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

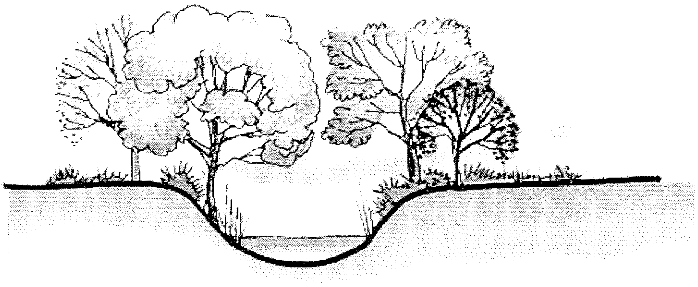
Natural channels are formed by the concentration of storm water runoff. The flowing water has the energy to scour the earth, which continues throughout the life of the stream. Sediment is deposited in the channel bottom at the same time that the channel is eroding. The channel bottoms and banks will 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

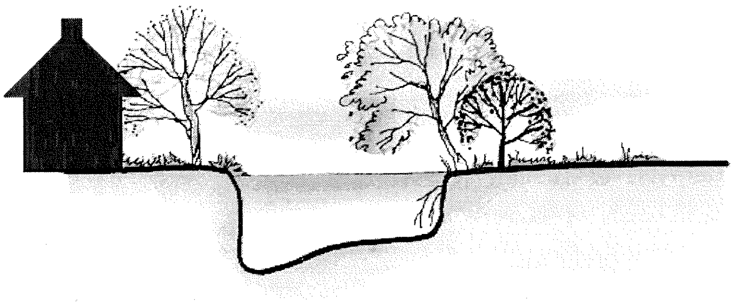
A region's climate can influence the need for stream bank stabilization and dictate which methods might be most successful in mitigating erosion damage. The study area for this Stream Bank Stabilization Manual lies in a region of temperate mean climatological conditions and experiences occasional, short 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^{o}F and 37 days with temperatures below 32^{o}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.

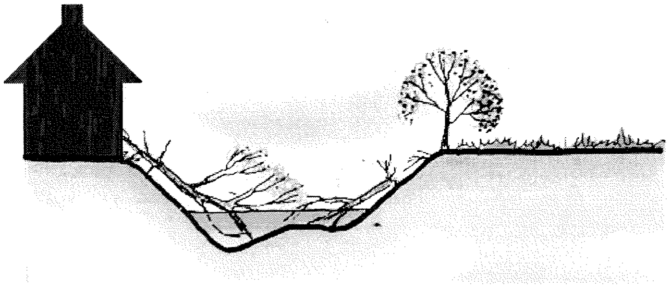
The primary factors that affect creek microclimates are trees, stream side slopes, and water. The orientation of a channel side slope, that is, the direction in which the slope faces has a significant effect on the microclimate. South facing slopes which receive more sunlight experience faster evaporation 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).



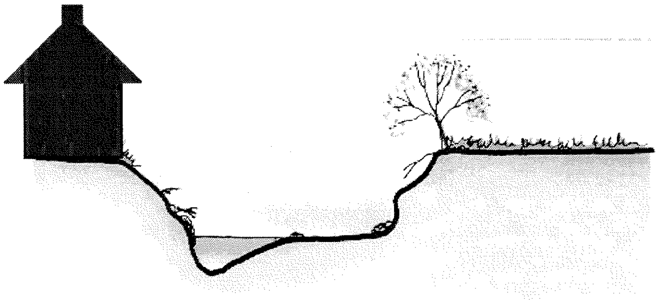
Pre-urbanization Condition



1. 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

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 ($\sum F=ma$), then:

$$\sum F_i = 0$$

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:

$$W_s = wALS$$

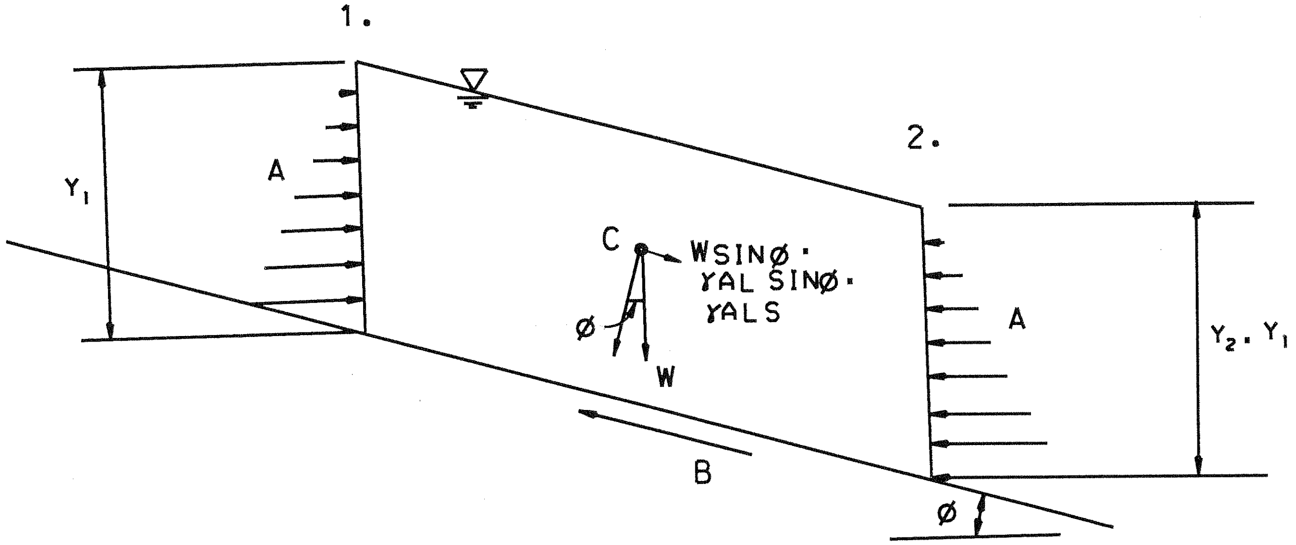
where: w = unit weight of water, pounds per cubic foot;
A = wetted area, square feet;
L = length of channel reach, feet; and
S = slope of channel bottom, feet per foot.

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	V, fps	WATER TRANSPORTING COLLOIDAL SILTS 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

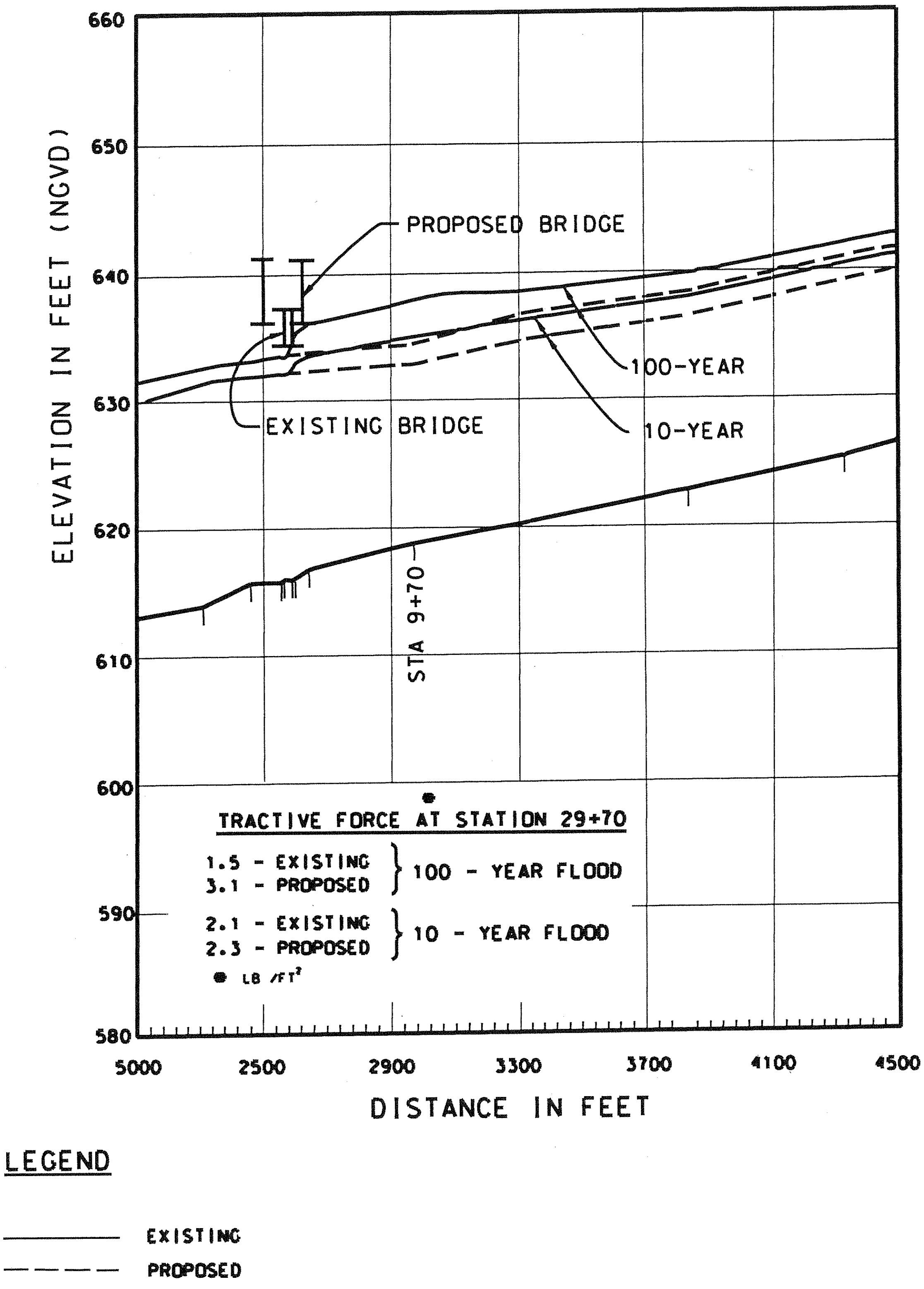


Figure I-4

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.

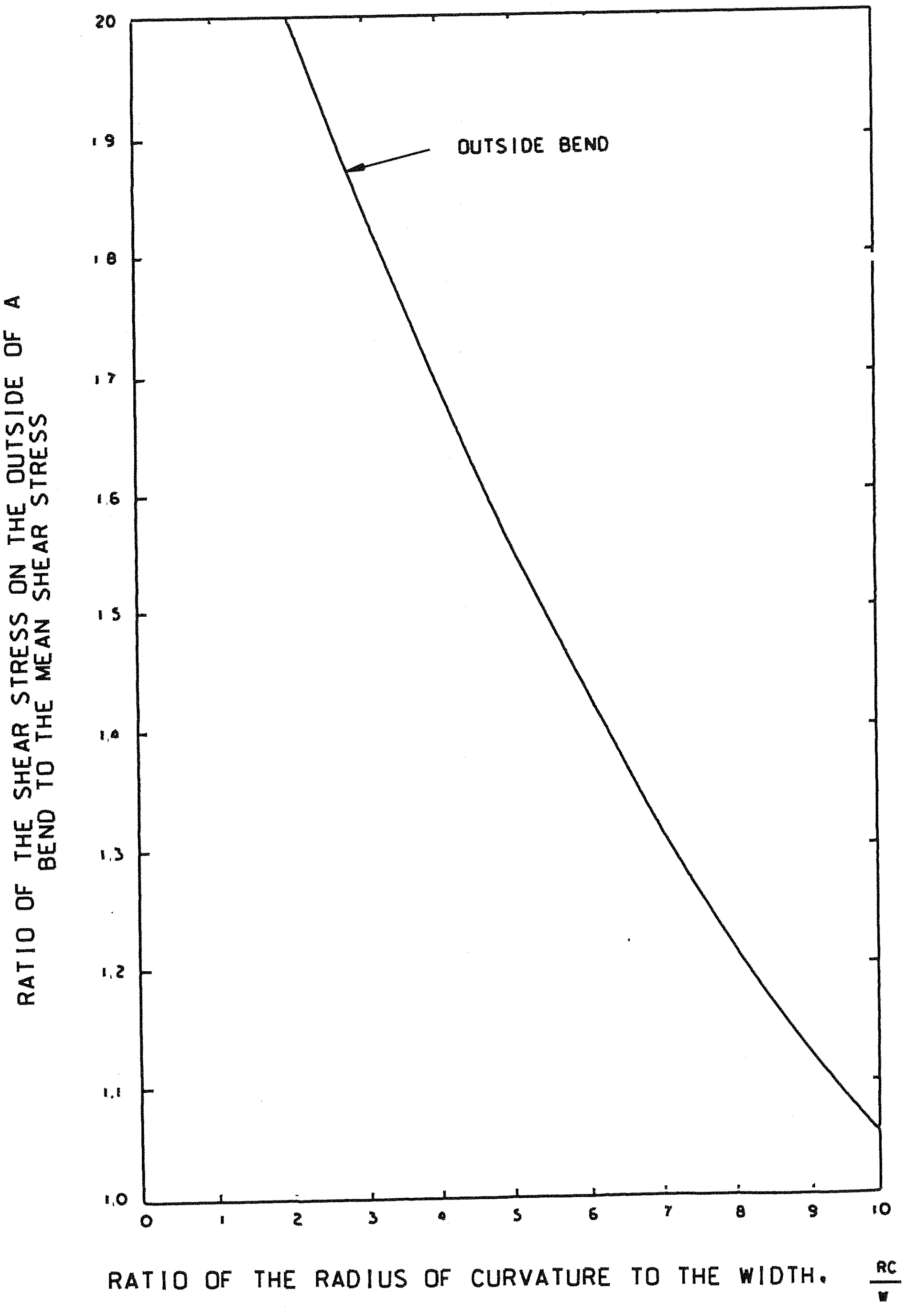


FIGURE I-5

BOUNDARY SHEAR STRESS
AT OUTSIDE OF BEND

(LANE, 1955)

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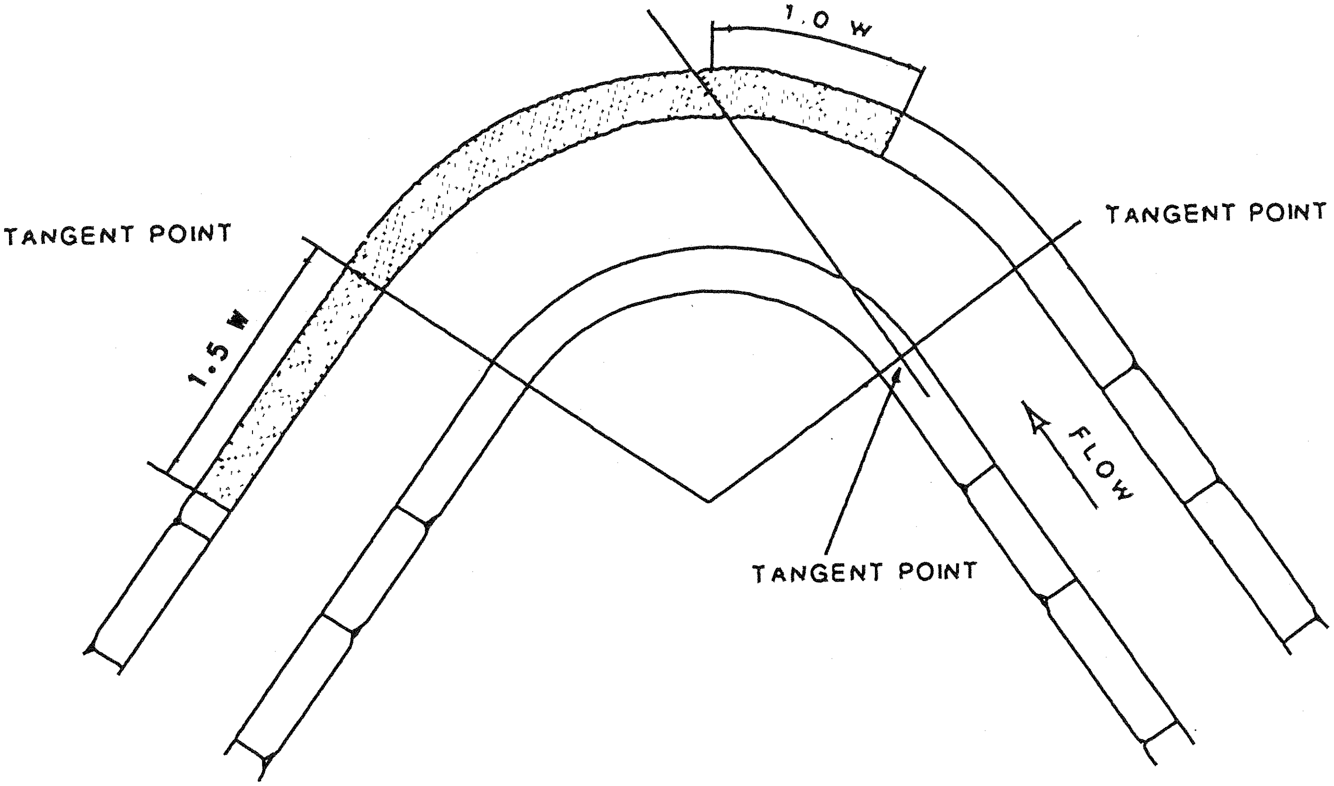


W = STREAM BANK TOP WIDTH AT DESIGN FLOW

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

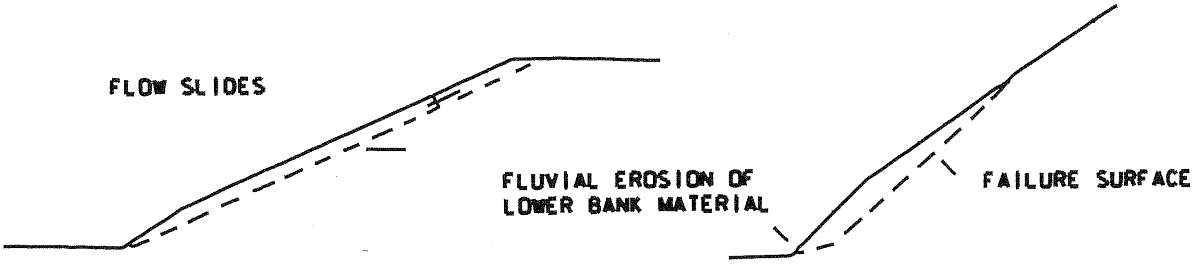
Generally, neither swelling clays nor groundwater pressure in a bank can be directly observed. In certain cases, evidence of soil creep can be observed by the development of bank cracks that form parallel to the stream.

b) Increase in Shear Stress

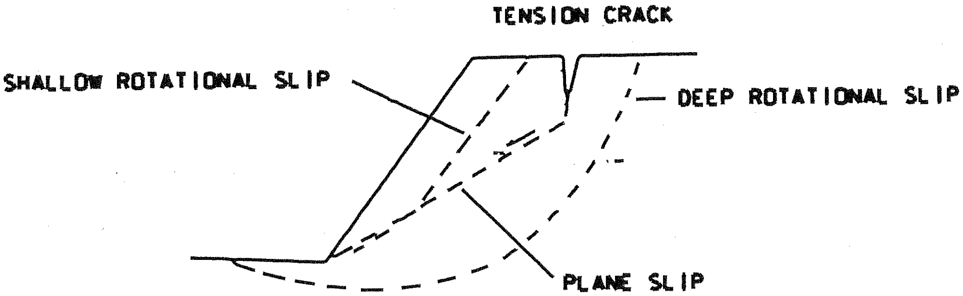
Shear stress in a bank can increase by several means, but is most commonly associated with changes in channel bed elevation, undermining of the bank toe by surface erosion, increased loads on the bank, and rapid drawdown of stream flow.

3. Erodibility

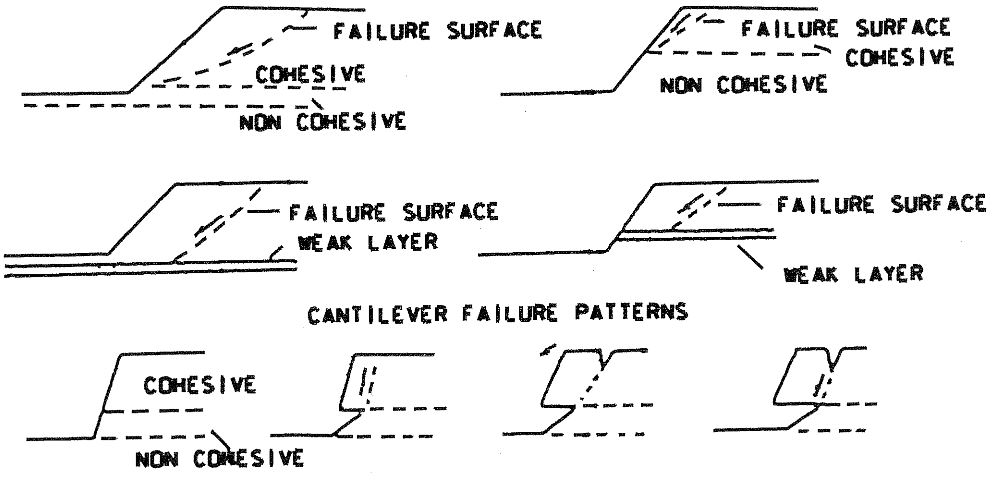
Of all these factors contributing to stream bank erosion in the project area, urbanization probably has the most impact. Studies have shown that urbanization of the drainage basin tends to roughly double the channel area as the stream attempts to reach a new state of relative stability (Allen, 1985).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



COHESIVE



COMPOSITE

FIGURE I-7

TYPICAL BANK FAILURE SURFACES
FOR VARIOUS SOIL TYPES.

(BROWN, 1985)