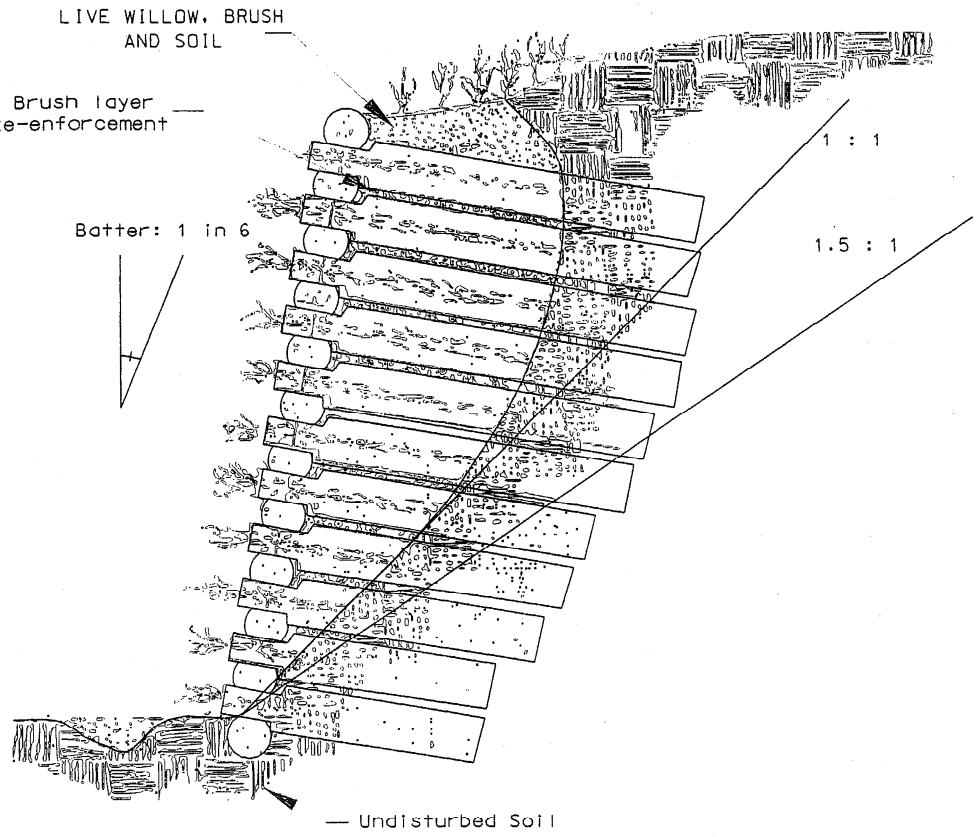
WILLOW OR OLDER BRUSH LAID SHINGLE FASHION WORKING UPSTREAM.

BUTTS PLACED UPSTREAM AND THE AXIS OF THE BRUSH INCLINED APPROX. 30° AS INDICATED.

(EDMINSTER ET AL - 1949)

McKINNEY	city of plano	**CONSTRUCTION PROCEDURE AND DETAILS FOR BRUSH MATTING.**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 26

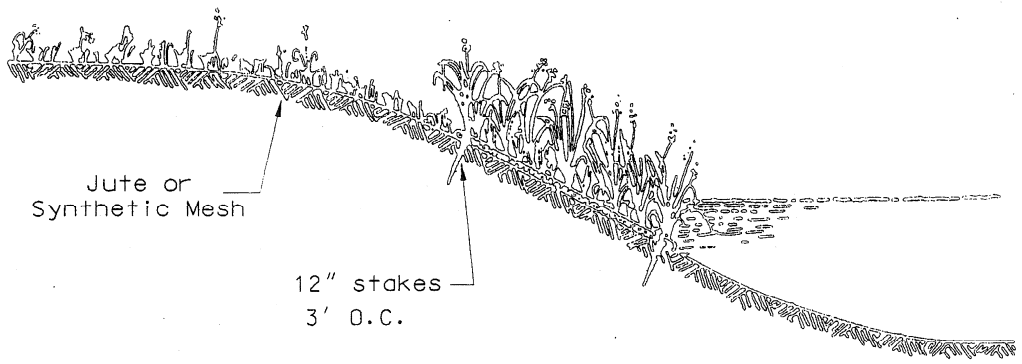
Log crib wall with brush layer re-enforcement



LOG CRIB SHALL BE CONSTRUCTED OF TREATED LUMBER. RAILROAD TIES ARE NOT ALLOWED.

(IECA - 1995)

McKinney	city of plano	LOG CRIB WALL	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 27

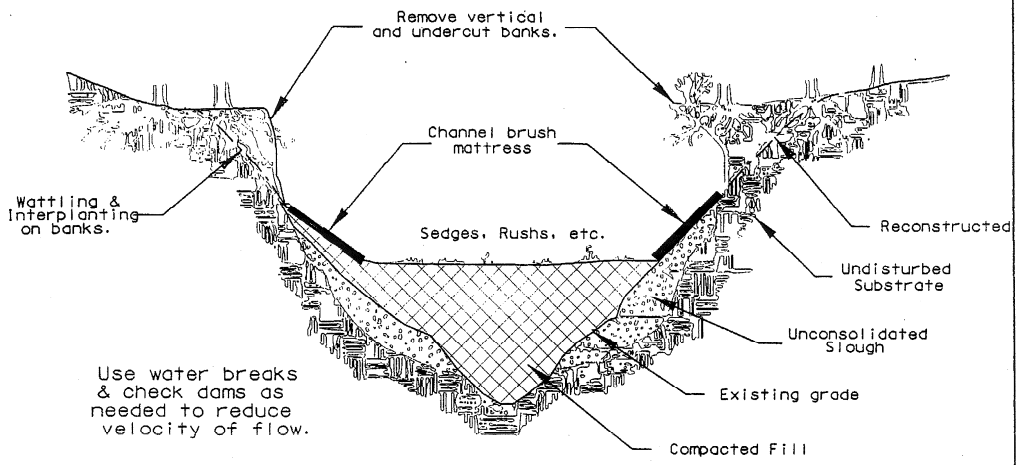


Pre-Vegetated
100% Coir Fiber Blanket
2" Trunk, 16.6 ' long, 39" wide

(LEISER)

McKINNEY	city of plano	**TYPE III- PRE-VEGETATED BLANKET BANK STABILIZATION**	STREAM BANK STABILIZATION MANUAL	
CITY OF ALLEN	GARLAND		Halff Associates	PLATE 28

GULLIED CHANNEL RECONSTRUCTION
SEE WATTLING, BRUSH LAYERING,
BRUSH MATTRESS SHEETS FOR DETAILS



(IECA - 1995)

	city of plano	GULLIED CHANNEL RECONSTRUCTION	STREAM BANK STABILIZATION MANUAL
CITY OF ALLEN	GARLAND		Halff Associates / PLATE 29

APPENDIX B

TxDOT SLOPE PROTECTION & FLEXIBLE
CHANNEL LINER INFORMATION

(from www.dot.state.tx.us/insdtdot/orgchart/cmd/erosion/sect11.htm)

SECTION 11 - APPROVED PRODUCT LISTS for TxDOT

The Texas Department of Transportation - Texas Transportation Institute

APPROVED PRODUCT LIST

ITEM 169 "SOIL RETENTION BLANKET"

Effective Date: April 1, 1998

The Contractor has the option of utilizing the following approved products in accordance with the Class and Type as specified on the plans. Direct all questions to the Maintenance Division, Vegetation Management Section, 125 E. 11th Street, Austin, TX 78701-2483, (512)416-3091.

CLASS 1 "SLOPE PROTECTION"

Type A - Slopes 1:3 or Flatter - Clay Soils:	
Airtrol	Landlok 407GT
Anti-wash/Geojute	Landlok FRS 3112
BioD-Mesh™ 60	Landlok TRM 435
BonTerra® EcoNet™ ENS2	Miramat TM8
BonTerra® EcoNet™ ENCS2	North American Green S150
BonTerra S1	North American Green S75
BonTerra S2	North American Green SC150
BonTerra SFB12	Poplar Erosion Blanket
Carthage Mills Veg Net	Soil Guard
C-Jute	Soil Saver
Contech Standard	SuperGro
Contech Standard Plus	Tensar Erosion Blanket TB 1000
Curlex I	Terra-Control®
Curlex™ -LT	TerraJute
EcoAegis™	verdyol Ero-Mat
ECS Excelsior Blanket Standard	verdyol Excelsior High Velocity
ECS High Velocity Straw Mat	verdyol Excelsior Standard

	verdyol Excelsior Standard
ECS Straw Blanket Standard	Webmat 280
Green Triangle Regular	Xcel Regular
Green Triangle Superior	Xcel Superior
Greenstreak Pec-Mat	

Type B - 1:3 or Flatter - Sandy Soils:	
BonTerra S1	Carthage Mills Veg Net
BonTerra S2	Miramat 1000
BonTerra CS2	Miramat TM8
BonTerra® EcoNet™ ENS2	North American Green S75
C-Jute	North American Green S150
Contech Standard	North American Green SC150
Contech Standard Plus	Poplar Erosion Blanket
Curlex LT	Soil Guard
ECS Straw Blanket Standard	Terra-Control®
ECS Excelsior Blanket Standard	TerraJute
Geojute Plus 1	verdyol Ero-Mat
Green Triangle Regular	verdyol Excelsior Standard
Green Triangle Superior	Xcel Regular
Landlok FRS 3112	Xcel Superior
Landlok 407GT	

Type C - Slopes Steeper than 1:3 - Clay Soils:	
Airtrol	
Anti-Wash/Geojute	Miramat TM8
BonTerra® EcoNet™ ENCS2	North American Green S150
BonTerra S2	North American Green S75
BonTerra SFB12	North American Green SC150
Carthage Mills Veg Net	Poplar Erosion Blanket
C-Jute	Soil Guard
Contech Standard Plus	Soil Saver
Curlex I	SuperGro

ECS High Velocity Straw Mat	Tensar Erosion Blanket TB1000
Green Triangle Superior	TerraJute
Greenstreak Pec-Mat	verdyol Excelsior High Velocity
Landlok 407GT	Webmat 280
Landlok FRS 3112	Xcel Superior
Landlok™ TRM 435	

Type D - Slopes Steeper than 1:3 - Sandy Soils:	
BonTerra S2	Landlok FRS 3112
BonTerra CS2	Miramat 1000
C-Jute	Miramat TM8
Contech Standard Plus	North American Green S150
Curlex I	North American Green SC150
Geojute Plus 1	Soil Guard
Green Triangle Superior	TerraJute
Landlok 407GT	Xcel Superior
Carghage Mills Veg Net	

CLASS 2 - "FLEXIBLE CHANNEL LINER"

Type E - Shear Stress Range 0 - 96 Pascal (0 - 2 Pounds Per Square Foot):	
BonTerra® C2	Koirmat™ 700
BonTerra® SFB™	Landlok TRM 450
BonTerra SFB12	Miramat TM8
Contech TRM C-45	North American Green C350 Three Phase
Curlex® -PCLE	North American Green S150
Earth-Lock	Pyramat®
ECS High Impact Excelsior	Tensar Erosion Mat TM3000
Enkamat 7018	Tensar Erosion Blanket TB1000
Enkamat 7020	Webmat 280
Greenstreak Pec-Mat	

Type F - Shear Stress Range 0 - 192 Pascal (0 - 4 Pounds Per Square Foot):	
BonTerra® C2	Koirmat™ 700

BonTerra® SFB™	Landlok TRM 450
BonTerra SFB12	Miramat TM8
Curlex® -PCLE	North American Green C350 Three Phase
Contech TRM C-45	North American Green S150
Earth-Lock	Pyramat®
ECS High Impact Excelsior	Tensar Erosion Blanket TB1000
Enkamat 7018	Tensar Erosion Blanket TM3000
Greenstreak Pec-Mat	Webmat 280

Type G - Shear Stress Range 0 - 287 Pascal (0 - 6 Pounds Per Square Foot):	
BonTerra® SFB™	Landlok TRM 450
BonTerra SFB12	North American Green C350 Three Phase
Contech TRM C-45	Pyramat®
Earth-Lock	Tensar Erosion Mat TM3000
Enkamat 7018	Tensar Erosion Blanket TB1000
Greenstreak Pec-Mat	Webmat 280
Koirmat™ 700	

Type H - Shear Stress Range 0 - 383 Pascal (0 - 8 Pounds Per Square Foot):	
BonTerra SFB12	Pyramat®
Contech TRM C-45	Tensar Erosion Blanket TB1000
Landlok TRM 450	Tensar Erosion Mat TM 3000
North American Green C350 Three Phase	

APPROVED PRODUCT LIST

ITEM 164 "SEEDING FOR EROSION CONTROL"

Cellulose Fiber Mulches

Clay or Tight Soils:
American Fiber Mulch
American Fiber Mulch (with Hydro-Stick)
Conwed Hydro Mulch
Enviro-Gro
Excel Fibermulch II (with Exact-Tac)

Excel Fibermulch II (with Exact-Tac)
Pro Mat
Pro Mat (with RMBplus)
Pro Mat XL
Second Nature Regenerated Wood Fiber
Silva Fiber Plus
Sandy or Loose Soils:
American Fiber Mulch
American Fiber Mulch (with Hydro-Stick)
American Fiber Mulch with Stick Plus
Conwed Hydro Mulch
Enviro-Gro
Excel Fibermulch II (with Exact-Tac)
Pro Mat
Pro Mat (with RMBplus)
Pro Mat XL
Second Nature Regenerated Wood Fiber

SECTION 1 | SECTION 2 | SECTION 3 | SECTION 4 | SECTION 5 | SECTION 6 | SECTION 7 | SECTION 8 | SECTION 9 | SECTION 10 | SECTION 11

Maintenance Division Page | Doing Business with TxDOT Page

Updated April 06, 1998

APPENDIX C

SAMPLE APPLICATIONS

- STREAM BANK STABILIZATION PLAN
- RANKING

SAMPLE APPLICATIONS

Stream Bank Stabilization Plan

A residential developer wants to subdivide 9 acres along Erskine Creek in Collin County shown in Figure C-1. Analyze the project for stream bank stability issues.

Stream Assessment

Site Reconnaissance. A site visit was conducted by the hydraulic engineer, environmental scientist and geologist to evaluate hydrologic, geomorphic and environmental characteristics of the stream reach directly impacted by the project. Photographs taken during the field investigations are included following this section. The findings are summarized below.

Hydrology. Erskine Creek drains approximately 7 square miles of Collin County at the project location. The watershed is currently undeveloped, but surrounding areas are rapidly urbanizing and the area is zoned for residential development with supporting commercial uses. The currently effective Flood Insurance Study (FIS) hydraulic model for the stream indicates peak flood discharges of 10,800 cubic feet per second (cfs) and 16,800 cfs for the 10 % and 1 % events respectively. These FIS discharges reflect land uses as of 1986 in the basin. The local community commissioned a flood plain management study which included this stream. Design discharges for fully developed land use (based on zoning) in the watershed were computed in this study. The local community regulates its flood plains based on the design discharges from the flood plain management study, which results in a 1% flood discharge of 18,800 cfs for the project area. Channel velocities for the 10 % flood (FIS) discharge range from 6.2 to 9.5 feet per second (fps) in the reach based on existing hydraulic models.

Geology. The relatively small channel is cut into the Austin Chalk and is trapezoidal in shape. In general, the banks are steep and the upper portions are comprised of silty clays. A vertical bank (20+ feet high) extends from stream station 75+00 to 85+00. Although the channel slope is steep at 21 feet/mile, small pools and riffles are frequently found along the stream bottom. The project reach includes a pronounced meander at about stream station 74+00.

Environment. A bottomland hardwood mix of trees line the banks. Significant numbers of mature red oaks with a few pecans are present, some with canopies arching over the channel. Cedar Elms and Red Cedar are also present. The steep banks are bare, other banks are have grasses and ground covers such as Canadian Wild Rye, coralberry, greenbrier and grapevine. Little Bluestem and Johnson Grassis found in flood plain areas adjacent to the channel. Approximately 100 feet of channel bed and banks have been disturbed at station 68+50, the site of a water line easement. This area is devoid of trees, but native grasses have re-established on the disturbed bank.

Initial Erodibility Index. An initial erodibility index is calculated to determine the necessity for a stream stability analysis:

- Urbanization- 2 (the watershed is zoned for single family and commercial land uses
- Sinuosity- 2 (1060'(stream length)/ 800'(valley length)= 1.3)
- Channel Bank Soils- 2 (50% rock, 50% clay)
- velocity- 3 (8.6 ft/sec)
- Initial erodibility index- 14

The erodibility index of 14 requires that a stream bank stabilization plan be developed for this reach of Erskine Creek.

Hydraulic Analysis. The existing stream hydraulic model for Erskine Creek has two cross sections in the project reach labeled 6670 and 7730. Flood water surface elevations and velocities for this model are shown in Table C-1. Because of the excessive velocity change through the reach, 35 per cent, supplemental cross sections are added to the reach as depicted in Figure C-1. The resulting velocity changes do not exceed 20 percent and are shown in Table C-2. Cross section plots are also provided.

Bank Stabilization Plan

Option 1. The developer desires to know the stream bank stabilization alternatives and costs associated with the reach from 75+00 to 78+00. The options to reduce the amount of land lost in the establishment of the Erosion Hazard Zone are limited to the construction of a gabion or reinforced concrete wall. A gabion wall is selected, preliminary designs are performed and an engineer's estimate of probable construction cost is prepared. The least expensive alternative, a 22 foot high gabion wall, is estimated to cost $390,000 and adds a maximum developable area of 2300 square feet to the project. This alternative is rejected by the developer.

Option 2. The developer elects to preserve the natural stream channel. Therefore, erosion setback limits, which will define an erosion hazard zone must be established. Based on the cross section geometry, the erosion hazard setback can be calculated as follows:

- At section 7730, the bank is steep and about 22 feet high. The limestone outcrops here and the lower 12 feet of the bank is essentially unweathered Austin Chalk. The upper 10 feet of the bank is clay with silty seams. Therefore, the setback from the top of unweathered rock at this location will be 3x10' + 15' or 45 feet, using the guidance found on Figure III-2 of the manual.
- At the downstream end of the project (section 6670), the bank is lower (16 feet), less steep and is comprised of silty clay. Based on Figure III-2, the setback from the toe of the stream bank at this location will be 4x16' + 15' = 79 feet.
- Intermediate setback limits are similarly determined and are shown on the cross section plots found at the end of this section.

The resulting erosion hazard zone is depicted on Figure C-1.

Ranking

A community has a number of well established neighborhoods along a scenic, wooded stream corridor. The area has been developed for about 25 years and the watershed has been completely urban for about the last 15 years. In the last 5 years, stream bank erosion has begun to threaten both public and private improvements. The city council has established a stream bank stabilization program and participates in projects with homeowners. However, funds are limited and projects must be ranked or prioritized to establish construction sequence over the next 4 year bond program.

Three residential sites along the stream are candidates for stream bank stabilization. Sites are described and ranked as follows:

- Homeowner A
  - house atop 22 foot high bluff composed of limestone with an 8-10' silty clay overburden
  - edge of bluff has apparently receded about 5 feet due to stream bank erosion over the last 25 years according to historical photographs provided by the owner and nearby cross section information in city files
  - the stream is relatively straight in this area with a valley length of 470 feet for a 500 foot reach centered on the site
  - the existing house is set back 60 feet from edge of bluff
  - the owner constructed a deck some years ago which is now within 5' of edge of bluff
  - several large trees are threatened by stream bank erosion
  - original floodway easement included top of bluff plus 10'
  - channel velocity for the FIS 10% flood is 6.2 fps

- Homeowner B
  - house is located on fill immediately adjacent to stream bank
  - fill is retained by railroad tie retaining wall
  - the stream is meandering in this area with a valley length of 320 feet for a 500 foot reach centered on the site
  - stream bank is eroding, due to the site's location on the outside bank of the stream meander and general channel enlargement as a result of urbanization influences
  - stream bank is composed of silty clay which is eroding, undermining retaining wall which has partially failed
  - Failure of the retaining wall has put the home at risk of damage due to stream bank instability
  - several large trees are threatened by stream bank erosion
  - floodway easement ends at top of retaining wall
  - channel velocity for the FIS 10% flood is estimated to be 7.8 fps

- Homeowner C
  - house located outside flood plain 150 feet from channel bank
  - patio, walks and short retaining walls built in close to stream bank
  - the stream is relatively straight in this area with a valley length of 450 feet for a 500 foot reach centered on the site
  - stream bank is eroding, primarily due to enlargement as a result of urbanization influences
  - owners improvements are threatened by stream bank erosion
  - several large trees are threatened by stream bank erosion
  - channel velocity for the FIS 10% flood is 9.5 fps

Ranking Calculations

	Site		
Criteria	**A**	**B**	**C**
1. Threat to Major Structures	0	20	0
2. Threat to Minor Structures	15	20	15
3. Threat to Environment	10	10	10
4. Erosion Outside Easement	0	10	0
5. Potential Erosion Outside Easement	5	15	0
6. Erodibility Easement*	10	10	12
Total Score	**40**	**80**	**37**
Rank	**2**	**1**	**3**

- Erodibility Index Computations

	Site		
	A	**B**	**C**
Urbanization	2	2	2
Sinuosity	1	3	1
Bank Soils	2	2	2
Velocity	2	2	3
Erosion Index	**10**	**14**	**12**

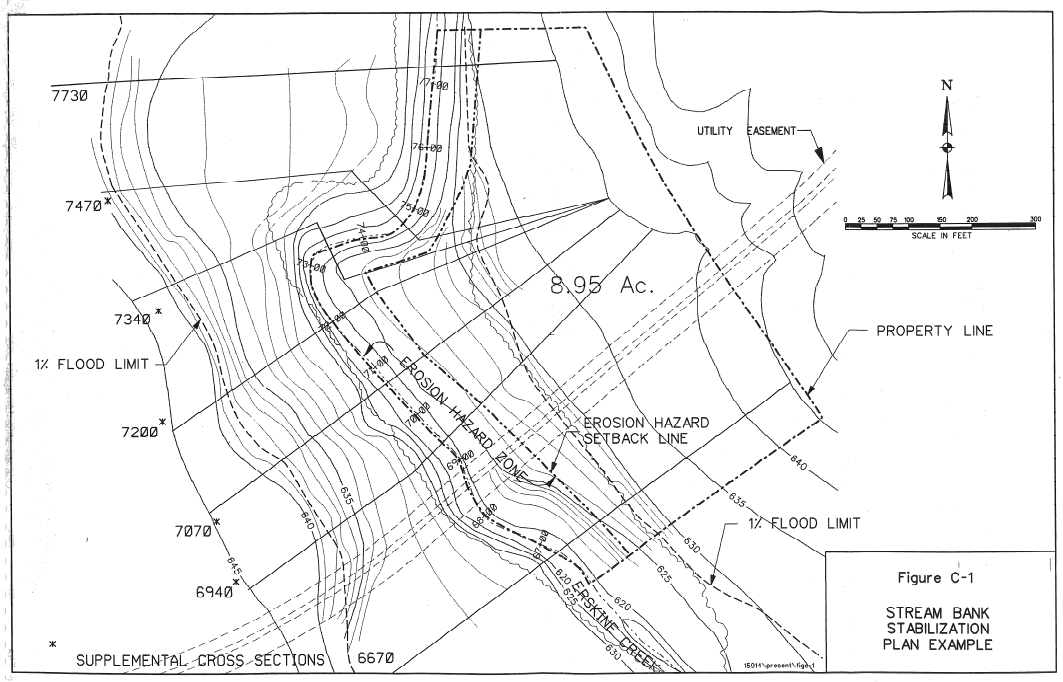


Figure C-1

STREAM BANK STABILIZATION PLAN EXAMPLE

LOOKING UPSTREAM FROM STREAM STATION 59

LOOKING UPSTREAM AT UTILITY CROSSING (68+50)

LOOKING UPSTREAM FROM UTILITY CROSSING (68+50)

LOOKING UPSTREAM AT LIMESTONE BLUFF, LEFT BANK AT STATION 77

TABLE C-1

HEC-RAS Plan: Exist River: Erskine Creek Reach: Sample

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Vel Left	Vel Right	Flow Area	Top Width
			(cfs)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(ft/s)	(ft/s)	(sq ft)	(ft)
Sample	1293	Q10	10800.00	590.48	608.65	609.20	0.002752	7.37	2.15	2.05	2890.87	760.96
Sample	1293	Q100-Ultimate	18800.00	590.48	611.90	612.24	0.001704	6.65	2.73	2.58	5459.05	813.61
Sample	1575	Q10	10800.00	589.66	609.51	609.82	0.001524	5.78	1.98	1.80	3629.73	760.18
Sample	1575	Q100-Ultimate	18800.00	589.66	612.42	612.70	0.001302	6.00	2.58	2.36	5921.14	809.66
Sample	1869	Q10	10800.00	590.94	609.90	610.61	0.003740	7.98	2.52	1.94	2422.11	670.56
Sample	1869	Q100-Ultimate	18800.00	590.94	612.78	613.30	0.002642	7.75	3.29	2.61	4481.55	758.24
Sample	2179	Q10	10800.00	592.61	611.11	611.52	0.002320	6.67	2.12	1.71	3366.84	921.33
Sample	2179	Q100-Ultimate	18800.00	592.61	613.66	613.96	0.001780	6.55	2.70	2.20	5847.46	1018.42
Sample	2440	Q10	10800.00	589.00	611.63	612.46	0.004234	8.00	1.97	2.01	2096.96	586.58
Sample	2440	Q100-Ultimate	18800.00	589.00	614.02	614.83	0.004374	8.95	3.08	3.06	3697.43	749.63
Sample	2964	Q10	10800.00	591.35	613.88	614.64	0.004312	7.72	1.59	2.36	2074.92	546.43
Sample	2964	Q100-Ultimate	18800.00	591.35	616.23	617.04	0.004484	8.78	2.68	3.35	3598.86	726.27
Sample	3564	Q10	10800.00	596.99	616.29	616.95	0.003538	7.45	2.17	2.39	2293.58	531.82
Sample	3564	Q100-Ultimate	18800.00	596.99	618.73	619.45	0.003812	8.58	3.22	3.10	3774.63	676.15
Sample	4324	Q10	10800.00	598.78	618.84	619.32	0.002731	6.40	2.10	2.04	2667.79	599.78
Sample	4324	Q100-Ultimate	18800.00	598.78	621.42	621.92	0.002780	7.22	2.82	2.82	4415.70	757.48
Sample	4791	Q10	10800.00	599.12	620.07	620.63	0.002980	6.83	1.63	2.22	2478.67	551.75
Sample	4791	Q100-Ultimate	18800.00	599.12	622.65	623.24	0.003083	7.74	2.35	3.15	4065.76	676.95
Sample	5920	Q10	10800.00	604.40	623.11	623.45	0.002335	5.89	2.72	2.28	3047.63	689.43
Sample	5920	Q100-Ultimate	18800.00	604.40	625.54	625.87	0.002081	6.21	3.49	2.98	4828.68	768.59
Sample	6670	Q10	10800.00	605.30	625.20	626.38	0.006512	9.50	3.25	2.70	1573.31	421.70
Sample	6670	Q100-Ultimate	18800.00	605.30	627.40	628.69	0.006985	10.88	4.03	4.79	2603.92	530.87
Sample	7730	Q10	10800.00	611.20	630.44	630.87	0.003069	6.18		3.00	2411.61	582.82
Sample	7730	Q100-Ultimate	18800.00	611.20	632.62	633.07	0.002920	6.60		4.15	3749.85	643.31
Sample	8330	Q10	10800.00	612.60	632.42	633.26	0.004741	7.77		2.10	1808.05	611.27
Sample	8330	Q100-Ultimate	14400.00	612.60	634.36	634.85	0.002920	6.63		2.97	3095.54	708.97

TABLE C-2

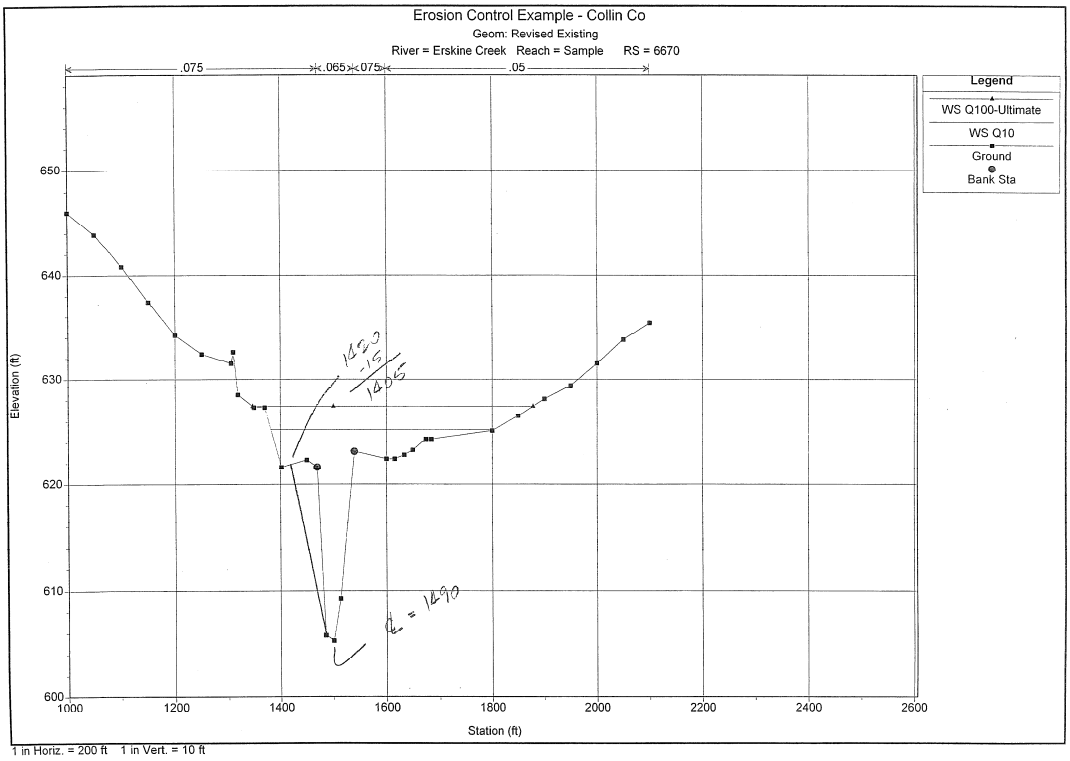
HEC-RAS Plan: RExist River: Erskine Creek Reach: Sample

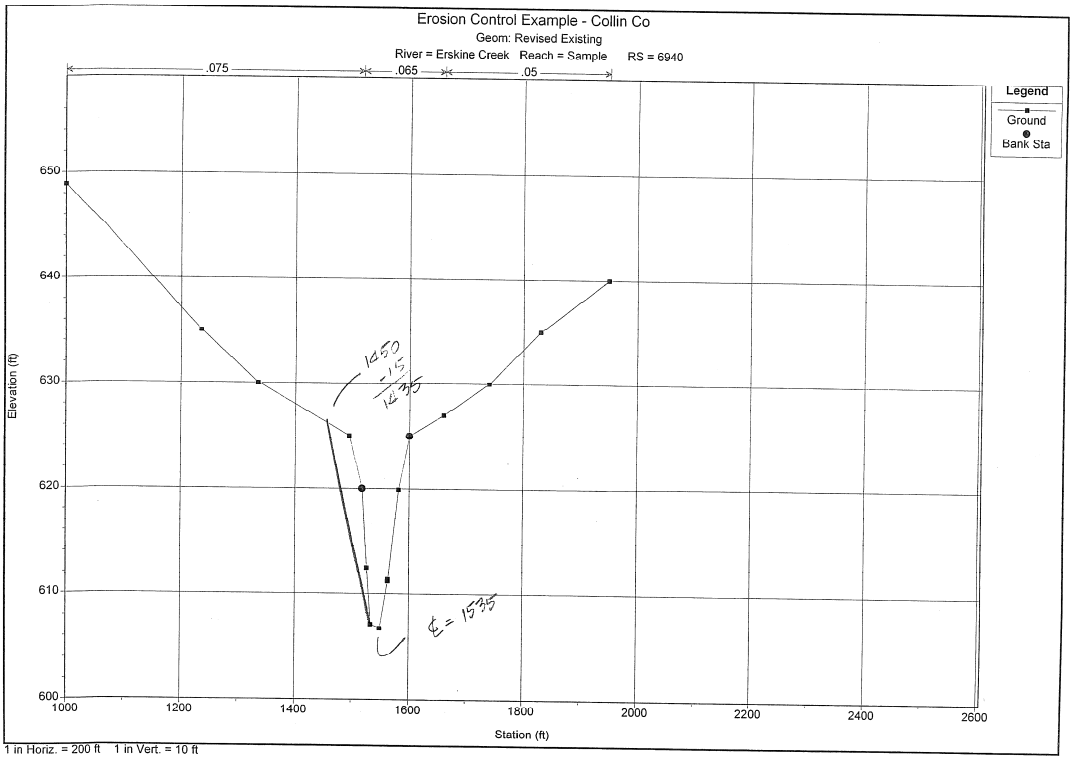
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Vel Left (ft/s)	Vel Right (ft/s)	Flow Area (sq ft)	Top Width (ft)
Sample	1293	Q10	10800.00	590.48	608.65	609.20	0.002752	7.37	2.15	2.05	2890.87	760.96
Sample	1293	Q100-Ultimate	18800.00	590.48	611.90	612.24	0.001704	6.65	2.73	2.58	5459.05	813.61
Sample	1575	Q10	10800.00	589.66	609.51	609.82	0.001524	5.78	1.98	1.80	3629.73	760.18
Sample	1575	Q100-Ultimate	18800.00	589.66	612.42	612.70	0.001302	6.00	2.58	2.36	5921.14	809.66
Sample	1869	Q10	10800.00	590.94	609.90	610.61	0.003740	7.98	2.52	1.94	2422.11	670.56
Sample	1869	Q100-Ultimate	18800.00	590.94	612.78	613.30	0.002642	7.75	3.29	2.61	4481.55	758.24
Sample	2179	Q10	10800.00	592.61	611.11	611.52	0.002320	6.67	2.12	1.71	3366.84	921.33
Sample	2179	Q100-Ultimate	18800.00	592.61	613.66	613.96	0.001780	6.55	2.70	2.20	5847.46	1018.42
Sample	2440	Q10	10800.00	589.00	611.63	612.46	0.004234	8.00	1.97	2.01	2096.96	586.58
Sample	2440	Q100-Ultimate	18800.00	589.00	614.02	614.83	0.004374	8.95	3.08	3.06	3697.43	749.63
Sample	2964	Q10	10800.00	591.35	613.88	614.64	0.004312	7.72	1.59	2.36	2074.92	546.43
Sample	2964	Q100-Ultimate	18800.00	591.35	616.23	617.04	0.004484	8.78	2.68	3.35	3598.86	726.27
Sample	3564	Q10	10800.00	596.99	616.29	616.95	0.003538	7.45	2.17	2.39	2293.58	531.82
Sample	3564	Q100-Ultimate	18800.00	596.99	618.73	619.45	0.003812	8.58	3.22	3.10	3774.63	676.15
Sample	4324	Q10	10800.00	598.78	618.84	619.32	0.002731	6.40	2.10	2.04	2667.79	599.78
Sample	4324	Q100-Ultimate	18800.00	598.78	621.42	621.92	0.002780	7.22	2.82	2.82	4415.70	757.48
Sample	4791	Q10	10800.00	599.12	620.07	620.63	0.002980	6.83	1.63	2.22	2478.67	551.75
Sample	4791	Q100-Ultimate	18800.00	599.12	622.65	623.24	0.003083	7.74	2.35	3.15	4065.76	676.95
Sample	5920	Q10	10800.00	604.40	623.11	623.45	0.002335	5.89	2.72	2.28	3047.63	689.43
Sample	5920	Q100-Ultimate	18800.00	604.40	625.54	625.87	0.002081	6.21	3.49	2.98	4828.68	768.59
Sample	6670	Q10	10800.00	605.30	625.20	626.38	0.006512	9.50	3.25	2.70	1573.31	421.70
Sample	6670	Q100-Ultimate	18800.00	605.30	627.40	628.69	0.006985	10.88	4.03	4.79	2603.92	530.87
Sample	6940	Q10	10800.00	606.78	626.80	628.22	0.006828	9.75	2.46	1.76	1257.82	216.38
Sample	6940	Q100-Ultimate	18800.00	606.78	628.82	631.28	0.010570	13.38	3.84	4.32	1818.11	335.95
Sample	7070	Q10	10800.00	607.52	627.95	629.01	0.004902	8.67	2.35	2.50	1574.33	314.18
Sample	7070	Q100-Ultimate	18800.00	607.52	631.22	632.30	0.004532	9.61	3.29	4.45	2847.57	456.34

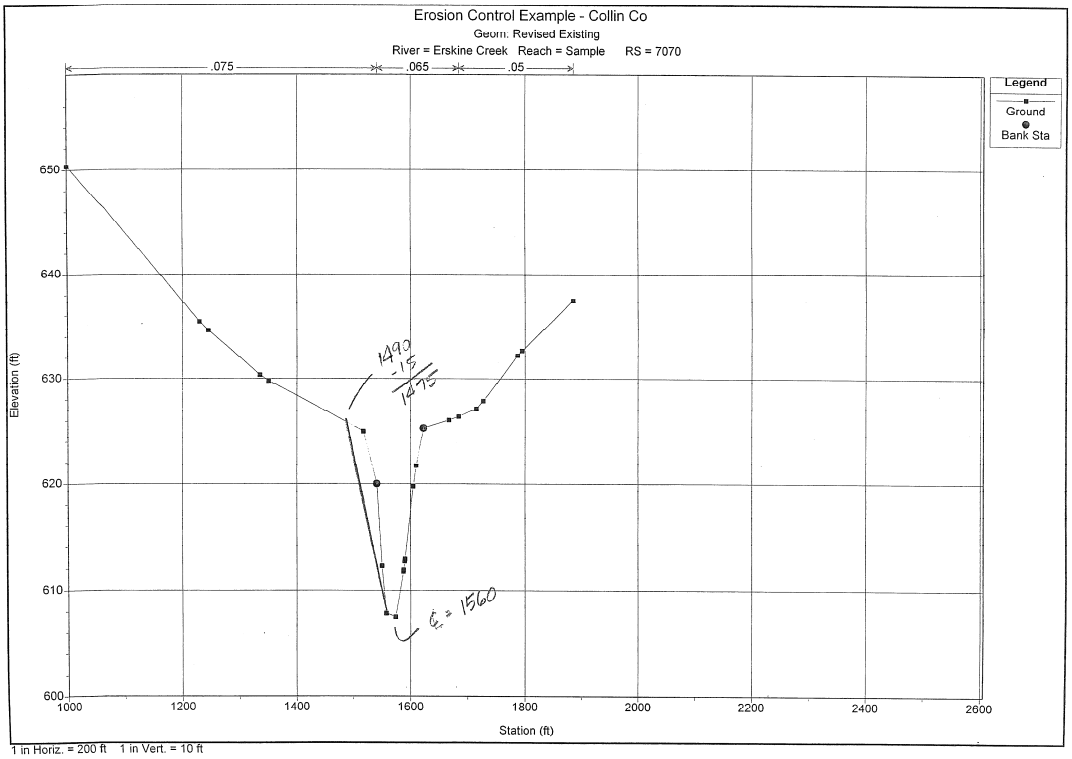
TABLE C-2 (cont'd)

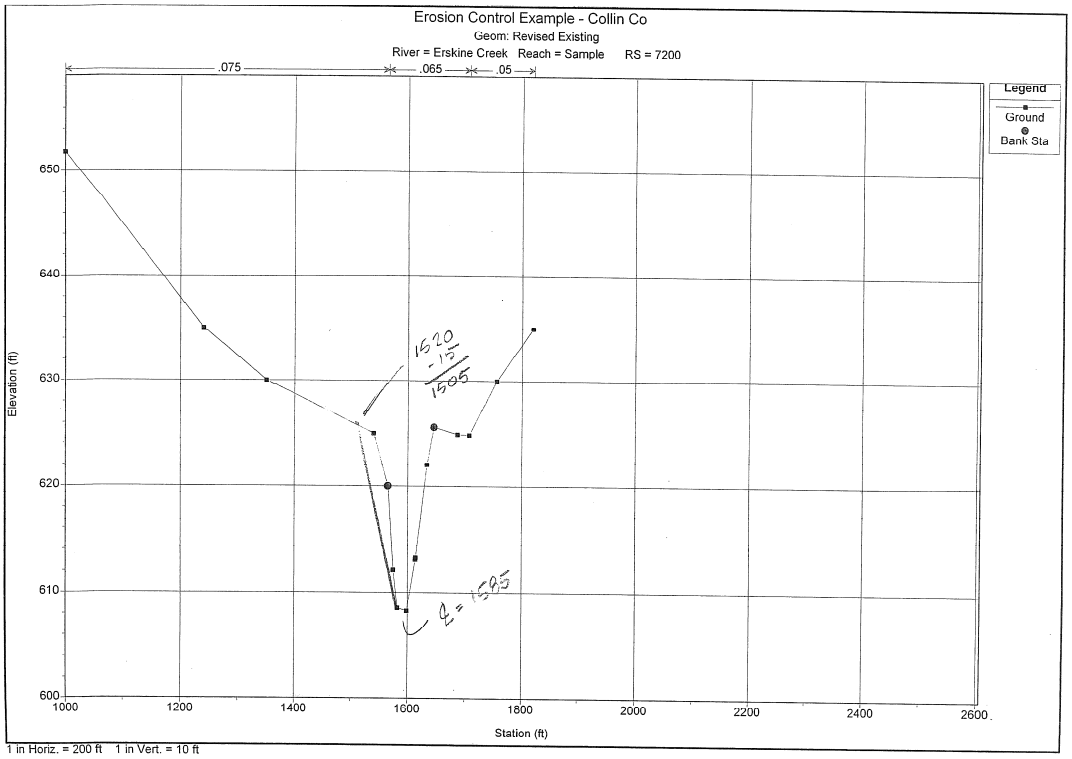
HEC-RAS Plan: RExist River: Erskine Creek Reach: Sample (Continued)

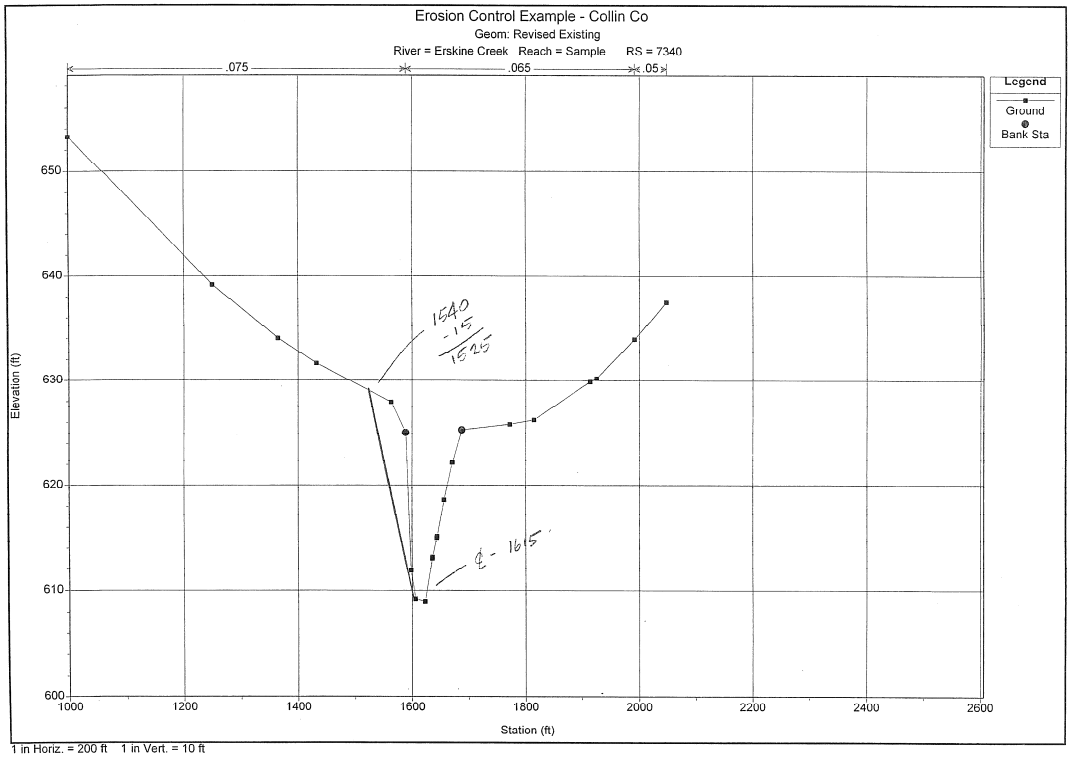
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Vel Left	Vel Right	Flow Area	Top Width
			(cfs)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(ft/s)	(ft/s)	(sq ft)	(ft)
Sample	7200	Q10	10800.00	608.25	628.82	629.60	0.003646	7.72	2.23	3.18	1885.56	348.94
Sample	7200	Q100-Ultimate	18800.00	608.25	632.02	632.85	0.003506	8.65	3.14	4.53	3219.13	475.56
Sample	7340	Q10	10800.00	608.98	629.43	630.05	0.003088	6.80	1.42	2.54	2059.60	390.91
Sample	7340	Q100-Ultimate	18800.00	608.98	632.61	633.26	0.002917	7.60	2.19	3.61	3592.20	562.29
Sample	7470	Q10	10800.00	609.72	630.03	630.43	0.002271	5.57		2.62	2418.67	477.99
Sample	7470	Q100-Ultimate	18800.00	609.72	633.22	633.59	0.001743	5.66	1.12	3.67	4211.38	645.69
Sample	7730	Q10	10800.00	611.20	630.68	631.06	0.002662	5.82		2.94	2554.15	589.87
Sample	7730	Q100-Ultimate	18800.00	611.20	633.73	634.03	0.001745	5.35	0.46	3.67	4482.51	676.02
Sample	8330	Q10	10800.00	612.60	632.45	633.28	0.004674	7.73		2.12	1824.68	612.98
Sample	8330	Q100-Ultimate	14400.00	612.60	634.85	635.23	0.002261	5.94		2.85	3453.32	736.09


Erosion Control Example - Collin Co
Geom: Revised Existing
River = Erskine Creek Reach = Sample RS = 6670
.075
.065
.075
.05
Legend
WS Q100-Ultimate
WS Q10
Ground
Bank Sta
Elevation (ft)
650
640
630
620
610
600
1000
1200
1400
1600
1800
2000
2200
2400
2600
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 10 ft

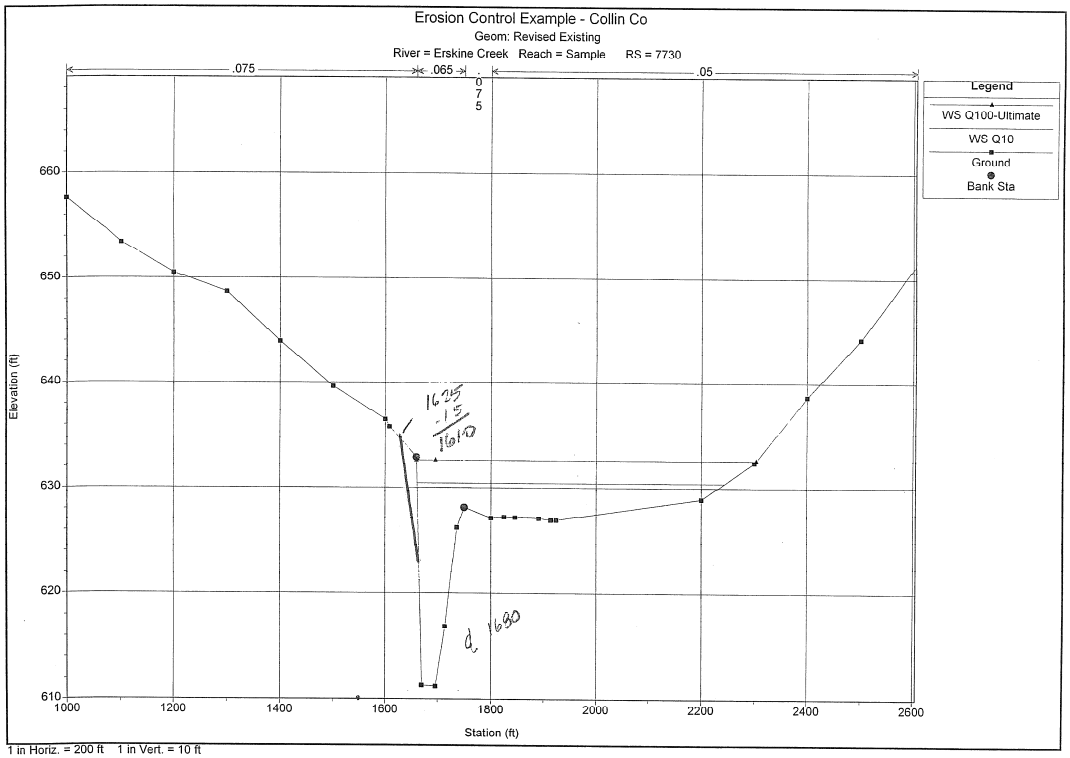

Erosion Control Example - Collin Co
Geom: Revised Existing
River = Erskine Creek Reach = Sample RS = 6940
.075
.065
.05
Legend
Ground
Bank Sta
650
640
630
620
610
600
Elevation (ft)
1000
1200
1400
1600
1800
2000
2200
2400
2600
Station (ft)
1450
1535
℄ = 1535
1 in Horiz. = 200 ft 1 in Vert. = 10 ft


Erosion Control Example - Collin Co
Geom: Revised Existing
River = Erskine Creek Reach = Sample RS = 7070
.075
.065
.05
Legend
Ground
Bank Sta
650
640
630
620
610
600
Elevation (ft)
1000
1200
1400
1600
1800
2000
2200
2400
2600
Station (ft)
1490
-15
1475
Lc = 1560
1 in Horiz. = 200 ft 1 in Vert. = 10 ft


Erosion Control Example - Collin Co
Geom: Revised Existing
River = Erskine Creek Reach = Sample RS = 7200
.075
.065
.05
Legend
Ground
Bank Sta
650
640
630
620
610
600
Elevation (ft)
1000
1200
1400
1600
1800
2000
2200
2400
2600
Station (ft)
1520
- 15
1505
1 in Horiz. = 200 ft 1 in Vert. = 10 ft



1 in Horiz. = 200 ft 1 in Vert. = 10 ft


Erosion Control Example - Collin Co
Geom: Revised Existing
River = Erskine Creek Reach = Sample RS = 7730
.075
.065
.05
0
7
5
Legend
WS Q100-Ultimate
WS Q10
Ground
Bank Sta
Elevation (ft)
660
650
640
630
620
610
1000
1200
1400
1600
1800
2000
2200
2400
2600
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 10 ft

APPENDIX D

ADDITIONAL EROSION CONTROL SOURCES

APPENDIX D

ADDITIONAL DESIGN GUIDELINE SOURCES

Other Sources

In the following section, relevant bank erosion control design projects and programs conducted by Federal, State, and Local government agencies are described.

1. Federal Agencies

U.S. Army Corps of Engineers, 1997. Development of a Stream Bank Erosion Control Manual for the U.S. Environmental Protection Agency.

The U.S. Army Corps of Engineers, Waterways Experiment Station, is currently developing a Stream Bank Erosion Control Manual for the U.S. Environmental Protection Agency. The manual will include a literature review, description of the mechanics of bank erosion, and summary of alternative bank erosion control methods. Work on the project has just begun and a final schedule for completion of the manual has not been established.

U.S. Army Corps of Engineers, 1996. Demonstration Erosion Control (DEC) Program.

The Corps, in conjunction with the Natural Resource Conservation Service (formerly the Soil Conservation Service), is conducting a multi-year Demonstration Erosion Control Project. The objective of the project is to develop and implement methods for reducing erosion in actively incising streams. Many of the streams being studied were channelized and straightened during the early part of the century.

U.S. Army Corps of Engineers, Stream Bank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587), Section 155 and Section 161, October 1976.

A seven year study was conducted by the U.S. Army Corps of Engineers to examine the causes of stream bank erosion, to evaluate the effectiveness of existing and new methods of bank protection, and to prepare documentation for the Congress describing the findings of the Section 32 Program.

National Research Council, 1992. Restoration of Aquatic Ecosystems, Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, National Academy Press.

This publication describes the status and functions of surface water ecosystems, the effectiveness of aquatic restoration efforts, the technology associated with those efforts, and the kinds of research, policy management, and institutional changes required for successful restoration. The document identifies common factors of successful restoration projects. Case studies are evaluated in the document to define their scientific basis, performance over time, the technologies used, the monitoring effort, the costs, the objectives of the effort, the degree to which objectives were fulfilled, and political and regulatory factors which influenced the projects. It includes several case studies involved with river and stream restoration.

2. State Agencies

Papio-Missouri River Natural Resource District, 1988. State of Nebraska, Elkhorn River Bank Stabilization Project.

The Elkhorn River Bank Stabilization Project involves a channel cut-off and the placement of rock revetment at severely eroding sites along a seven-mile reach of stream in Eastern Nebraska. The project was designed to control rapidly advancing meanders, thereby preventing the erosion of cropland, woodland, and some residential property. The project was completed in 1988 and utilized a grant of $1,164,965 and a loan of $135,742.

3. Local Agencies

King County Storm Water Management, Washington, 1997. Stream Bank Erosion Control Volunteer Program.

The Storm Water Management Agency of King County, Washington, organizes a program for stream bank stabilization and habitat enhancement along waterways within the county. The program relies on volunteer labor from the public to accomplish a variety of projects. Typical projects include:

Native plant salvage efforts at public development sites such as schools, roads, and municipal buildings.
Vegetative plantings along disturbed or degraded waterways
Exotic plant species eradication efforts (weed pulls)

The county organizes the events, provides hand tools, and directs the efforts. Citizen participation is voluntary. For one recent planting project, over 10,000 people participated.

Additional Design Guidelines

In the following sections, a summary is provided of design guidelines and construction details relevant to bank erosion control.

1. Federal Agencies

U.S. Army Corps of Engineers, 1983. Stream Bank Protection Guidelines For Landowners and Local Governments, prepared by Waterways Experiment Station, Vicksburg, MS.

This document summarizes information developed as part of the Section 32 Program. It is intended to present information developed from the program in laymen's language. It does not present detailed design procedures but provides detailed guidance on the applicability, advantages, and disadvantages of a wide range of stream bank erosion control technologies. The publication includes a number of photographs and diagrams that illustrate the topics presented. Information in the document includes:

- A description of the nature of streams
- Characterization of stream bank erosion and failure
- A Plan of Action to protect a stream bank
- Typical means of providing stream bank protection

U.S. Army Corps of Engineers, 1991. Hydraulic Design of Flood Control Channels, Engineer Manual No. 1110-2-1601.

This manual presents procedures for the design analysis and criteria of design for improved channels that carry rapid and or tranquil flow. Procedures are presented without details of the theory of the hydraulics involved. Theories and procedures in design are discussed for flow in curved channels, flow at bridge piers, flow at confluences and side drainage inlet structures, and other situations which are not covered fully in textbooks. Typical calculations are presented to illustrate the principles of design for channels under various conditions of flow. Information presented in the

manual particularly relevant to stream bank erosion and its control includes:

Description of procedures for calculation of flow in curved channels, including consideration of issues of superelevation and freeboard
Stable channel design and prevention of scour
Riprap protection design

U.S. Department of Agriculture Soil Conservation Service, 1992. Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction, Engineering Field Handbook.

This document is one of the 18 chapters of the U.S. Department of Agriculture Soil Conservation Service (SCS) Engineering Field Handbook. It provides field personnel with a guide for soil bioengineering intended primarily for upland slope protection and erosion reduction. It describes design and construction techniques of soil bioengineering. Although not specifically directed at biotechnical stream bank erosion control methods, much of the design and construction techniques would be applicable.

Other chapters of the SCS Engineering Handbook which also contain useful design guidelines and construction details include:

Part 625 Soil Erosion Control and Reclamation
Part 639 Erosion Control Engineering

Federal Highway Administration, 1989. Design of Riprap Revetment, Report No. FHWA-IP-89-9016, HEC-11, prepared by Sutron Corporation.

This Hydraulic Engineering Circular No. 11 (HEC-11) is a comprehensive design publication. Detailed design guidelines are presented for rock riprap and design procedures are summarized in charts and examples. Design guidance is also presented for wire-enclosed rock (gabions), precast concrete blocks, and concrete paved linings.

2. State Agencies

Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA), 1994. Sediment and Erosion Design Manual, prepared by Resource Consultants & Engineers, Inc.

The purpose of this manual is to provide guidance for use in establishing an erosion limit line. The erosion limit line would have a low possibility of being disturbed by erosion, scour, or meandering of a natural (unlined) arroyo by any storm up to and including the 100-year storm occurring at any time during a 30-year period. The manual also contains criteria for placement of erosion barriers that may be incorporated with the erosion limit to maintain arroyos

while protecting property.

This manual presents procedures for establishment of a regulatory area along watercourses prone to rapid and significant bank erosion. It describes the geomorphology of the area of concern, hydraulics of flow in natural and developed channels, sediment transport in steep, erodible channels, channel adjustments, and design criteria for erosion countermeasures. This includes design criteria for stabilization using both flexible and rigid revetments.

Washington State Department of Transportation, 1996. Construction Site Erosion and Sediment Control Certification Course, Environmental Affairs Office, Water Quality Program.

This course manual presents guidelines and design details for best management practices for erosion control at construction sites. This information includes definitions of best management practices, identifies conditions where the practice applies, and defines the advantages and disadvantages associated with each practice. Standard details for construction drawings are defined. Information relevant to stream erosion control includes construction site erosion control details and design criteria. These include best management practices such as interceptor dikes and swales, sedimentation ponds, filter fences, pipe drops, and revegetation.

North Carolina State University, 1997. STREAM BANKS, Internet Web Site, H2OSPARC.WQ.NCSU.EDU/ESTUARY/REC/STRMBNKS.HTML.

This web site presents a summary of information regarding stream bank erosion and best management practices. The information includes a brief discussion of the causes of bank erosion, a description of erosion control methods, and a list of technical references. The description of erosion control methods includes management techniques, soil bioengineering techniques, and hardened structural techniques.

3. Other

King County, Washington. No date. Guidelines For Bank Stabilization Projects, prepared by Jeanne Stypula.

This document has been developed to assist scientists and engineers with the planning and design of bank stabilization projects. It presents information on bank erosion and stabilization techniques for large river systems. This is a practical guide for assessing erosion problems and evaluating alternative solutions.

American Excelsior Company, 1996. ErosionWorks Reference Manual, Version 1.0.

This manual describes a windows-based computer program with utilities for analysis of typical slope and channel applications related to hydraulics and sediment transport. It allows evaluation of best management practices for erosion control. It facilitates analysis of open channel flow conditions and selection of erosion control products such as blankets, concrete blocks, and riprap. The technical library of the software contains suggested specifications and details, including computer-based construction details for use in production of construction drawings.

APPENDIX E

PERMITTING ISSUES

EROSION HAZARD ORDINANCE GUIDANCE

1. An Erosion Hazard Zone shall be established along the communities streams and rivers.
2. The Erosion Hazard Zone shall consist of the stream's bed and banks plus any additional setback as established by procedures outlined in the *Stream Bank Stabilization Manual.*
3. The purpose of the Erosion Hazard Zone is to allow passage of floodwaters with minimal threat from erosion or stream bank instability to public and private facilities adjoining the communities rivers and streams and to minimize expenditure of public funds for stream bank stabilization.
4. No construction, reclamation or alteration will be allowed in the Erosion Hazard Zone without the permission of the City Engineer.
5. The Erosion Hazard Zone shall be a designated easement for affected properties that are being subdivided or platted for the purposes of development.
6. If adjoining landowners desire to construct, reclaim or otherwise alter stream bed, banks or flood plains within the Erosion Hazard Zone, a Stream Bank Stability Analysis shall be performed according to guidelines established in the *Stream Bank Stabilization Manual.*
7. If stream bank stabilization measures are needed, those measures shall be designed and constructed in accordance with the *Stream Bank Stabilization Manual* and all applicable flood plain and drainage ordinances and regulations in the community.
8. The design return period for erosion control facilities shall be the 2-Year (50%) Flood. The 10-Year (10%) flood for the currently effective FIS study can be substituted at the applicants discretion.
9. This ordinance shall apply to all watersheds greater than 130 acres in drainage area and any water course in which the stream bed and banks remain in their nature state.
10. A permit shall be required for projects which involve construction, reclamation, or alteration within the Erosion Hazard Zone.
11. The permit does not remove the landowners responsibility to obtain other applicable city, state and federal permits and approvals.
12. Homeowners can receive assistance from city staff to determine this ordinances applicability to their property or proposed improvements.
13. Permit fee?