Ontario

Technical Guide

River & Stream Systems: Erosion Hazard Limit

Ontario Ministry of Natural Resources
Water Resources Section
300 Water Street, 5th Floor, South Tower, P.O. Box 7000
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Selected figures were reproduced from:

Newbury, R. & Gaboury, M., Stream Analysis and Fish Habitat Design: A Field Manual. 1993, and
R.B. Sotir presentation notes. This material used by permission of Newbury Hydraulics Ltd. and R. Sotir & Associates.

Introduction

The 1996 Provincial Policy Statement issued under the authority of Section 3 of the Planning Act provides policy direction on matters of Provincial interests related to land use planning and development. According to the Planning Act, planning authorities "shall have regard to" policy statements issued under the Act. One important principle behind the policy statement to achieve long-term economic prosperity, environmental health and social well-being is the reduction of public cost and risk to Ontario's residents by directing development away from areas where there is risk to public health or safety or risk of property damage. Accordingly, the Province of Ontario issued policies under Public Health and Safety policy areas addressing natural and human-made hazards. The new planning approach also empowers municipalities to promote efficient, cost-effective development and land use patterns through the use of coordinated approaches when dealing with issues which cross municipal boundaries including ecosystem and watershed related issues, shoreline and riverine hazards.

Figure 1 - Slope Slide Caused By River Erosion

Natural hazard studies form an important part of watershed management and planning. Proper planning requires the balancing of a wide range of public and private interests. Ecosystem based planning within a watershed or a sub-watershed, involves an up-front evaluation of numerous, and sometimes competing, land use and natural resources interests. It provides a means of examining and developing planning strategies that balance local as well as community-based needs. Through ecosystem based planning processes, environmental and social concerns such as flood and erosion hazard lands can be identified and incorporated into the land use planing process.

The Ministry of Natural Resources (MNR) is the lead administrative Ministry having overall Government responsibility for natural hazard policies and programs (flooding, erosion, etc.). The Provincial Policy Statement (PPS) of the Planning Act outlines areas of provincial interest respecting natural hazard policies (Section 3.1).

Provincial reforms have streamlined municipal planning into a "one-window" process. Municipal planning decisions are guided by the policy direction in the Provincial Policy Statement, as opposed to comment and input received from individual ministries. MNR is a signatory of the Provincial One Window Protocol and assists the Ministry of Municipal Affairs and Housing in the achievement of Provincial One Window Vision. Municipalities are delegated with authority to address areas of provincial interest in their planning documents. The Ministry of Natural Resources (MNR) through its water management program will ensure that the program is effectively aligned with the Ministry's vision of sustainable development and its mission to achieve ecological sustainability. MNR's objectives to achieve ecological sustainability include the continuation of Provincial programs for the protection of life and property from flooding and other water-related hazards, and the provision of direction and input through policy, information and science support.

The Provincial government's role in the planning and management of flood risk areas is to protect society, including all levels of government, from being forced to bear unreasonable social and economic burdens due to unwise individual choices.

The Province sets minimum standards to ensure that these risks and costs to society are reduced. There are instances where local conditions dictate that the minimum standards may not be sufficient and a higher standard may be more appropriate. The Province has empowered municipalities to assume responsibilities for the management of natural hazards, the associated liability and the risk relative to planning for new land uses in and around these areas. The municipality making these decisions should ensure that natural hazards studies are undertaken by accredited professionals such as a Professional Engineer.

The Technical Guide - Rivers and Streams: Erosion Hazard Limit document has been prepared to assist in the understanding of the latest Provincial Policy Statement and to describe approaches which have been determined to be consistent with the new policies. The enclosed document is based on the 1996 Provincial Policy Statement and it updates previous documents (i.e. Natural Hazards Training Manual) which address riverine erosion hazards.

This guide serves in an advisory role and is not intended to introduce any changes from the Policy Statement. Instead, it should be read in conjunction with the Provincial Policy Statement as well as other natural hazards related technical and implementation guides.

The primary purpose of the Rivers and Streams Technical Guide Erosion Hazard Limit***, is to provide a consistent and standardized procedure for the identification and management of riverine erosion hazards in the Province of Ontario.*** Designers and review agency staff will find the Guide helpful in their work as it is based on a standard and relatively simplistic methodology, intended to be applied to two generalized landform systems through which river and stream systems flow; confined and unconfined systems.

This document describes, in general terms, an important component of watershed management; it presents the hydraulic work as well as soil and slope stability analyses needed to conduct riverine erosion studies to determine appropriate management strategies. It is not intended to be a list of mandatory instructions on technical methodologies to be rigidly applied in all circumstances. Instead, the Guide serves to assist technical staff experienced in natural hazards management to select the most appropriate methods and flexible implementation measures in the identification of riverine erosion lands. The Guide cannot replace good engineering, scientific and environmental judgement in adopting the most appropriate procedures required when undertaking and adopting a local or watershed-based erosion and slope stability related study program.

The Rivers and Streams Technical Guide Erosion Hazard Limit is composed of the following six sections:

Section 1: Introduction
Section 2: description of the physical features and processes
Section 3: application of the Provincial Policy, definitions of *erosion hazard* limits and associated "allowances" based on a simplified landform system
Section 4: description of the study, site and field investigation information
Section 5: direction on how to address the hazards within a watershed context
Section 6: introduction to environmentally sound hazard management approaches

The meteorological (rainfall) and physical process and factors which impact upon watersheds and the nature of their interactions with the surficial materials and local geology are extremely complex and the subject of many current ongoing scientific investigations. River and stream systems undergo continuous changes in form and configuration as a result of natural processes such as erosion, transport and deposition of sediment and varying hydraulic conditions. The primary agents are water flow rates and natural channel gradients. The degree of impact that the erosive forces have is dependent on the relative strength of the materials that comprise the channel bed and banks. Land use change and alteration to the watersheds hydrologic cycle may accelerate impacts. Numerous other physical, biological and human induced processes also impact river and stream systems and continue to influence the characteristics of the constantly evolving watershed. The interactions amongst these processes and their inter-relationships need to be understood, assessed and integrated as part of any implementation option or strategy aimed toward sound management of watershed ecosystems and hazard lands.

To address in part, the importance of some of these processes, their inter-relationships and impacts on river and stream systems the following documents should be consulted:

- Adaptive Management of Stream Corridors in Ontario (2001, In press)
- Technical Guide River and Stream Systems Flooding Hazard Limit, MNR (2001)
- Geotechnical Principles for Stable Slopes, MNR (1998)
- Stormwater Management Practices Planning and Design Manual, MOE (2001 - in press)
- Stream Corridor Restoration: Principles, Processes and Practices, USDA (1998)
- Stream Assessment Protocol, MNR (2001)

For more detailed technical information, the reader is urged to consult the bibiography which includes a number of references on hydraulics, geomorphology and river engineering.

2.0 Erosion Process

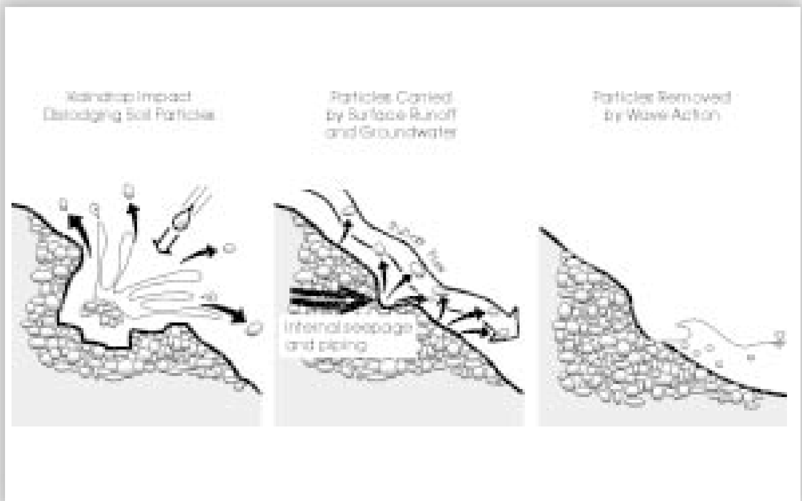

Figure 2 - Water Action on Soil

Erosion and slope instability are two different processes which are often associated together. The erosion process affects the soil surface at the particle level, by gradually dislodging and removing (transporting) the soil particles from the parent mass (Figure 2).

Slope instability consists of the sudden movement or sliding of a large mass of soil over a failure plane. Slope instability is not restricted to the removal of the surface particles. It consists of the sudden movement or sliding of a large mass of soil over a failure plane. (See figure 3)

The following examples indicate the erosion process not slope instability. Slope instability will be addressed further on in Section 2.4.5 of this document.

Water movement is often the agent (see Figure 5) commonly occurring in one of the following manners;
- channel bed and bank erosion by watercourse flow
- slope toe erosion by watercourse flow coincident with slope
- internal seepage, springs, piping near or over the bank, flooding
- surface runoff, gully erosion, sheet and rill erosion near and over the bank by surface drainage (upland areas) into the watercourse.

Figure 7 - Bank Erosion due to deflected flow debris

Other processes such as wind and frost may assist in the weathering or dislodging and transport of soil particles. Streams also widen their channels in several ways;

- bank erosion due to lateral corrasion during flood flows,
- bank erosion due to deflected flow from debris (tree trunks, boulders, dumping, slumps), and
- impinging of a meander belt against valley slopes.

Figure 3 - Slope Instability

Figure 4 - River Erosion

Figure 5 - Gully Erosion of Slope

Figure 6 - Rill Erosion of Slope

2.1 PHYSIOGRAPHY

GEOMORPHOLOGY - GLACIAL DEPOSITS AND LANDFORMS

The surface features of Ontario have been shaped by Quaternary Period glaciation which also produced the Great Lakes. The section on The Formation of Streams from AMSC[1] should be reviewed.

The Quaternary Period began about 1.8 million years ago and has been subdivided as follows.

Pleistocene Epoch OR "the Great Ice Age"	1.8 million years before present	time of growth and decay of several continental-scale ice sheets
	115,000 years ago	beginning of Wisconsinan glaciation
	20,000 years ago	Laurentide Ice Sheet covers Ontario
		end of Wisconsinan glaciation
Holocene Epoch	10,000 years before present	post-glacial times
	present	

Large sheets of ice (estimated at to 1 km thick) advanced and retreated over the bedrock surface which was carved and scoured. Clay, silt, sand, and gravel were deposited. What remained were the Canadian Shield of Precambrian bedrock, and Quaternary glacial deposits. The glacial deposits had an average depth of 30 to 60 metres.

The most widespread glacial deposit was "till". Till describes "sediment that has been transported and deposited by or from glacier ice, with little or no sorting by water" (Dreimanis, 1982). Till is typically massive in structure, without stratification or lamination. Till is often compact or over-consolidated due to the pressures exerted by the glacier ice mass.

In addition to till sheets, there were also glaciofluvial deposits (sand and gravel), and glaciolacustrine deposits (clays, silts, sands), and post-glacial deposits of alluvium or peat.

The glacier ice movements also caused landform features including:

a) fluted (grooved) till plains;
b) drumlinized till plains;
c) hummocky (or ribbed or washboard) ground moraine;
d) crag-and-tail features;
e) eskers, spillways, kames, kettles.

Drumlins are oval-shaped hills composed of till or stratified sediments. The nature of the glacial deposits (dense or hard soil, landform features) can have significant influence on the natural drainage characteristics and patterns that develop.

The numerous sequences of glacier ice advance and retreat were accompanied by the drainage of vast quantities of meltwater and the formation of streams, rivers, and lakes. For further information, see the section on Glacial History, The Formation of Streams, AMSC[2]. As glaciation left southern Ontario, the landscape was covered mostly by coniferous forests (pines and spruce). These features are indicated on the following (figure 8 and 9). The Quaternary Geology for Southern Ontario.

After the glacier retreat, the Ontario landscape was subjected to erosion and the cutting of river valleys as the result of surface run-off and drainage. Locally the glacial deposits have been modified by this erosion. Soil materials are often referred to as 'overburden' or unconsolidated materials. Bedrock is encountered beneath the soil materials, and is generally strong and consolidated, see the section on Surficial Material & Landforms, AMSC[3].

Most of southern Ontario is underlain by sedimentary rocks such as shale and limestone. Central and northern Ontario is predominantly underlain by igneous and metamorphic rocks such as granite and gneiss. The Bedrock Geology of Ontario is shown on the following maps, Map 2 A & B (figure 10). Further details can be found in the section on Bedrock Geology, AMSC and the document "Geotechnical Principles For Stable Slopes", April 1998.

Figures 8 and 9 : Quarternary Geology
For Southern Ontario
Figure 10: Bedrock Geology of Ontario

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[1] Work in Progress: Adaptive Management of Stream Corridors in Ontario, 2000
[2] Work in Progress: Adaptive Management of Stream Corridors in Ontario, 2000
[3] Ibid

Figure 11 - Confined system

Figure 12 - Confined system

Figure 13 - Confined system

Geologic constraints on rivers (valley walls, bedrock sills, terrain) can affect their channel shape and pattern, and susceptibility to erosion. Valley systems can include alluvial deposits, flood plains, and terraces. Most rivers are not "alluvial rivers" since they do not flow on self-deposited sediments, but rather across terrain that has been formed or altered by glacial processes.

For the purpose of addressing erosion and slope stability hazards in river and stream systems, the following general landform types have been selected;

a) Confined watercourse is within a valley corridor with or without a floodplain, confined by the valley walls,

b) Unconfined watercourse is not within a valley corridor, but relatively flat to gently rolling plains, and is not confined,

Figure 14 - Unconfined system

The **confined** river valley or stream system is one in which the physical presence of a valley corridor containing a river or stream channel (may or may not contain flowing water) is visibly detectable from the surrounding landscape by either field investigations, aerial photograph and/or map interpretation. The location of the river or stream channel may be located at the base or toe of the valley slope, in close proximity to the valley slope toe (less than 15 m) or removed from the valley slope toe (15 m or more).

Figure 15 - Unconfined system

An **unconfined** river valley or stream system is one in which a river or steam is present but there is no discernible valley slope that can be detected from the surrounding landscape by either field investigations, aerial photography and/or map interpretation. For the most part, unconfined systems are usually located within the headwater areas of drainage basins and in fairly flat terrain. The river or stream channels contain either perennial (year round) or ephemeral (seasonal or intermittent) flow and may range in channel configuration from seepage and natural springs to detectable channels.

2.2 SOIL COMPOSITION AND PROPERTIES

Soil has properties that can be unique to each site and quite variable, so that a subsurface investigation of soil stratigraphy and strength properties should be considered at every site where the slopes are high and steep (i.e., higher than 2 m and steeper than 3 to 1, horiz. to vert.) or where there are issues of public safety or property value.

Soil slopes and river banks can be composed of a single soil type (referred to as 'massive' or homogeneous) or, of many soil layers (stratified) with different strength properties. Similarly a wide variety of ground water and seepage conditions may occur, ranging from dry conditions to several distinct ground water flow systems within the same slope.

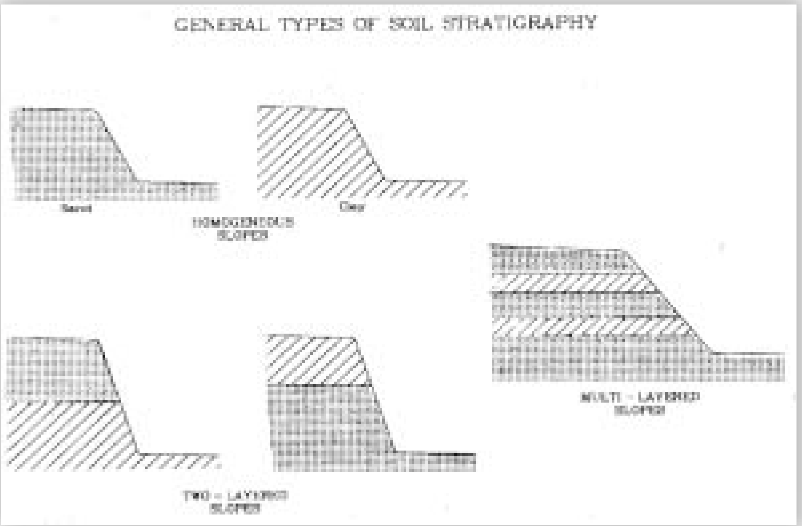


Figure 16 - Layered Soil Stratigraphy

Figure 17 - Layered Soil Stratigraphy

Much of Ontario has been subjected to the Wisconsinan glaciation (about 12,000 years ago) when thick glaciers advanced and retreated across the land. This period created the soil deposits , surface features, and drainage patterns of much of southern Ontario (refer to Chapman and Putnam, 1984; Physiography of Southern Ontario). The most common glacial deposits found in Ontario are noted below;

- •**glacial till** is a heterogeneous mixture of many particle sizes ranging from clay to boulders (clayey silt, sandy silt, silt and sand); transported and laid down near the base of a glacier; typically consolidated and competent; non-sorted and non-stratified; 'till' is a Scottish word describing a stony clay; sometimes referred to as 'boulder clay'
- •glaciofluvial **outwash sands and gravels** (alluvium) were deposited by drainage of ice meltwater, often well-sorted and stratified.
- •**glaciolacustrine clays and silts** (laminated or varved) deposited in bottoms of glacier lakes and ponds; fine-grained.
- •**glacial marine sediment** (Leda clays) clay-rich, flocculated structure, sensitive,
- •**ice-contact stratified drift** (kames, eskers, kettles) modified by meltwater during or after deposition; may have considerable sorting and stratification, as well as large range of sizes, chaotic structure, and inclusions of till.
- •**eolian deposits** of sand dunes, sand sheets, and loess.

After the glacier retreat, the Ontario landscape was subjected to erosion and the cutting of river valleys as the result of surface run-off and drainage. Locally the glacial deposits have been modified by this erosion. Land development activities such as cutting and filling (earth-moving) and drainage may also result in significant changes to soil and ground water conditions.

A soil mass is composed of individual soil particles in which there are void spaces between the particles, filled by either air or water. In engineering terms, soil is defined as "unconsolidated material composed of discrete solid particles". There is a large variety in distribution of the particle sizes and shapes in soils, ranging from granular soils such as gravel or sand, to clay soils or mixtures thereof. Soil descriptions are based on the "gradation" or distribution of particle sizes (by weight) for the following general types;

Table 2.0 - Soil Particle Sizes

Soil Type	Range of Particle Size (equivalent diameter)	Texture	Notes
gravel	2 to 60 mm	coarse	grape-, pea like; cobbles 60 to 200 mm, grapefruit-like
sand	0.06 to 2.0 mm	gritty	particles visible by eye, salt-, sugar-like, gritty feel
silt	0.002 to 0.06 mm	smooth	powder-like, grains not visible to eye, cannot roll thread
clay	< 0.002 mm	silky	smears, can roll thread, like play-dough

Coarse grained soils can be readily recognized in the field by visual examination (by eye) and direct measurement of soil particle sizes (by tape measure). A "rapid sedimentation test" can also be helpful. Place soil in a tall bottle of water, shake, then place bottle upright and allow the suspended soil particles to sediment. Sand sizes and coarser will have settled to the bottom after about 1 minute.

The sense of touch (tactile examination) can be used to distinguish between sand, silt, and clay. Sand has a gritty, sharp feel. Silt has a rough feel and clay has a smooth, greasy feel. Clay sticks to your fingers and dries slowly. Silt dries fairly quickly and can be dusted off the fingers easily (slight stain residue left).

Silty soil can also be identified with the "dilatancy test". A wet pat of soil is shaken or tapped in the palm of the hand. If there is a high silt content in the soil, it will exhibit dilatancy and will show free water on the surface. This water will disappear when the soil pat is squeezed.

Figure 18 - Dilatancy Test

The "shine test" can be used to determine the presence of clay. A lump of slightly moist soil is cut using a knife blade. The cut soil surface will appear either shiny (indicating a significant clay content and high plasticity) or dull (indicating a low clay content and low plasticity).

In addition to the grain size distribution, soils are also identified or classified on the basis of various other "index properties" such as "density, water content, and plasticity".

Soils containing significant amounts of clay and silt are termed "cohesive". These soils can stick together in a cohesive mass or clump. The individual particles are generally not distinguishable by the unaided eye (too fine). These soils are termed "plastic" as they can be moulded in a cohesive mass or shape when moist. A measure of the "plasticity" can be obtained with a laboratory Atterberg Limits test.

The very fine individual clay particles are plate-shaped or flake-shaped and can be arranged in a "flocculated" condition similar to a house of cards or, in a "dispersed" condition with aligned orientation of the particles.

For further information on the soil properties of cohesionless and cohesive soils, see Appendix 1, Appendix 2 and the document "Geotechnical Principles for Stable Slopes", 1998.

The erosion rates and properties of bedrock can vary from a hard granite, to limestone, to a very soft shale as indicated below.

The properties of shale can vary greatly depending on its durability. Long-term stable slope angles of 8° to near vertical have been observed. Most natural slopes of shale have weathered to a stable inclination (usually not steep unless interbedded with more resistant rocks) and stability becomes an issue only for excavations or highway cuts. For highway cuts in shale slopes, it is quite common to see design slope inclinations of about 1 to 1 (horiz. to vert.) to about 1.5 to 1 (horiz. to vert.).

As previously discussed, potential natural hazards in river and stream valley systems are typically related to either or both; toe or bank erosion by water flow, and slope instability and slope slides or failures.

The following soil classifications or categories have been chosen for use in evaluating slope toe or bank erosion resistance to river and stream flows;

1. **Hard Bedrock (i.e., granite)**.

2. **Soft Bedrock (e.g., shale, limestone), or**
   Cobbles, or Boulders.

3. **Stiff/Hard Cohesive Soil (e.g., clays, clayey silt), or**
   Coarse Granular (e.g., gravels, sandy gravel), or
   Glacial Till.

4. **Soft/Firm Cohesive Soil, or**
   Fine Granular (e.g., sand, silt), or Fill.

(see illustration below)

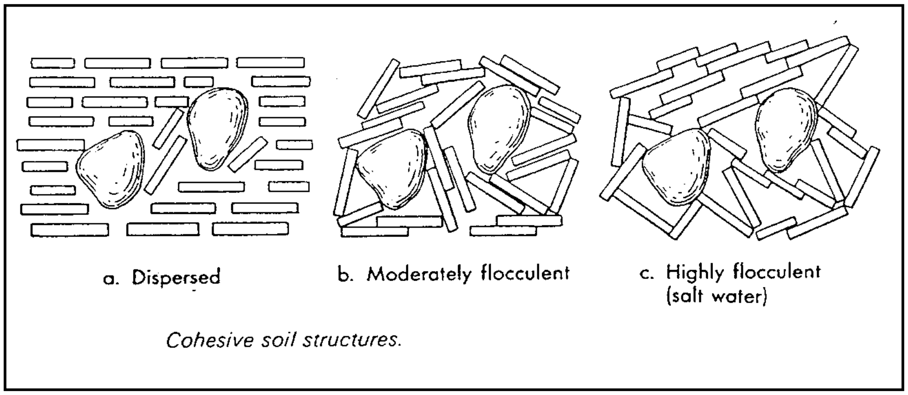


Figure 19 - Flocculated Particle Arrangement

Figure 20 - Soft Bedrock - Limestone

Figure 24 - Soft Bedrock Shale

Figure 21 - Soft Shale Slope

Figure 26 - Stiff/Hard Cohesive - Clayey Sill

Figure 22 - Hard Bedrock - Granite

Figure 26 - Coarse Granular - Gravel

Figure 23 - Soft/Firm Cohesive

Figure 27 - Fine Granular - Sand

2.3 PHYSICAL FEATURES AND PROCESSES

Most of the drainage features in Ontario, were formed as a result of very large surface runoff following Pleistocene glaciation some 10,000 to 12,000 years ago. River valleys and stream corridor systems are by nature dynamic, constantly changing landforms due to the erosive forces of flowing water and the relative stability of surrounding bank sand slopes. The spring season usually experiences fierce fluvial action (snow meltwater, rains, ice jams, flooding). The degree and frequency with which morphological (physical) change will occur in these drainage systems depends on the interaction of a number of interrelated factors including hydraulic flow, storm frequencies, channel configuration, sediment load in the system, and the stability of the banks, bed and adjacent slopes. A summary of the fundamental processes of river and stream systems can be found in the section on Stream Corridors: Form, Function & Processes of the AMSC[5] report.

Man-made changes to the watershed, have also affected water courses and their equilibrium of hydrology and hydraulics. These result in ground loss or movement, and the creation of hazardous conditions that pose a threat to human lives and cause property damages. Millions of dollars are spent annually in attempts to remedy erosion and slope stability problems of varying degrees of risk to life and property.

Even with the installation of remedial measures (i.e., assumed to address the erosion hazard), the natural forces of erosion and water flow rates may prove to be such that the remedial measures may only offer a temporary solution or a very limited measure of protection.

River and stream systems are part of larger overall drainage watersheds, and the river and stream mechanics are linked to the watershed processes. The natural importance of rivers and stream systems in providing physical, biological, and chemical support functions for sustaining ecosystems (including that of humans) is well established. These support functions are strongly associated with the physical processes of discharge (flow), erosion, deposition and transport that are inherent in any fluvial system. Given that ecological sustainability is based on the dynamic nature of these systems, it is essential that their physical processes (i.e., flow dynamics) be allowed to function in a natural state. Erosion is dependent on a number of processes as well as the composition and morphology of the watershed.

Figure 32 - Manmade Hazard Damages - Collapsed Wall

Figure 28 - River Processes - Erosion

Figure 29 - River Processes - Ice

Figure 30 - Wind Erosion Damages on Soft Sand

Figure 31 - Manmade Hazard Damages

2.3.1 Scope, Scale & Spacial Extent

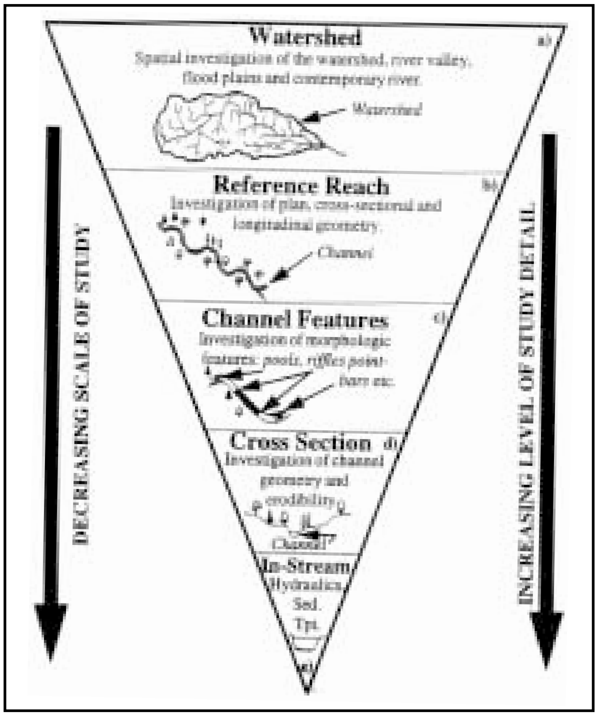


Figure 33 - Scales of Investigation (MNR)

The river and stream systems function on a watershed/subwatershed basis, it is for this reason that it is extremely important to determine the extent of the scope, scale and spacial extent of the site that it effects. The river systems study area is likely much larger than the site itself. Rivers and streams are integrated flowing systems that create and maintain habitats within the structure of their flow as well as on and beyond their wetted boundaries. The effects from the site may not only be felt up or downstream but also well outside the areas that maintain the flows along the valley or stream corridor.

In order to determine the scope, scale and spacial extent required in an investigation for a particular site, it is important to recognize the major differences in information requirements associated with these variables. A discussion on the effect and role of scale is presented in the AMSC[6]. It is helpful to outline the general range of possible levels of investigation. The following list illustrates four general levels and is presented from work prepared by MNR, 1994 fig. 33 and Newbury, 1993 fig. 34. The MNR ranges are described according to the level of investigation required depending on the geographic scale of the application and its related hydrology and flow network. In Newbury's work, within the watershed the flow habitats are nested within one another at smaller and smaller scales. These habitat scales coincide with the levels presented by MNR.

Level 1: Watershed or Channel Segment

This involves the investigation of the stream system in the context of its watershed. The overall stream and valley system network and linkages to the adjacent table lands are considered. The size and geometry (width, depth, slope) of stream segments within the overall watershed are determined using such things as flows from the tributary drainage areas, ground water recharge and discharge areas should also be identified.

Level 2: Individual Reach

Reaches may be distinguished within a segment with characteristic riffles, pools, substrates, and channel patterns. This will also include identification of boundary conditions such as the flow regime from an upstream area or sediment loads.

Level 3: Cross Section of Reach

A specific cross sectional area within a section of the reach is defined. The local flow conditions within a specific section of the reach can be determined.

Level 4: Site

The specific, localized features and issues are identified at this level. Newbury's fourth level considers the boundary layer habitat of an individual benthic organism located within the local flow structure. It may be characterized by direct and analogous measurements. Newbury extends this level by introducing a further level which can not be observed directly but can be implied from measurement of the local piezometric gradient and the conductance of the streambed deposits.

The following figure indicates the levels and how they relate to the nesting of smaller and smaller levels of stream habitats.

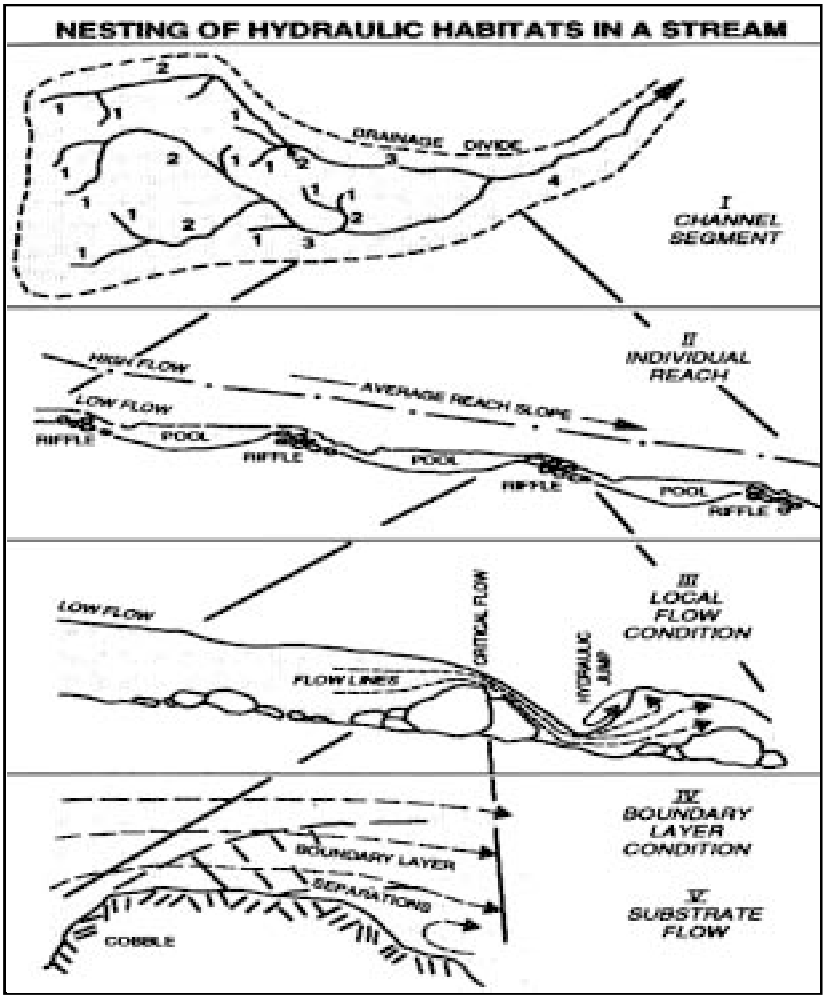


Figure 34 - (Newbury, 1993) - Nesting of Smaller Levels of Stream Habitats

2.3.2 River and Stream Classifications

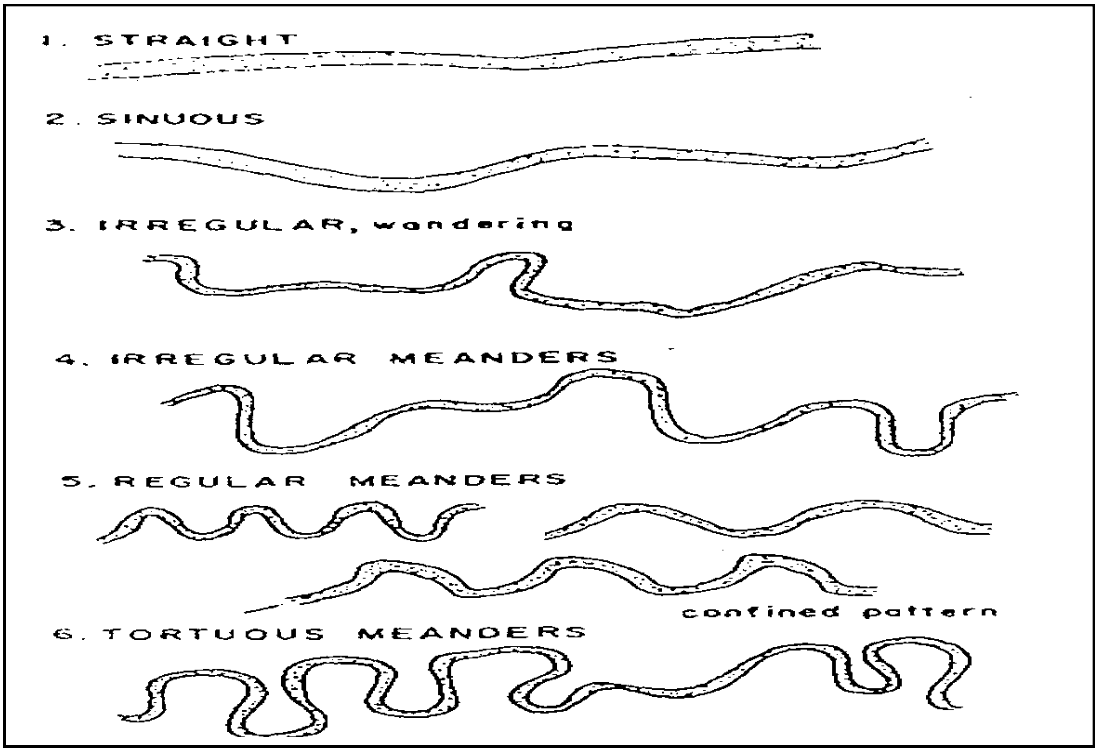


Figure 35 - River Patterns

Classification systems allow comparison of river features and behaviour, based on similar characteristics.
The complexity of the interaction of the above variables in ravines, river valleys, and stream corridor environments results in a wide array of drainage and stream/ river types and patterns (Leopold et al, 1964).

There are a variety of classification systems available. A discussion on the various systems and their attributes is provided in a section of the AMSC[7] report.

2.3.3 Flow Regime

The flow component of river and stream systems plays a significant roll in the determination of the channel form. The “flow regime” defines the amount, intensity, duration, magnitude, and frequency of a precipitation event. This can encompass valley, floodplain, riparian, baseflow and bankfull flows. Refer to chapters 2 and 4 of the AMSC document for further details on the various flow regimes and the following figure.

2.3.3.1 Bankfull Conditions

The bankfull conditions are important in determining the erosion hazards for river and stream systems. For confined and unconfined systems the erosion hazard guide indicates the bankfull width can be used to determine the erosion allowance and the “meander belt allowance (20 x bankfull width).’ If information on the Flooding Hazard Limit is not available or if the proponent prefers to determine the erosion hazard allowance by using the meander belt analysis then a detailed study may be conducted for the particular stream or river.

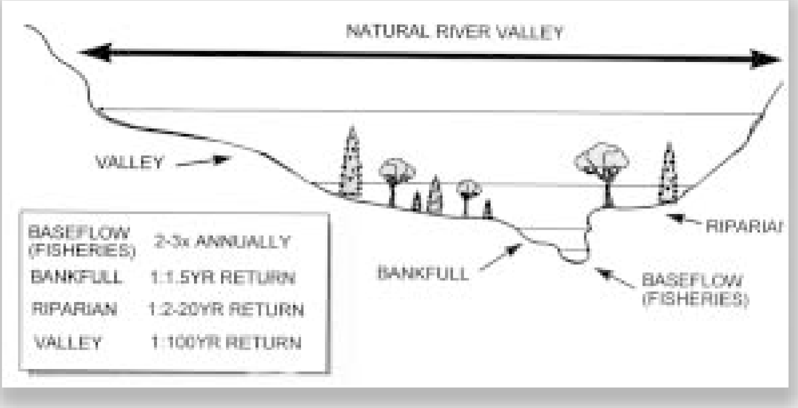
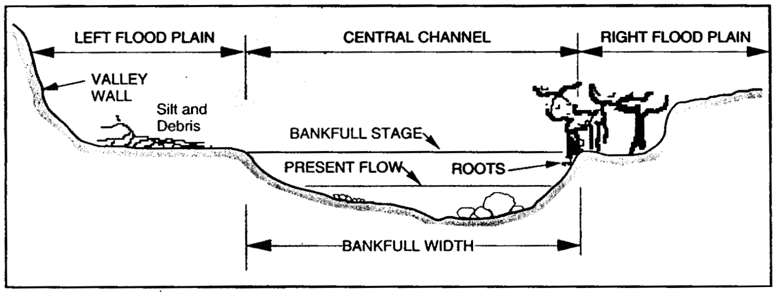


Figure 36 - Stages of Flow

Numerous technical sources have indicated that the bankfull discharge is the event that determines channel morphology or change. The “channel-forming discharge” or the bankfull width can be identified in the field by scour lines, vegetation changes, or recent sediment. Bankfull channel width is commonly determined through either field investigations or through aerial photograph interpretation. (See Section 3.3 for



Cross section of stream valley with floodplains and a well-defined central channel and bankfull stage.

Figure 37 - Stream Valley Cross-section

Figure 38 - Bankfull Conditions

Figure 39 - Bankfull Conditions

further information). It can also be estimated on the basis of hydrologic analysis of storm flow levels for bankfull conditions.

The regularly recurring bankfull flood maintains the central channel or channels and may be used as the channel characteristic or maintenance flow in relationships that describe the width, depth, and bed materials in sample reaches. In many basins, a strong correlation exists between the bankfull discharge and the tributary drainage area. As indicated in Figure # 40, the relationship may be used to compare the runoff characteristics of different basins. The dashed lines in Figure 40 bracket the range of relationships for streams with high and low runoff regimes in the United States (Newbury, 1994).

Establishing the natural channel geometry relationships for a stream is an important step in understanding the stream's behaviour and characteristics. The drainage area the channel geometry measurements may be linked to the channel pattern and profile. If structures in these areas are required, they can be used to dimension stream rehabilitation works that mimic natural conditions. Even a preliminary estimate of the hydraulic geometry based on an abbreviated field survey in which only the bankfull width and depth are measured will provide useful guidelines. (Newbury 1994) The following graphs (Figures 41 to 42) was produced by plotting data from Ontario streams on top of existing data from the United States and Canada.

For further details and plots, please see Section 3.1.1, A procedure entitled "Stream Assessment Protocol for Ontario", 1998 included a procedure for determining the bankfull characteristics in the field. It is a very useful tool for application of the bankfull width.

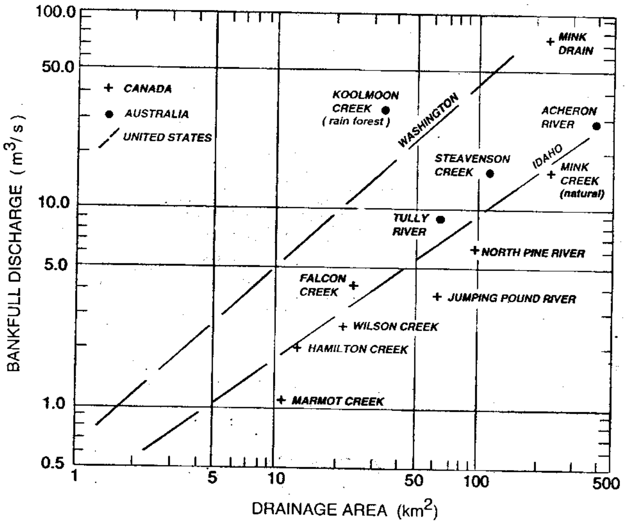
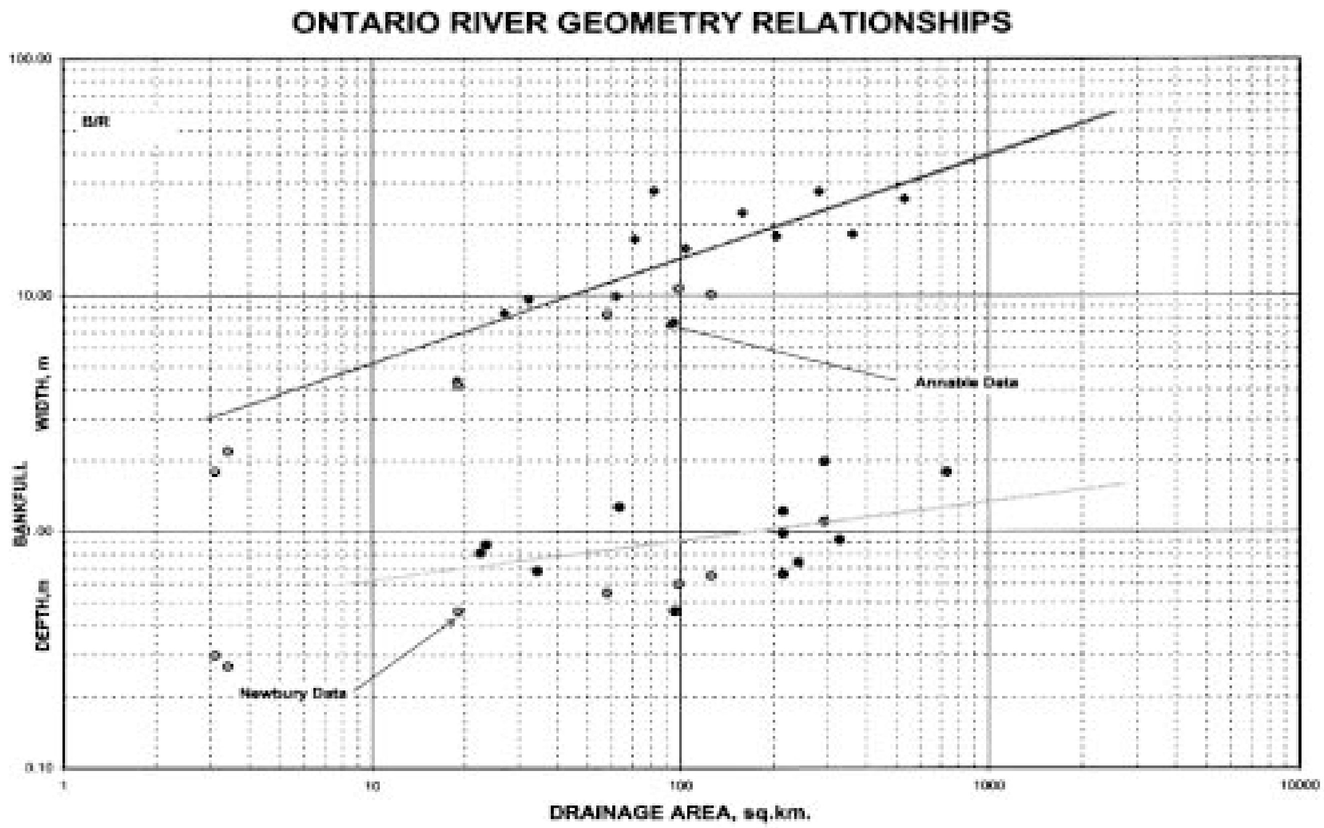


Figure 40 - Bankfull Discharge vs Drainage (Newbury, 1994)

ALL DATA

	Watercourse	DRAINAGE AREA (km2)	BANKFULL DEPTH (m)	BANKFULL WIDTH (m)	BANKFULL DISCHARGE cu.m/s	STREAM CLASS
ANNABEL DATA						
1	BEAR CREEK BELOW BRIGDEN	533.0	2.38	25.67	27.94	C6
2	BEAVERTON RIVER NEAR BEAVERTON	282.0	0.94	27.60	42.40	C4
3	BIG CREEK NEAR DELHI	362.0	1.42	18.20	29.73	F4
4	BLACK CREEK BELOW ACTON	18.9	0.61	4.36	2.27	E4
5	BOWMANVILLE CREEK NEAR ELMIRA	104.0	0.60	15.80	18.40	C3
6	BURNLEY CREEK ABOVE WARKWORTH	71.2	0.68	17.30	16.35	C4
7	CANAGAGIGUE CREEK NEAR ELMIRA	82.3	0.74	27.63	26.23	C4
8	COLD CREEK AT ORLAND	159.0	1.22	22.34	19.21	C4
9	COPELAND CREEK NEAR PENETANGUISHENI	26.9	0.52	8.40	3.61	C5
10	CREDIT RIVER AT BRIMSTONE	22.5	0.81	12.70	18.25	B3
11	CREDIT RIVER NEAR CATARACT	205.0	0.84	17.80	17.48	C4
12	CREDIT RIVER - ERIN BRANCH ABOVE ERIN	32.3	0.59	9.60	3.29	C5
13	WEST CREDIT RIVER ABOVE THE FORKS OF	96.0	0.46	10.40	9.64	B3
14	CREDIT RIVER NEAR ORANGEVILLE	62.2	0.80	9.90	6.72	C5
15	EAST HUMBER RIVER AT KING CREEK	94.8	1.38	7.70	13.70	E4
16	EELS CREEK BELOW APSLEY	241.0	0.74	15.40	21.68	B1
17	ERAMOSA RIVER ABOVE GUELPH	236.0	0.60	27.40	17.80	C3
18	FAREWELL CREEK AT OSHAWA	58.5	0.54	19.20	8.74	C4
19	GANARASKA RIVER NEAR DALE	262.0	1.30	27.60	49.87	C4
20	GANARASKA RIVER NEAR OSACA	67.3	0.93	11.30	14.26	E4
21	HOG CREEK NEAR VICTORIA HARBOUR	65.2	0.91	10.20	14.15	E4
22	HORNER CREEK NEAR INNERKIP	108.0	1.37	8.50	15.28	E5
23	HUMBER RIVER NEAR PALGRAVE	117.0	0.84	15.20	12.60	C4
24	IRVINE CREEK ABOVE SALEM	215.0	0.66	32.60	53.84	C1
25	IRVINE CREEK AT ELORA	215.0	1.22	16.50	53.84	F2
26	IRVINE CREEK AT SALEM	215.0	0.98	15.60	53.84	F1
27	MAITLAND RIVER AVOVE WINGHAM	528.0	1.80	43.60	96.40	C3
28	MAITLAND RIVER NEAR HARRISTON	112.0	0.74	26.50	24.67	C4
29	McKENZIE RIVER NEAR CALEDONIA	171.0	0.57	22.30	15.29	C5
30	NOTTAWASAGA RIVER AT HOCKLEY	172.9	0.92	14.30	20.00	C3
31	NOTTAWASAGA RIVER NEAR BAXTER	1180.0	1.99	39.00	98..73	C5
32	PEFFERLAW BROOK NEAR UDORA	332.0	0.76	22.60	18.45	C4
33	PINE RIVER NEAR EVERETTE	195.0	0.83	11.50	14.50	F4
34	PINE RIVER NEAR KILGORIE	75.0	0.65	12.30	9.97	B3
35	REDHILL CREEK BELOW ALBION FALLS	23.5	0.88	14.50	18.16	B3
36	SAUGEEN RIVER ABOVE DURHAM	329.0	0.92	41.70	73.50	C3
37	SILVER CREEK AT NORVAL (ROGERS CREEK	127.0	0.64	18.80	12.92	B4
38	SIXTEEN MILE CREEK BELOW HILTON FALLS	34.5	0.68	14.90	16.79	B3
39	SWAN CREEK NEAR ELORA	34.0	0.78	5.20	7.62	E4
40	SYNDENHAM RIVER AT ALVINSTON	730.0	1.79	48.70	84.90	C1
41	TROUT CREEK NEAR FAIRVIEW	36.0	1.14	8.60	16.93	F4
42	TWELVE MILE CREEK BELOW DECEW FALLS	63.5	1.27	8.60	19.25	A3
43	TWENTY MILE CREEK ABOVE BALLS FALLS	293.0	1.10	31.50	66.94	C1
44	TWENTY MILE CREEK BELOW BALLS FALLS	293.0	1.98	15.20	66.94	A2
45	WILLOW CREEK ABOVE LITTLE LAKE	94.8	1.57	13.70	22.65	E5
46	WILLOW CREEK AT MIDHURST	127.0	0.78	15.70	10.98	C4
47	WILMOT CREEK NEAR NEWCASTLE	82.6	0.90	13.71	18.00	C5
NEWBURY DATA						
48	DON RIVER	3.1	0.30	1.80		
49	DON RIVER	3.4	0.27	2.20		
50	DON RIVER	19.0	0.46	4.20		
51	DON RIVER	57.9	0.55	8.30		
52	DON RIVER	98.3	0.60	10.70		
53	DON RIVER	125.5	0.65	10.10		

Figure 41 - Ontario River Data List



Sources: Database of Morphologic Characteristics of Watercourses in Southern Ontario (W.K. Annable, Oct. 1994)
Stream Analysis and Fish Habitat Design (R.W.Newbury, M.N.Gaboury, 1993)

Figure 42 - Ontario River All Data - Chart 1

2.4 Sediment Regime

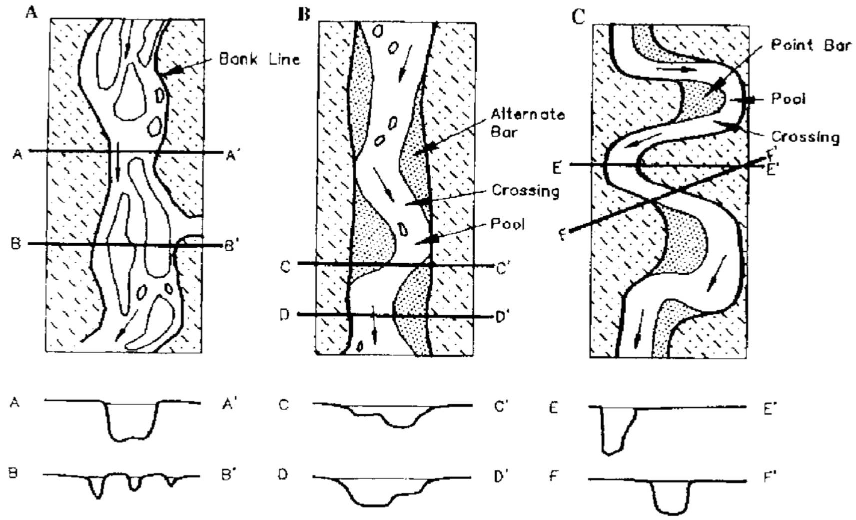


Illustration of planform patterns for stream channels (after Simons *et al.*, 1975; Simons, Li and Associates, 1982). (A) Braided, (B) straight, (C) meandering.

Figure 43 - Plan View River Patterns

The pattern (plan view) of rivers has been classified as “braided, straight, or meandering”, or some combination of all three (Leopold and Wolman, 1957). If the channel walls and bed are alluvial (cohesionless sediments), the natural river shape tends to be sinuous and not straight.

A discussion on sediment loads and channel thresholds can be found in the section on Form, Function and Processes in (AMSC, 1999).

Meandering channels are S-shaped and serpentine. Within the channel width is a narrow deep section termed the “***thalweg***.” Along the channel, the position of the thalweg shifts in a sinuous shape. The deepest part of the channel is located in a “pool” at the apex of the meander. A shallow “riffle” often occurs in the straight sections between meanders.

The degree of **sinuosity** (index) is the ratio of the channel length, to the length of the meander belt axis. Studies on channel meanders (Schumm and Khan, 1972) found that sinuosity increased with increasing channel gradient, to a threshold gradient beyond which the channel pattern changes from meandering to braided (Figure 45) (Lane 1957).

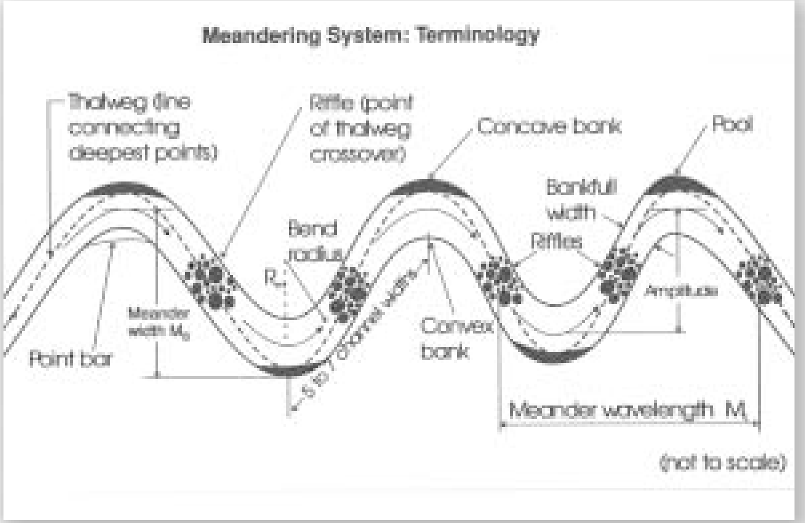


Figure 44 - Meandering Systems

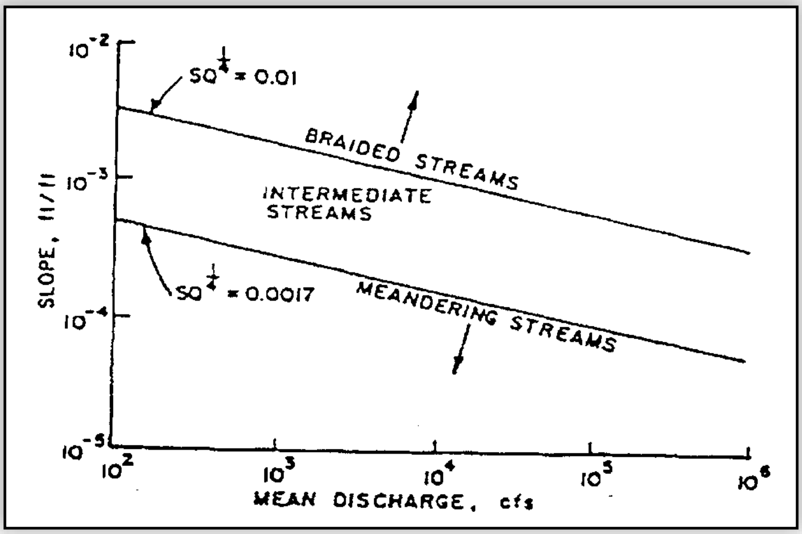


Figure 45 - Threshold River Gradients

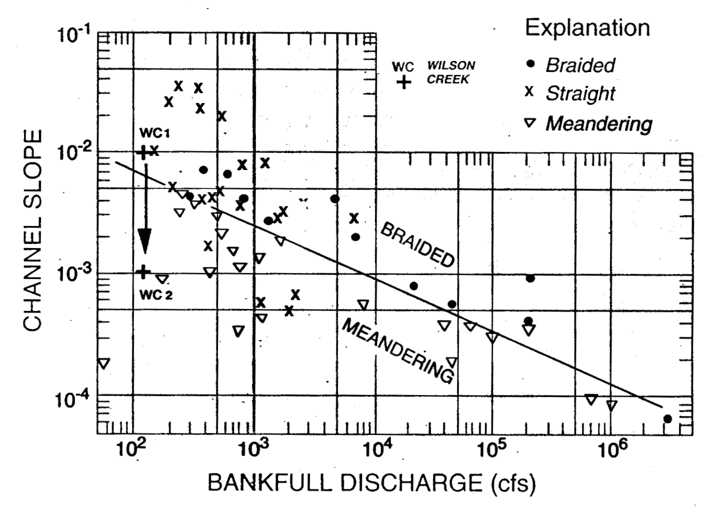


Figure 46 - Bankfull Discharge & Channel Pattern (from Newbury, 1994)

Stream patterns are seldom uniform throughout a drainage basin. For example, in streams with steep reaches and low-gradient lower reaches, the channel often shifts from a straight or braided pattern to a meandering pattern. A relationship between the reach slope, bankfull discharge, and channel pattern has been observed by Leopold and Wolman (1957) as shown in Figure 46 . The figure also illustrates two sample reaches where there is a shift in pattern from straight to meandering pattern (Newbury 1994).

Studies on watercourse channel profiles (Schumm, 1960) found the following affect of sediment load on width to depth ratio.

Sediment Type	**Width to Depth Ratio**
clay and silt	small
sand	large

In any fluvial system, the resultant "morphology" or change of the channel is a result of the dynamic balance of energy (flowing or discharge of water) and the resistance of material comprising the channel perimeter (Morisawa, 1985). As such, the channel form (e.g., shape, size, configuration) is governed by its need to carry sediment load (bed, suspended and dissolved) using the availability of water flows (discharge). A change in any of the variables (discharge, load, resistance) will result in a change in the channel form. One result of this change may be a shifting of the watercourse channel causing a meander and new channel orientation to form.

Several empirical relationships have been derived to describe river or stream morphology, referred to as "regime" equations (Leopold et al, 1964). For a list of some of these empirical relationships refer to Appendix 2. These describe relationships between the discharge flow and the river shape and dimensions. It has been accepted that channel shapes and patterns are formed mainly by the "bankfull discharge". Often flood events in Ontario are produced by snow melt which may be accompanied by rainfall. Natural watercourses experience frequent changes in flow rates and sediment loads.

Relationship observed between slope, bankfull discharge, and channel pattern (Leopold and Wolman 1957).

2.4.1 Sinuosity

Figure 47 - Meandering Systems

Figure 48 - Meandering River System

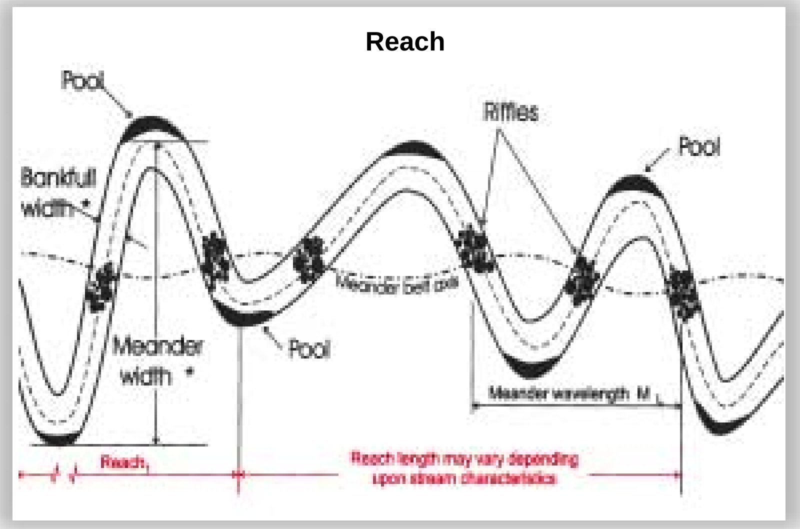


Figure 49 - "Reach", a length of channel over which channel characteristics are stable or similar.

Unconfined ravines, river valleys and stream corridor systems tend to be predominately located within relatively flat terrain. They normally contain perennial (year round) or ephemeral (intermittent) flows which may have a tendency to constantly shift or meander (laterally and downstream) in response to the continuous changes associated with the natural influence of discharge and load. The maximum extent, or area of provincial interest that a water channel migrates is termed "meander belt allowance". The term "meander belt" is derived from terminology used to describe meandering systems.

Watercourses have a natural tendency to "sinuosity" in the lower reaches where bed downcutting is reduced. "Meandering" refers to the tortuous shape of the channel in plan view. The sinuous bends develop to a size governed by the bed and bank materials, and by the bankfull discharge. Changes in the bankfull discharge can result in changes in the size of the sinuous bends. A limit to the width of the meander can be caused by the development of "chutes" (short channels formed during high flows) across the inner bank sediments. The "Sinuosity Index" (SI) is used to describe the degree of meandering and is the ratio of the channel length to the downvalley distance. The Sinuousity Index can range from less than 1.05 to more than 1.5. 1.5 is appropriate for many streams and is a measure of the "wiggliness" or "tortuosity" of a watercourse. Meandering channels have an SI of 1.5 or more and are more common to cohesive bed and bank soil materials. The typical bankfull velocity of a meandering stream is between 1 and 3 metres per second.

2.4.2 Reach

A meandering system is comprised of a series of interconnected reaches. A "reach" is defined as a length of channel over which the channel characteristics are stable or similar. The extent of a reach depends on the geometry and dynamics of the channel. It is often measured in multiples of channel width, meander wavelengths, or riffle-pool sequences. Measurements should be taken over a length sufficient to establish the stable characteristics of the channel. All geomorphological features and types of aquatic habitat should be proportionally represented in the section of the stream being assessed, and at least two of each of the major features of the section should be represented. Measurements of channel characteristics within a reach should be carried out so that the range of conditions within the reach can be specified (MNR, 1994).

Similar biological characteristics can also be measured to assist in determining the reach. Frissell et al. , 1986 suggest that habitats follow the same organization as the branching network of the stream reaches, implying that sample reaches for habitat surveys may be selected on the basis of stream segment order numbers or position in the drainage network.

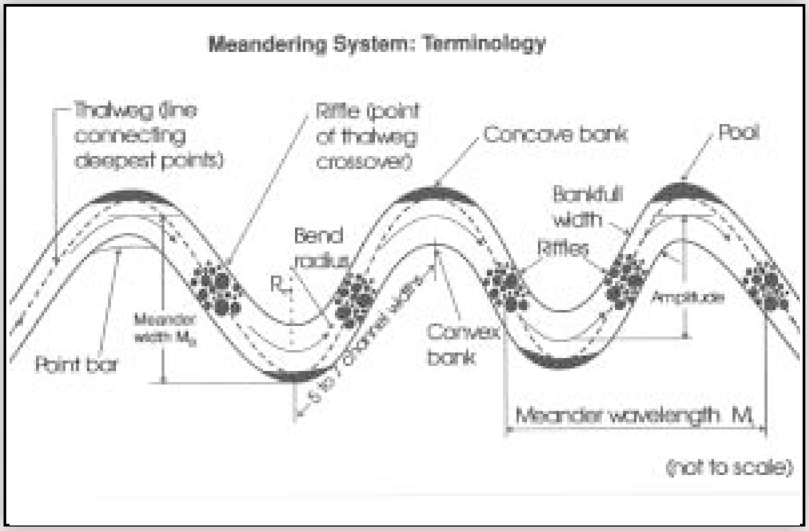


Figure 50 - Thalweg

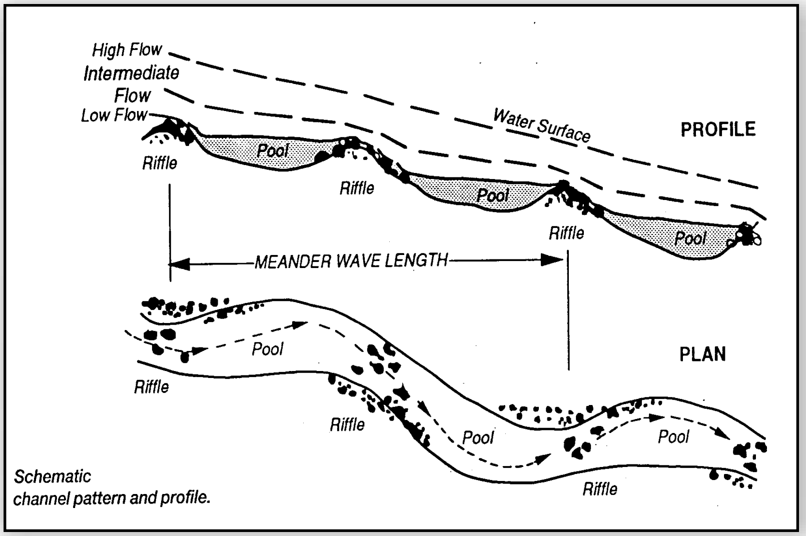


Figure 51 - Riffles and Pools (Newbury, 1993)

Figure 52 - Riffle

Meandering channels are often S-shaped and serpentine. Within the channel width is a narrow deep section termed the "thalweg". Along the channel, the position of the thalweg is the path traced by the flow that follows the deepest part of the channel, it shifts in a sinuous shape along the river or stream.

2.4.3 Riffles & Pools

Most natural channels comprise a series of riffles, made up of high points composed of coarser sediment, and pools or step-pools made up of low points with finer bed particles. The pool and riffle profile creates the diverse hydraulic habitat conditions that are required in rivers and streams with healthy habitats. At low flows, riffles have turbulent, shallow flow that aids to increase the stream's dissolved oxygen content, and are the most productive areas for generating food and acting as spawning grounds. The deepest part of the channel is located in a "pool" at the apex of the meander. The pools are resting and rearing habitat for fish. A shallow 'riffle" often occurs in the straight sections between meanders. Some natural systems, such as very steep gradient streams or ephemeral streams do not exhibit pool and riffle formations.

Pools and riffles are characteristic of meandering streams. The riffle, pool sequence occurs in intervals on average that occur 6 times the bankfull width. Upstream from the accumulations, a shallow pool is formed and downstream from the crest of the accumulation, a local increase in slope causes the flow to accelerate, forming a riffle of rapids. Under low discharge conditions, the pool and riffle profile stores water in the channel and re-aerates the flow. The effect of the pool and riffle forms are less apparent under flood conditions, although high discharges are required to scour the pools and maintain the riffle form. A further description of riffles and pools can be found in the 'Natural Channel Systems An Approach to Management and Design' MNR 1994.

The overall longitudinal profile of a stream in erodible materials is generally concave. However, with a stream segment the profile is broken into a series of smaller steps that form pools and riffles under low flow conditions as shown in Figure # 51. This naturally stepped profile forms a vertical wave form that has been observed for all channel patterns. In straight channels, the length of the pool or distance between riffles is equal to the straight line distance between the riffles that occur at points of inflection in a meandering channel.

Often the same pool and riffle profiles will develop in a stream which has been channelized in spite of their uniformly constructed gradients. The strong tendency for natural streams to follow meandering paths and to form pool and riffle profiles suggests that straightened and uniformly channelized rivers with erodible beds can only be maintained by repeated reconstruction. (Newbury, 1994)

2.4.4 Channel stability and Tractive Force

Figure 53 - Point Bars & Pools

Figure 54 - Riffle - Pool Example

Flowing water can cause surface erosion of the bank or channel. This river or stream bank erosion is often a cause of slope instability. Erosion occurring at the slope toe, acts to steepen the slope locally, and removes slope support by undercutting. The erosion can be a result of increased flow velocities from climatic events such as heavy rains or snowmelt. The magnitude or rate of erosion can be quite variable over the course of a year dependent on the volume, velocity, frequency and duration of the flows through the river or stream corridor. A heavy rainfall or rapid snow melt event may increase the potential magnitude or rate of erosion as a result of a measurable increase in water flows (discharge) into and through the river valley and stream corridors.

The most potential for erosion is by the watercourse flow itself and this is directly related to the flow velocity and its shearing force or tractive force. Tractive force is the shear stress resulting from watercourse flow and acting on the stream bed or bank materials. Bank erosion (and toe erosion) is often highly variable and episodic, usually associated with flood flows. The level or rate of toe erosion in this instance, is a function of the amount, duration, and frequencies of water flowing through the system.

The movement of coarse sediments by rolling and bouncing along the channel bed has been studied by many researchers concerned with stable channel design. Erosion occurs when the velocity of the flow acting on a channel bed or bank are greater than the resistive forces of the local material. Channel bends are exposed to velocities of higher flow than are straight channels. High shear stress zones can develop along both the concave and convex parts of the channel.

The materials can consist of non-cohesive materials (e.g., sands and gravels) or cohesive (e.g., clay) materials. The movement of the non-cohesive particles depends on the shape, size, or density of the particles, or on their relative position. Since the cohesive soils have a cohesive bond between particles, the movement not only depends on the same criteria as previously mentioned for the non-cohesive but also on the resisting force created by the cohesive bond. Generally the cohesive soils are more resistant than the non-cohesive soils to erosion.

Two general approaches are available to estimate flows that will prevent erosion: an empirical method of estimating safe velocities, or theoretical methods of computing tractive force. The empirical method of estimating the velocities can be very difficult as the velocities can be extremely variable in a river or stream system. They should only be estimated by someone who has extensive experience in the area.

The shear force caused by the water is called the tractive force. The shear stress exerted by the flow on individual particles just at the point at which they begin to move (incipient motion) has been measured in laboratory flumes but only observed indirectly in canals and natural channels. In research studies, shear stress on the surface of the streambed or on an individual particle on: the bed is determined by measuring the adjacent velocity profile with miniature current meters.

In canal and stream studies, a more general measure of shear stress, the “tractive force”, is used to characterize the average shear stress in a reach. In the following relationship, the tractive force in Kg/m2 of the streambed may be determined from two simple field measurements, the average slope of the water surface in the reach and the depth of flow.

Where   = 1,000 x *d* x *s*

= tractive force of flow (kg/m2)
and (x 9.8 for Newtons/m2)
d = depth of flow (m)
s = slope of water surface

The tractive force can be related to the size of material at incipient motion as shown in Figure 55.

The field observations and recommended design guidelines were compiled by Lane (1955) for a wide range of canals and river channels. The data are widely scattered for several reasons, for example; smooth channels with cohesive bed materials (clays and fine silts) tolerate high shear stresses until they start to erode and then become highly mobile, coarser silt and sand bed streams form ripples and dunes that move along the streambed, and gravel and cobble bed streams may develop an erosion resistant "paving" of cemented or closely packed bed material. However, for non-cohesive bed materials greater than 1 cm in diameter (fine gravel), the relationship is less scattered and may be approximated as:

Tractive force (kg/m2) = incipient diameter (cm)

Flat shale gravels and cobbles have been observed to move at approximately half of the tractive force required for an equivalent rounded particle (Magalhaes and Chau 1983).

Bed stability:

The degree of stability of a stream channel may be estimated using the bed paving material sample and reach slope observations from the field. For coarse non-cohesive bed paving materials, the mean diameter at incipient motion may be determined for different depths of flow using Lane's general relationship. The percent of the bed materials that lie above or below this value may be determined from the cumulative frequency of mean bed material size plot. (Newbury 1994).

Studies have found that a soil mass can sustain water flow without erosion of soil particles, up to a "limiting" or "critical" or "competent flow velocity" beyond which the tractive force becomes sufficient to dislodge and transport (erode) soil particles from the soil mass.

The following table (Lane, 1955) shows allowable flow velocities and tractive force for several types of bed and bank materials. The values are **for aged stable channels.**

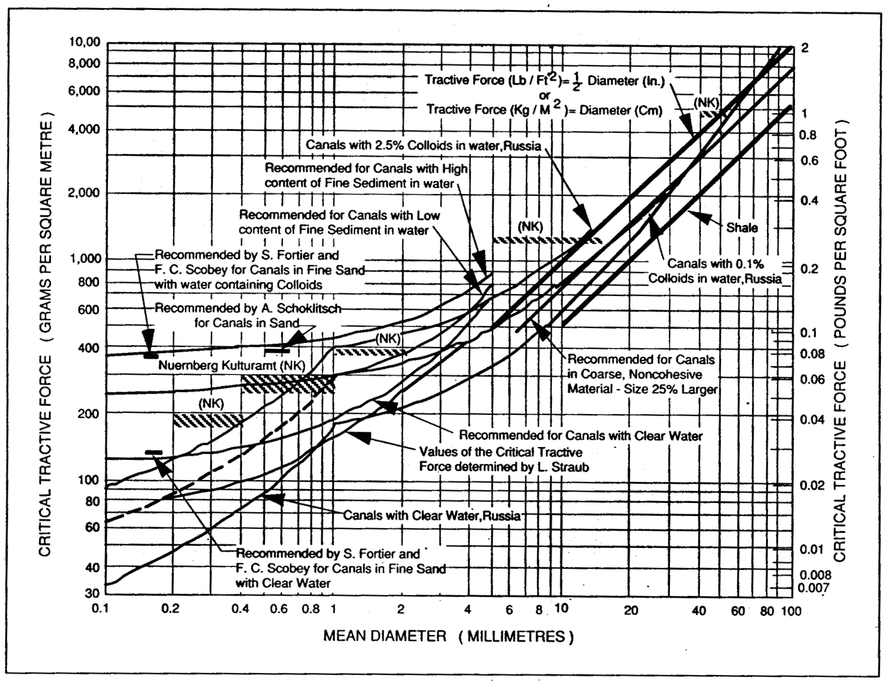


Figure 55 - Tractive Forces

Table 2.1 - Allowable Flow Velocity and Tractive Force, Aged Channels

	CLEAR WATER		SUSPENDED SILTS	
Material	Velocity (fps)		Tractive Force (psf)	Velocity (fps)
Tractive Force (psf)				
Fine Sand	1.5	0.027	2.50	0.075
Sandy Silt	1.75	0.037	2.50	0.075
Silty Clay	2	0.048	3.00	0.110
Silt	2	0.048	3.50	0.150
Firm Clay	2.5	0.075	3.50	0.150
Stiff Clay	3.75	0.260	5.00	0.460
Shale, Hardpan	6	0.670	6.00	0.670
Fine Gravel	2.5	0.075	5.00	0.320
Coarse Gravel	4	0.300	6.00	0.670
Cobbles, Shingles	5	0.910	5.50	1.100

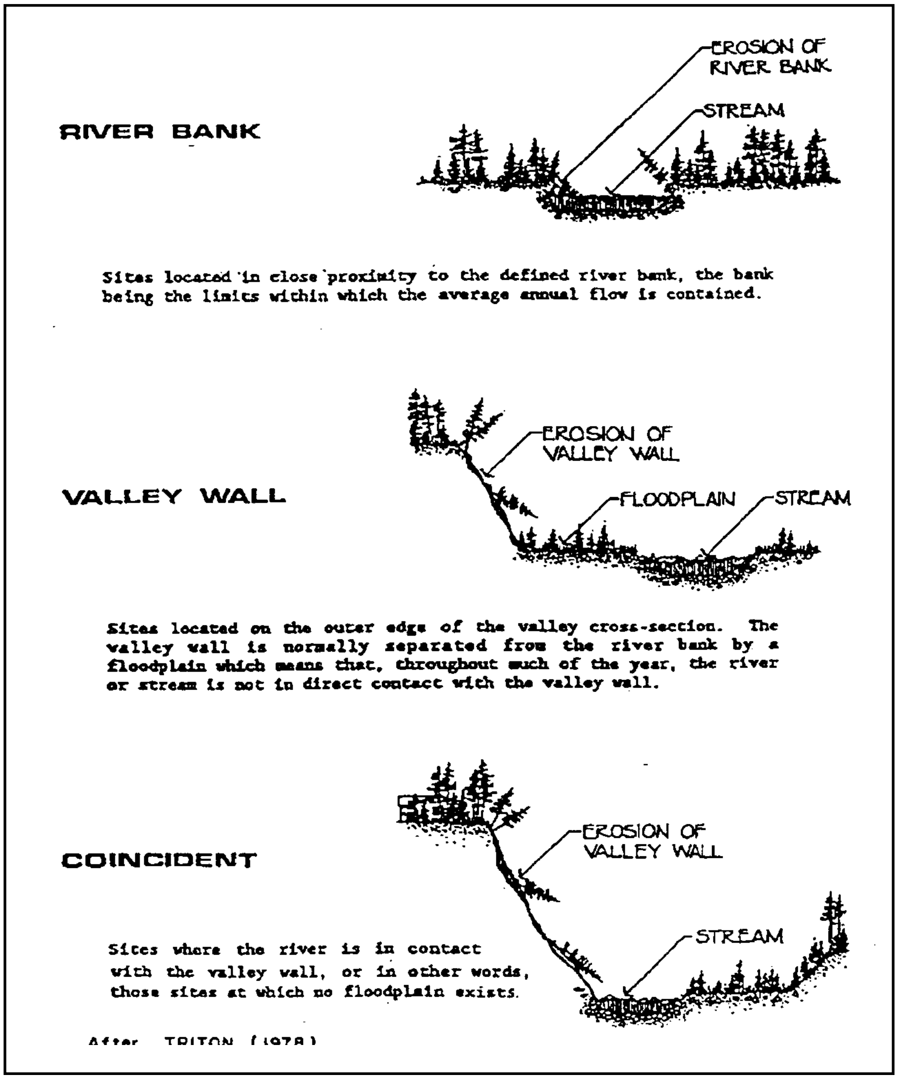
For newly constructed channels, the following values have been suggested, For high flow velocities, **rip rap** has been commonly used to protect against erosion. Rough angular shaped rock can interlock and resist over turning, better than smooth, rounded stone. Environmental considerations must be addressed when designing any structure when considering the type of material to be installed.

For the purposes of the application of the provincial policy the tractive force may be calculated to determine whether or not the existing materials are stable and whether 'active' erosion is occurring. If 'active' erosion is occurring then the left hand side of Table 3 from Section 3 should be applied when determining which erosion allowance is appropriate.

Table 2.3 - Permissible Flow Velocity, New Channels

	Material	**PERMISSIBLE VELOCITIES (fps)** Bare Channel			
Poor Fair Good	Vegetation				
	Sand, Silt	1.5	1.5	3	4
	Sandy Clay	2	2.5	4	5
	Silty Clay	2	2.5	3	4
	Clay	2.5	3	4	5

2.4.4.1 Proximity of Watercourse to Valley Wall



Sites located in close proximity to the defined river bank, the bank being the limits within which the average annual flow is contained.

Sites located on the outer edge of the valley cross-section. The valley wall is normally separated from the river bank by a floodplain which means that, throughout much of the year, the river or stream is not in direct contact with the valley wall.

Sites where the river is in contact with the valley wall, or in other words, those sites at which no floodplain exists.

After TRITON (1978)

Figure 56 - River Valley Profiles

Many rivers and streams flow in valleys that exert some degree of lateral (e.g., slopes) or vertical (e.g., bedrock) control over the river. Valleys often contain a flood plain within which the river flows. Some watercourses do not have confined valley slopes. Alluvial channels adjust their shape, gradient, and dimensions according to the discharge flow and sediment load.

If the river or stream channel is in close proximity or abuts the valley slope wall, the erosive forces of the flowing water will cause a local steepening and then undercutting of the valley wall. The degree or severity of this erosive action and its hazard or risk, are dependent on many factors including,
- the soil composition and strength
- the proximity and exposure of the slope to the water flow
- the discharge volume, rate, flow velocity, frequency, duration, sediment load.

The hazard of slope toe erosion is also a function of the proximity of the river or stream channel to a valley wall. Locations where there are changes in watercourse flow directions, such as the outside bends of rivers or channels, are particularly susceptible to slope toe erosion. This is due to the distribution of the flow velocity and the tractive force along the channel bed and bank.

The proximity of the river or valley wall to the watercourse is addressed in the policy through the application of the erosion allowance. If the river or valley wall is less than 15 m from the watercourse then Table 3 recommends an appropriate minimum setback depending on the particular soils at the site.

2.4.4.2 Internal Seepage (Ground Water)

Water seepage or ground water levels can also affect slope stability since they affect the soil strength. Piping on a slope face can be related to springs or seepage where soil erosion occurs in water bearing sands and slopes. As ground water emits from a soil slope in the form of springs, erosion of soil particles can occur and the loss of ground.

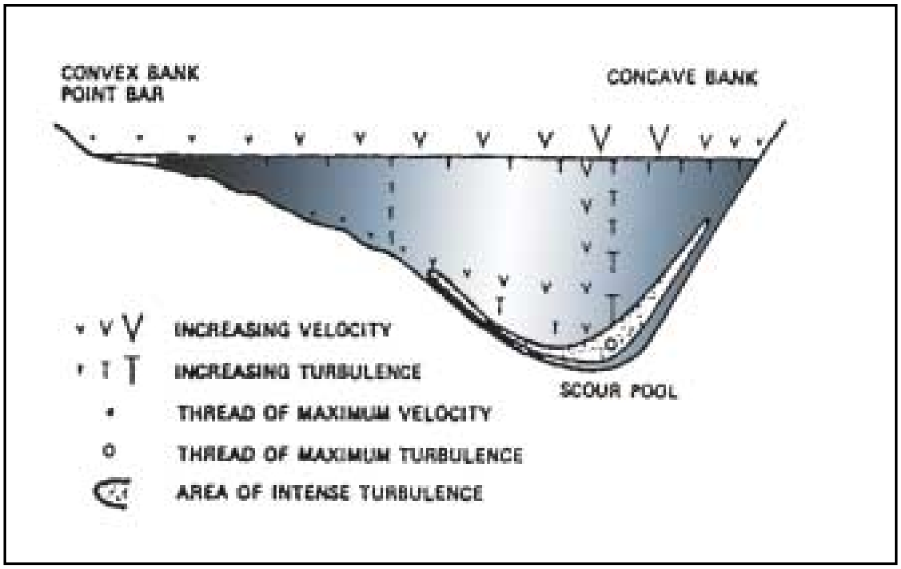


Figure 57 - Flow Velocity Distribution

Figure 58 - Piping

Figure 59 - Piping - Close up

Figure 60 - Piping Hole

Overall, water is generally regarded as the most significant cause or initiator of slope failures. As such, any hydrologic change to either surface or ground water drainage patterns can pose a direct impact on slope stability. Beyond the lubricant influence of ground water within a slope, the accumulation of ground water combined with the natural action of gravity and the overall weight of the ground water itself, will lead to a reduction in slope stability.

Figure 61 - Groundwater and Internal Drainage

Gully development typically starts at the slope toe and progresses up the slope face to the slope crest and into the table land. It also can be initiated inland by natural drainage

Figure 62 - Gully Erosion

Figure 63 - Gully Erosion

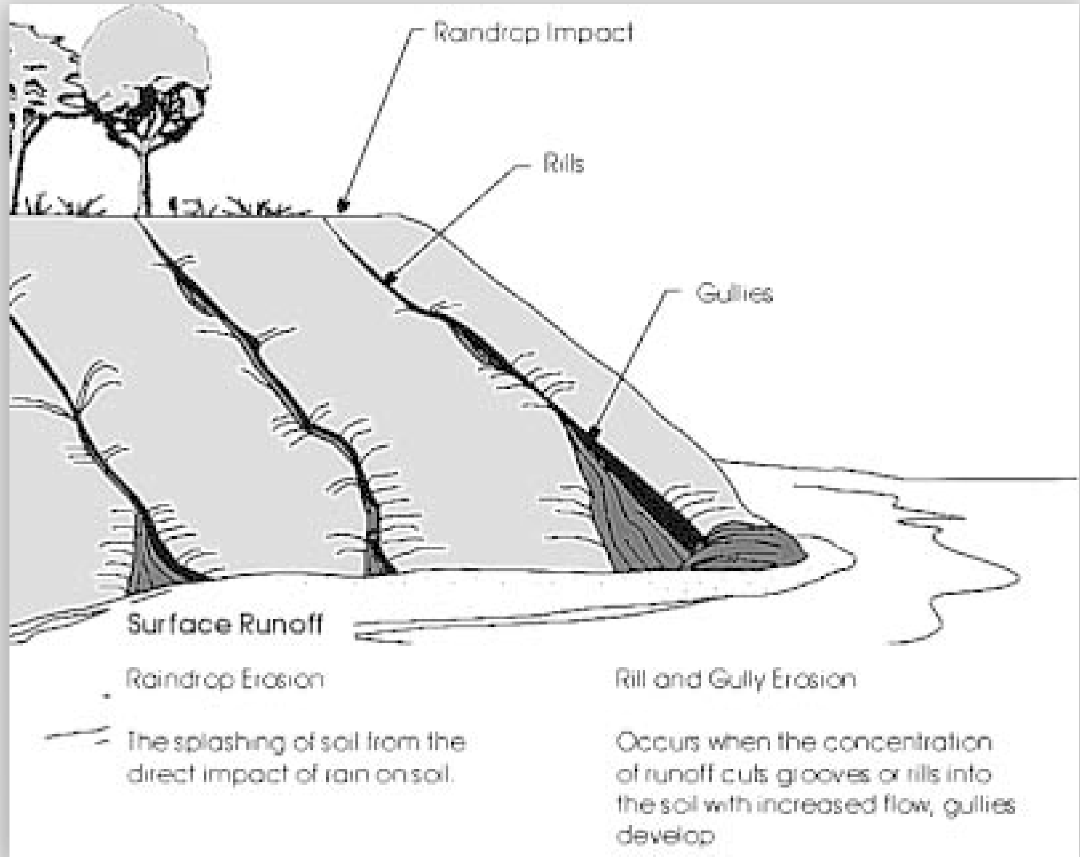
processes or by manmade drainage features such as storm sewer outfalls, ditches, farm field tiles, and the like.
The typical gully erosion process is summarized as follows;

1.sufficient run-off drainage to disrupt natural vegetation cover,
2.establishment of a drainage channel and start of downcutting,
3.channel banks steepen by continuing base erosion, until slope failure,
4.gully widens with slow slides, and debris interrupts downcutting,
5.cycle of downcutting and slumping is repeated after debris is washed away downcutting resumes,
6.gully can mature once stable gradient is achieved by drainage flows.

Erosion of the gully base followed by slumping of the side-slopes, will result in the gully slope crest receding and the loss of table land. The erodibility is influenced predominantly by the nature of the soil, and by the slope gradient (Steepness). Strongly bonded 'cohesive' soils (i.e., clays, clayey silts, tills) are generally less erodible than 'cohesionless' soils (i.e., sands, silts).

2.4.4.3 Surface Runoff

Surface runoff from rainfall or snowmelt can cause soil particles to be broken up and dislodged. The dislodged soil particles can then be transported away by water flowing over the ground surface. Rill erosion can develop when shallow flow concentrates in low spots and cuts tiny channels often only a few inches deep.



As flow increases, surface drainage can become concentrated and erosion may go unchecked, and gullies can develop. Depending on the level of concentrated flows and erosion, extremely large gullies can develop. The gully erosion process is attributed to 2 actions;

a)downcutting of the gully base by swiftly flowing water,
b)slumping or failure of the gully banks (this causes the gully to become wider).

Figure 64 - Rill and Gully Erosion

2.4.4.4 Stream Bank Cover and Vegetation

Stream bank cover increases bank stability and provides shade to the river or stream system. The shade provided by the vegetation is extremely important biologically providing a protective canopy for the river or stream and moderating the energy input into the stream by influencing the stream temperature and primary productivity. Vegetation is even more critical for smaller streams as the impacts vegetation have on the stability of the stream are greatly increased.

A vegetation cover on a slope is the primary defence against soil erosion and is very important to long term erosion protection. As indicated on Figure 65 to 66, vegetation protects against surface erosion and shallow translational slope slides by;

a)by holding, binding, or reinforcing the soil with a root system,
b)removing water from the soil by uptake and transpiration,
c)reducing run-off flow velocity,
d)by reducing frost penetration,
e)by the buttressing or reinforcing action of large tree roots

By reducing surface erosion, the likelihood of shallow instability is also decreased.

Vegetation also improves the visual aesthetics of a shoreline slope and is a vital part of the ecosystem.

Slope stability can also be decreased by the removal of stabilizing vegetation. This may be of particular importance where the removal of the smaller and more numerous tree roots, may also remove the binding strength and anchoring or reinforcement that roots provide. For further information on vegetation and its impacts please see the “Geotechnical Principles for Stable Slopes” and AMSC[8].

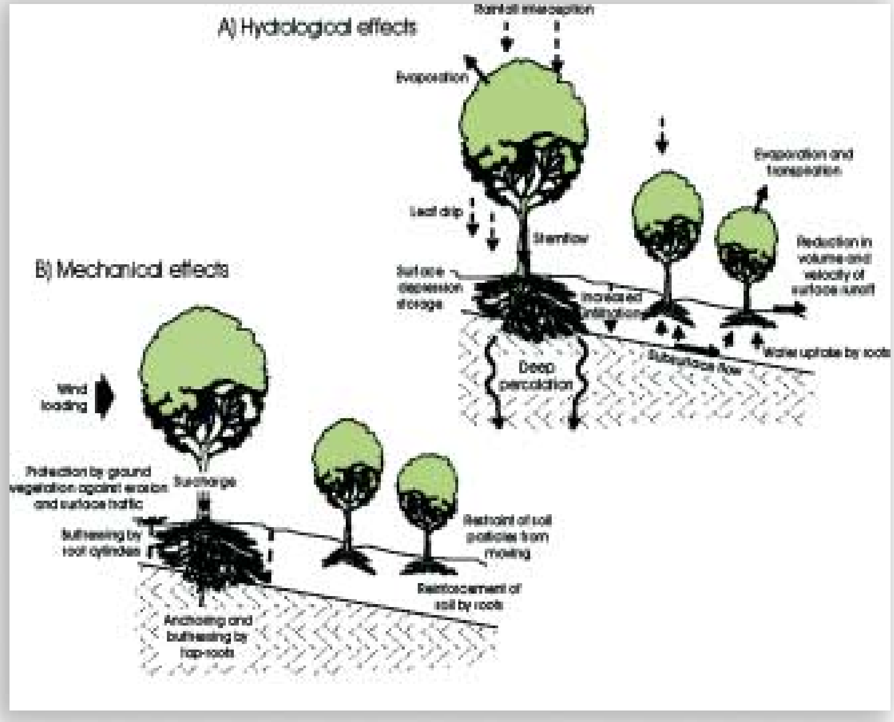


Figure 65 - Effects of Vegetation

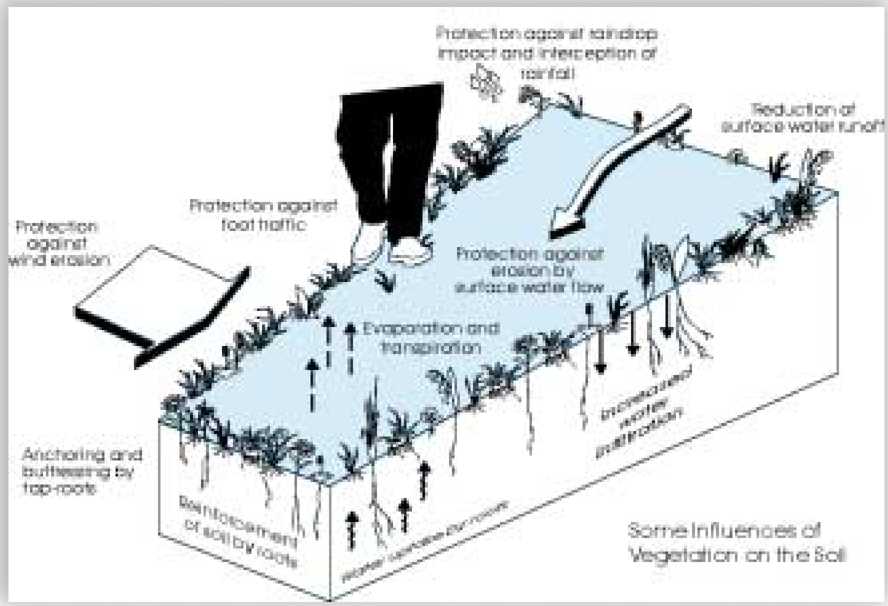
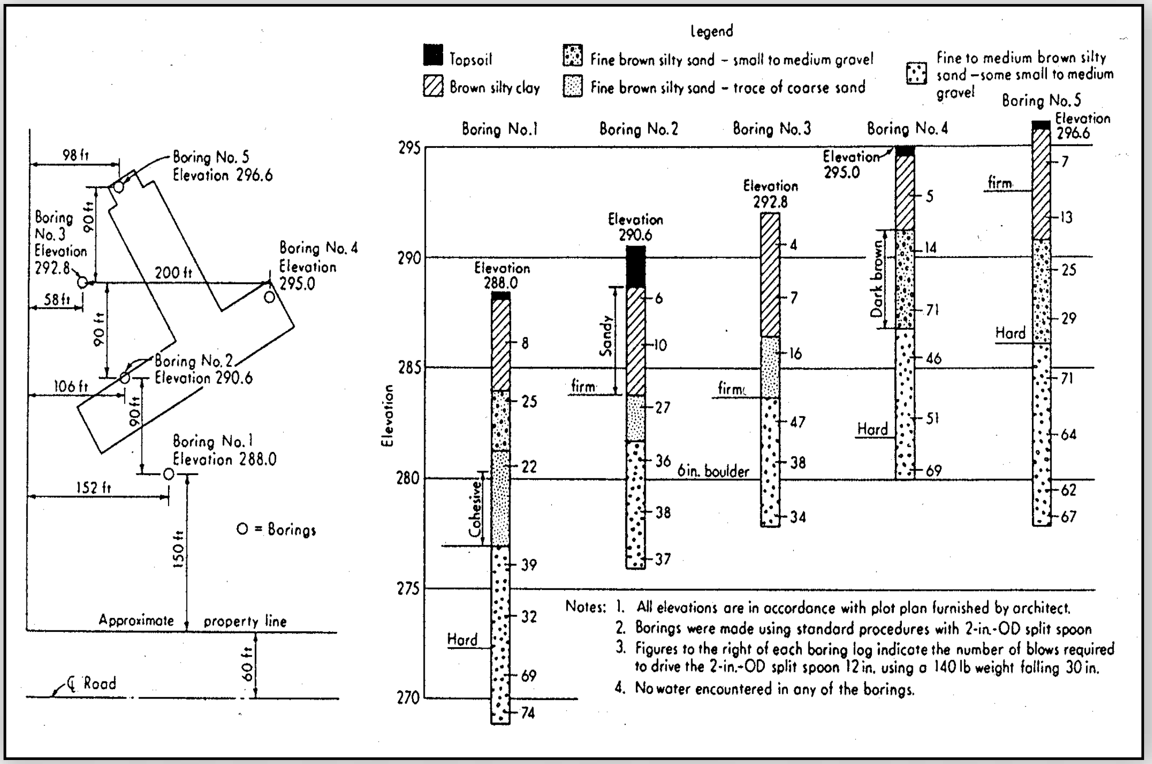


Figure 66 - Effects of Vegetation

Figure 68 - Vegetated Slopes

Figure 67 - Surface Erosion

2.4.5 Slope Failure or Instability Processes



Notes:
1. All elevations are in accordance with plot plan furnished by architect.
2. Borings were made using standard procedures with 2-in.-OD split spoon
3. Figures to the right of each boring log indicate the number of blows required to drive the 2-in.-OD split spoon 12 in. using a 140 lb weight falling 30 in.
4. No water encountered in any of the borings.

Figure 69 - Slope steepness and failures

Slope failures (i.e., instability) consist of the sudden movement or sliding of a large mass of soil over a failure plane. Slope movement or instability can occur in many ways but is generally the result of;

- •changes in slope configurations, such as steepness or inclination
- •increases in loading on or near the slope, such as structures or filling
- •changes in ground water conditions or drainage of the soil (i.e., heavy rainfall or spring melt, drainage blocked by filling, or broken watermains)
- •loss of vegetation cover and root systems
- •erosion of the slope toe.

Slopes are by their very nature, subject to movements and failure, whether it is large and deep-seated failure or a shallow and local failure. Failures within both these categories can occur rapidly under adverse conditions, causing immediate and disastrous damage to structures within the failure area. It can also take decades to develop to such a magnitude that movements pose a danger to structures located within or near the zone of failure. Permitting development along or in close proximity to slopes must take in account the potential for slope failure however, development should be located outside the hazard limit whenever possible. The following section briefly discusses some slope stability principles for detailed information on this subject please refer to the document "Geotechnical Principles For Stable Slopes", 1998.

Slopes comprised either in part or wholly of sensitive marine clay are prone to slope failure, which in the case of flow slides and earth flows, can involve many hectares of land. A large earth flow that occurred in sensitive marine clay on the east bank of the South Nation River at Lemieux, Ontario on June 20, 1993 involved an area of about 17 hectares and retrogressed about 680 m into the land. Borehole information indicated that a zone of soft, sensitive marine clay was underlying a stiff cap or crust consisting of laminated marine-estuarine sands and deltaic silts and sands. The landslide mechanism involved the fluidization of much of the landslide mass and subsidence, translation, and rotation of soils forming the cap or crust. The flow most likely occurred as a result of extrusion of the soft sensitive clay layer, due to an increase in the water table level. For further details on Sensitive Marine Clays please refer to the document " Technical Guide for Hazardous Sites ", 1997.

Slope failure or instability involves the sudden movement or sliding of a large mass of soil over a "failure plane" (also called slip plane). Slope movements or failures tend to occur rapidly, when compared to erosion processes. The movement often leaves a "scarp" at the top of the slope and slumped ground below.

The principle driving force in slope instability, is gravity. Therefore, the slope inclination or steepness, has the greatest effect on stability. Steep slopes are most susceptible or vulnerable to failure, if there are minor changes in the other important variables (loading, undercutting, wet weather). Flatter slopes tend to be affected less by changes in these other variables.

2.4.5.1 Slope Failure Types

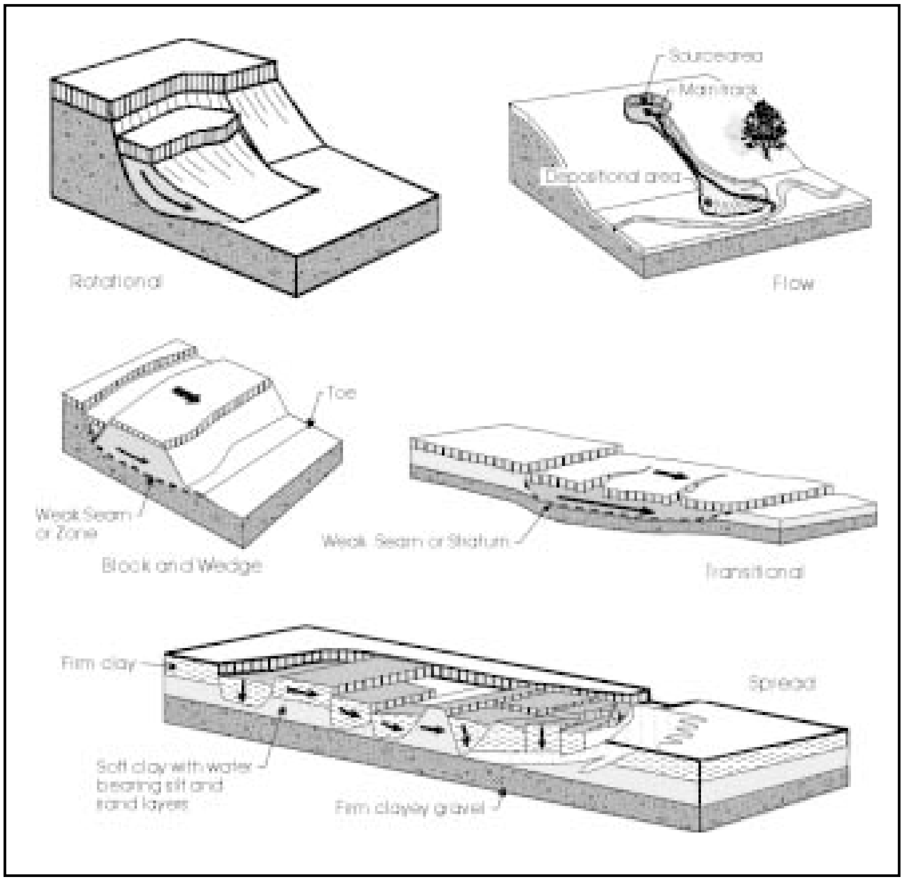


Figure 70 - Slope Failure Types

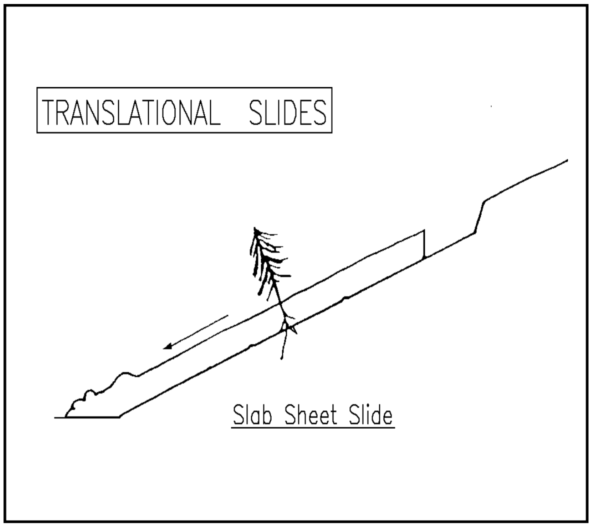


Figure 71 - Translational Failures

Slope movements are generally classified by a combination of the geometry and the nature of the failure. For details on all the various slope slide classifications see “Geotechnical Principles for Stable Slopes” 1994 by Terraprobe. For the purpose of this document, the four main classes of slope movement are as follows;

1)translational or surficial sliding,
2)rotational failures,
3)retrogressive failures,
4)flow slides or earth flows.

The mechanism of erosion at the slope toe can initiate any of these types of failures.

Translational Failures

- generally associated with a planar or sheet (non-circular) failure surface,
- typically occurs in granular soils (i.e., sands, silts), on relatively steep slopes where a thin soil layer slides,
- can occur on slopes composed of any soil type if the failure surface is influenced by the presence of discontinuities within the slope (i.e., bedding planes, faults, weak layers, fissures).

The failure surface can be deep depending on the location of the discontinuity.

Rotational Failures

- generally occur in relatively uniform soil conditions (i.e., few soil layers)
- typically involve movement along a curved or circular (concave upwards) failure plane; leaves an exposed back-scarp and the shifted soil mass rises at the slope toe,
- failure may be shallow or deep depending on the subsurface conditions, soil strength, and ground water,
- prevalent in fine grained soils (clays, silts).

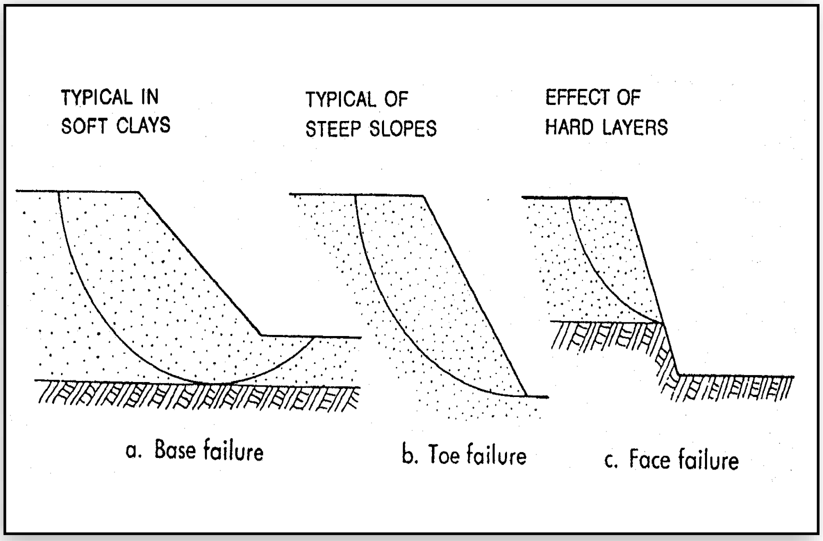


Figure 72 - Face Failures

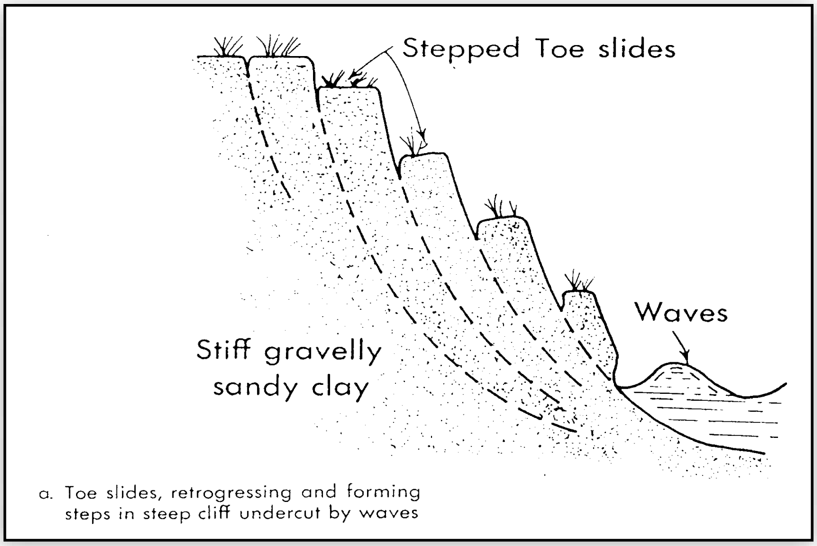


Figure 73 - Retrogressive Rotational Failures

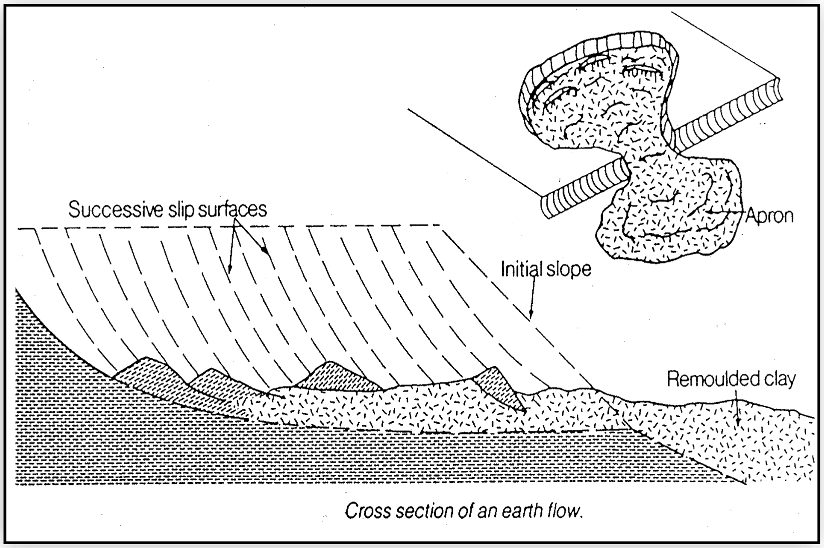


Figure 74 - Flow Slides Failure Mechanism

Retrogressive Failures

- initiated by a single simple rotational or translational failure, but successive slippages continue to occur within the slope due to a combination of slope geometry and disturbance of the clay soils composing the slope,
- occur in slopes composed wholly or partly of clay,
- characterized by the presence of remnants of the failed slices, a number of back-scarps along the slope face and an apron of failure debris at the slope toe,
- failure by successive rotational slippages can continue for large distances (retrogressive flow slides).

Earth Flows

- initiated by a single slide at the slope toe,
- initially similar to retrogressive failures, but movement of the soil mass continues over a larger area,
- studies are still ongoing to investigate the movement principles in earth flows (susceptible environments, and distance of retrogression),
- Tavenas et al (1982) have proposed the following four criteria to evaluate potential for earth flow occurrence (based on slope geometry prior and during failure, and on soil strength and remould ability),

1)the slope must be unstable; slope height and soil strength suitable for initial failure,
2)successive failure back-scarps must be unstable; again related to slope height and soil strength,
3)the slide debris must be able to flow; a combination of low remoulded strength (< 1 kPa) and high liquidity index (> 1.2),
4)the slide debris must continue to flow out of the failure scar without causing a blockage; there must be sufficient potential energy within the failing slope mass to cause remoulding and allow outflow of the slide debris (liquid limit of 40 % or more).

Further details on this can be found in the Technical Guide for Hazardous Sites, (Leda Clays) 1997.

Figure 75 - Retrogressive Slides

Figure 76 - Flow Slide

Figure 77 - Tension Cracks

Figure 78 - Failure Scarp

Figure 79 - Bank Failure

2.4.5.2 Indicators of Instability

There are several general indicators of slope stability, including slope inclination, soil types, groundwater levels, and other slope features such as tension cracks.

Immediately before a translational or rotational slide occurs, “tension cracks” may develop parallel and close to the slope crest.

The slope surface after a slide often display “tension cracks” above the slide and, a distinct “scarp” at the “head” or “crown” where the sliding mass has separated from the slope. A bulging soil mass is often found at the “toe” of the slide.

Slope failures tend to be self-stabilizing in that the slope configuration becomes flatter and more stable. This assumes that the slumped soil is not removed by toe erosion.

Evidence of past slope slides may include:
- a)bare slope areas (no vegetation);
- b)tree trunks which are bent or bowed, or dead trees whose roots may have been damaged by slope movements;
- c)scarps and tension cracks;
- d)irregular slope surface such as slumped soil masses, or humps.
- e)See the list on the following Figure.

It is important to note that in some steep slope areas, bent or bowed tree trunks are not necessarily caused by slope movements (though they often do). The curved tree trunks may be due to initial root development and twisting or bowing growth in response to reaching for moving sunlight and adjacent tree canopies.

Examination of historical air photographs, surveys, and discussions with local residents can be important in detecting the extent or presence of past slides.

2.4.5.3 Human Activities

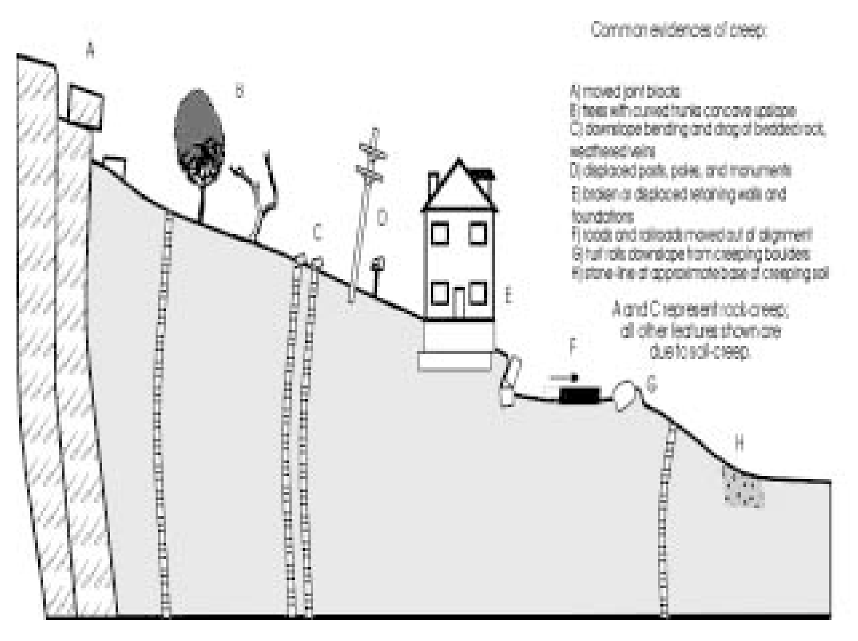


Figure 80 - Indicators of Instability

A number of human activities can aggravate or create slope instability. These include indiscriminate discharge or leakage of water from swimming pools, septic systems, storm runoff control ponds, and drains, as well as agricultural tile drainage systems. Changes in the topography, by cut and fill earth moving or land grading, can also alter the strength of any soil strata or add weight to the entire slope. The construction of buildings or protection works on or near these slopes can further weaken the slope which in turn may contribute to an increased instability in the future.

With the activities of urbanization and land development; fill placement near slope crests, construction of retaining walls near slopes, and excavations into slopes, may alter the slope stability. Filling is a common practice in most urban areas as people try to reclaim more usable flat tableland along existing slope crests. Fill placement often occurs in an uncontrolled manner (sometimes over an extended period of time) and may result in an unstable fill mass which eventually experiences movements. Slides within fill materials placed randomly and not engineered, can be quite unpredictable and extensive. The resulting instability may occur through the fill materials only or, through both fill and underlying native soil.

.

Filling on slopes can be carried out in a safe and stable manner with suitable control works, drainage measures included in the design and precautions taken during construction. The fill works must be designed and construction supervised under the responsibility of a qualified geotechnical engineer.

Figure 81 - Bent Guardrail Due to Failure Below Water Line

Figure 82 - Scarps, Slumped Soil Masses

Hazardous Lands: River and Stream Systems (Policy 3.1.1 (b)

By definition, *river and stream systems* includes all watercourses, rivers, streams and small inland lakes (i.e., lakes having a surface area of less than 100 square kilometres that have a measurable and predictable response to a single runoff event).

River and stream systems are by nature dynamic, constantly changing landforms due mainly to the erosive forces of flowing water and the relative stability of surrounding slopes. The degree and frequency with which the morphological or physical change will occur in these systems depends on the interaction of a number of interrelated factors including hydraulic flow, channel configuration, sediment load in the system, and the stability of the banks, bed and adjacent slopes.

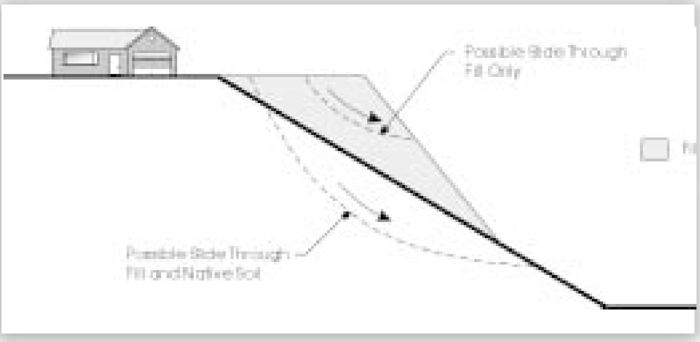


Figure 84 - Filling On Slopes

The *natural* importance of *river and stream systems* in providing physical, biological and chemical support functions for sustaining ecosystems, including that of humans, is indisputable. These functions are strongly associated with the physical processes of discharge (i.e., flow), erosion, deposition and transport that are inherent in any river and stream system. Given that ecological sustainability is based on the dynamic nature of these systems, it is essential that their physical processes (e.g., flow dynamics) be allowed to function in as natural a state as possible.

It is, however, the constant shaping and re-shaping of the *river and stream systems* by the physical processes associated with flooding, erosion and slope stability that result in the creation of hazardous conditions that pose a threat to human lives and cause property damages. Millions of dollars are spent annually in attempts to remedy flooding and erosion problems which pose a risk to life and property.

Defining the "area of provincial interest" within *river and stream systems* should first involve an understanding of the interrelationships between all of the physical processes acting on and influencing a particular system. These physical processes result from the interaction of numerous variables that comprise a watershed and/or river and stream system. These include, but are not limited to:

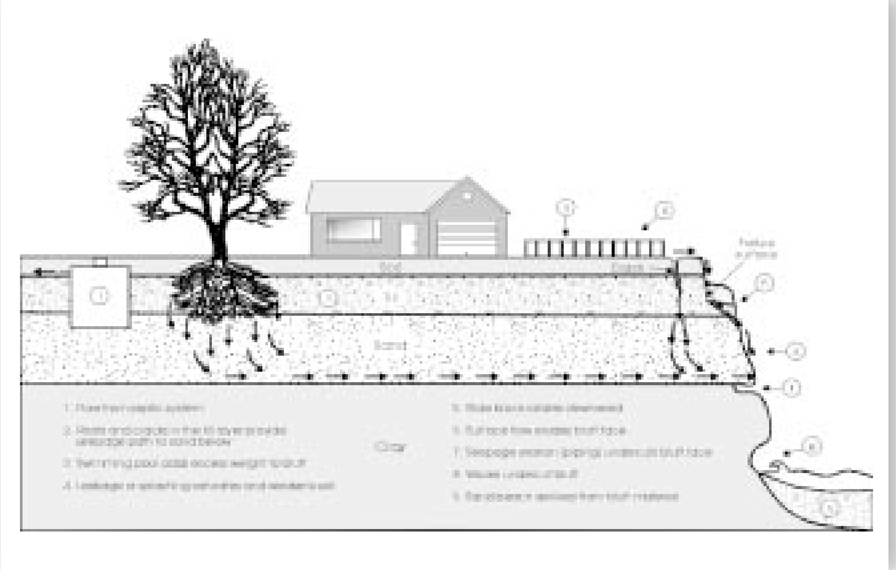


Figure 83 - Human Activities:Discharage of Water on Slope, Leakage of Pools

Figure 85 - Installation of Geomatting

Figure 86 - Drainage Designed by Geotechnical Engineer

Figure 87 - Repaired Slope, Filled Slope Designed by Geotechnical Engineer

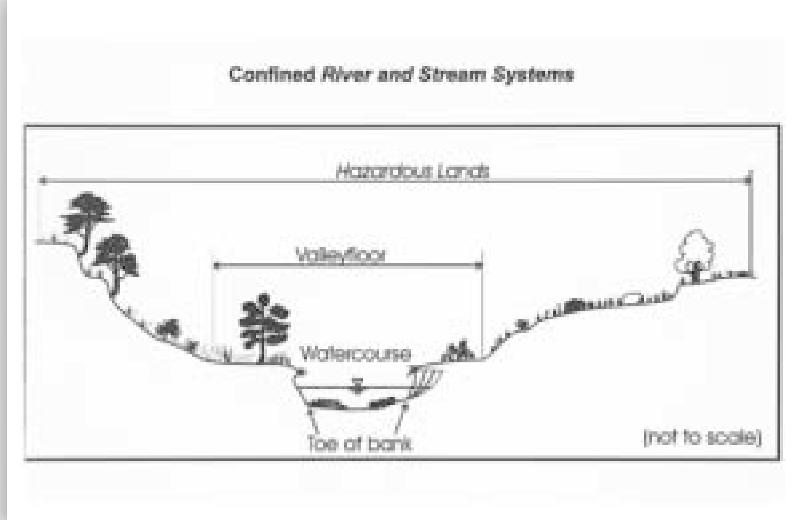


Figure 88 - Confined River and Stream System

Figure 89 - Confined River and Stream System

Figure 90 - Confined River and Stream System

- geology (e.g. , topography, lithology);
- climate (e. g. , precipitation including rain/snow, temperature, wind);
- soil properties (e. g. , structure, type, density, porosity);
- vegetation types (e. g. , grasses, shrubs, trees, density/depth of root systems);
- hydrologic & hydraulic conditions (e. g. , fluvial system);
- discharge (i. e. , volume per unit time)
- low flow, peak discharge, bank full discharge, ephemeral or perennial flow
- channel configuration
- width vs. depth, slope, roughness, composition of the bed/bank material, pattern (e. g., braided, meandering, straight)
- sediment load
- bedload, suspended load, dissolved load
- hydraulic conditions (e. g. , slopes); and
- ground water regime (e. g. , flow)
- soil drainage (e. g. , porosity)
- overland flow, through flow, saturation flow
- slope stability
- height
- inclination
- loading
- proximity to flowing water (e. g. , potential for toe erosion)
- water content
- land use and human impact

The complexity of the interaction of these variables in various *river and stream systems* results in a wide array of drainage and stream/river types (Leopold et al, 1964; Gregory and Walling 1974; Morisawa, 1985).

For *hazardous lands* associated with *river and stream systems* (Policy 3.1.1(b)), the numerous combinations of physical landforms have been simplified into two basic types:

•**confined system**;
•**unconfined system**.

Confined *river and stream systems* are ones in which the physical presence of a valley corridor containing a river or stream channel, which may or may not contain flowing water, is visibly discernible (i.e., valley walls are clearly definable) from the surrounding landscape by either field investigations, aerial photography and/or map interpretation. The location of the river or stream channel may be located at the base of the valley slope, in close proximity to the valley slope (i.e., within 15 m) or removed from the valley slope (i.e., a distance greater than 15 m) (see Figures 88-90).

Unconfined *river and stream systems* are ones in which a river or stream is present but there is no discernible valley slope or bank that can be detected from the surrounding landscape by either field investigations, aerial photography and/or map interpretation. For the most part, unconfined systems are found in fairly flat or gently rolling landscapes and can be located within the headwater areas of drainage basins. The river or stream channels contain either perennial (i.e., year round) or ephemeral (i.e., seasonal or intermittent) flow and may range in channel configuration from seepage and natural springs to detectable channels (see Figure 91-93).

Figure 92 - Unconfined System

Figure 93 - Unconfined System

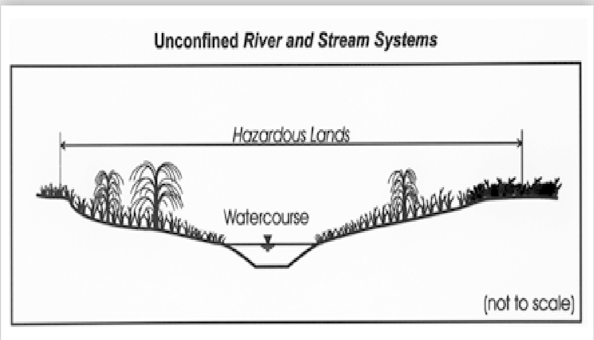


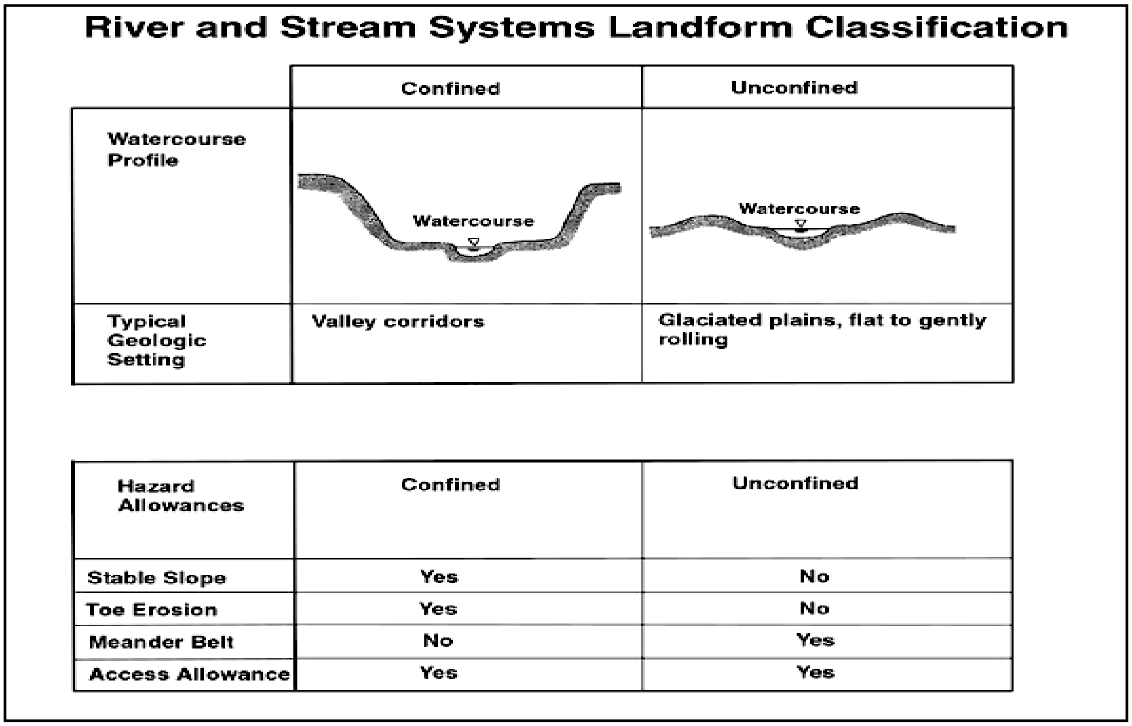
Figure 91 - Unconfined River and Stream System

Erosion Hazards

The three main forces that shape and re-shape *river and stream systems* are the natural processes of erosion, flooding (i.e., water flow), and slope stability. Erosion and slope stability are two natural processes which are quite different in nature yet often linked together. Erosion is essentially the continual loss of earth material (i.e., soil or sediment) over time as a result of the influence of water or wind. Slope stability, usually described in terms of the potential for slope failure, refers to a mass movement of earth material, or soil, sliding down a bank or slope face as a result of a single event in time.

By definition, the *erosion hazards* limit, depending on the type of *river and stream system* involved, should be based on the combined influence of:

- toe erosion allowance
- stable slope allowance
- ***flooding hazard* limit** or **meander belt allowance**
- erosion access allowance



River and Stream Systems Landform Classification

	Confined	Unconfined
Watercourse Profile	Watercourse	Watercourse
Typical Geologic Setting	Valley corridors	Glaciated plains, flat to gently rolling

Hazard Allowances	Confined	Unconfined
Stable Slope	Yes	No
Toe Erosion	Yes	No
Meander Belt	No	Yes
Access Allowance	Yes	Yes

Figure 94 - Landform Classification

Based on the type of *river and stream system* landform (i.e., confined, unconfined), Figure 94 provides guidance on which combinations of these factors (hazard allowances) should be used in defining the *erosion hazards* limit.

Defining the *erosion hazards* limit for the two basic types of *river and stream systems* landforms should be based on the following approaches:

Confined systems (see Figures 95a and 95b)

toe erosion allowance*	**+ allowance for stable slope**	**+ erosion access allowance**
(from Table 2; <u>OR</u> 100 times the average annual recession rate of the toe) **OR** as determined by a study using accepted geotechnical and engineering principles	3:1 (h:v) minimum **OR** as determined by a study using accepted geotechnical principles	6 metres **OR** as determined by a study using accepted scientific, geotechnical and engineering principles

* Note:

.where the soil type is not known, Table 3 recommends the use of a 15 m toe erosion allowance; and

.when using average annual recession rates to determine the toe erosion allowance a minimum of 25 years of reliable information is recommended.

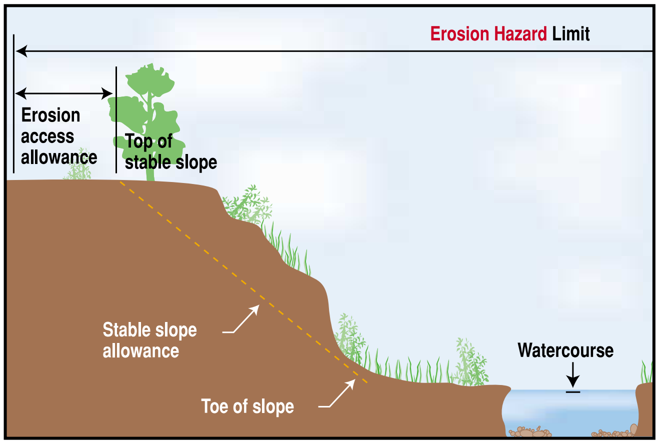


Figure 95 a Confined System, Erosion hazard limit where toe of valley slope is located more than 15 metres from the watercourse

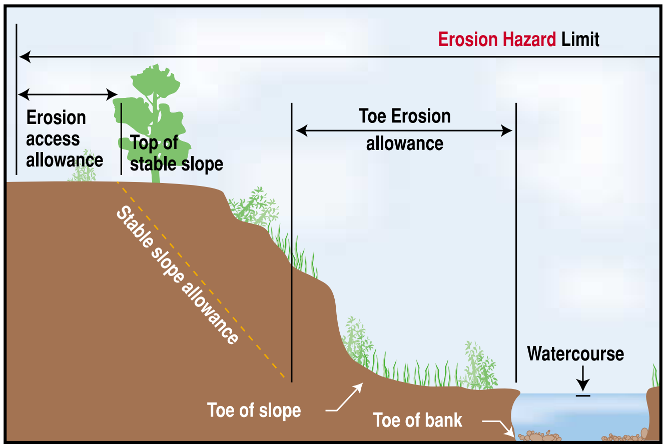
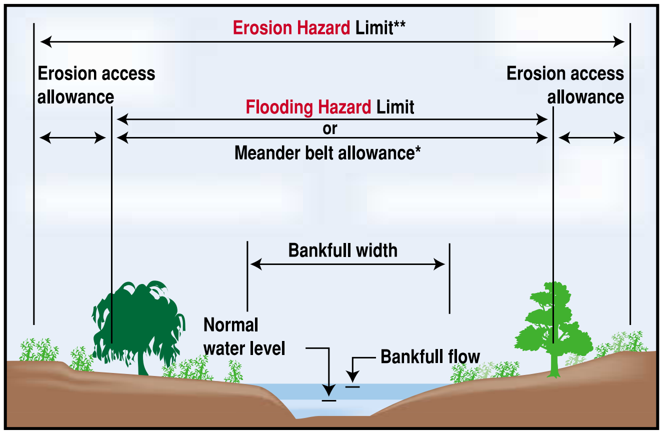


Figure 95 b Confined System, Erosion hazard limit where toe of valley slope is located less than 15 metres from the watercourse

Unconfined systems (see Figure 96)

an allowance for the *flooding hazard* limit <u>OR</u> meander belt allowance	**+ erosion access allowance**
20 times the bankfull channel width centred over the meander belt axis **OR** as determined by a study using accepted engineering principles	6 metres **OR** as determined by a study using accepted scientific, geotechnical and engineering principles



(NOT TO SCALE)

* The bankfull channel width with the largest amplitude meander in the reach is used to determine Meander Belt Width.

** Erosion access allowance is also added to the flooding hazard limit, when known, to define the erosion hazard limit.

Figure 96 Erosion Hazard Limit

The following subsections clarify how each of these components for defining *erosion hazards* should be determined and where flexibility may be provided to undertake studies to address unique, local situations (e.g., where the approach(es) may be considered excessive or insufficient to define the area of provincial interest). Where studies using accepted scientific, geotechnical and/or engineering principles were used to determine the landward limit of the *erosion hazards* are approved by the municipality, they should be applied only within the area studied.

3.1 TOE EROSION ALLOWANCE

The flow of water through *river and stream systems* can cause erosion of the surface or exposed face of the bank or channel. The magnitude or rate of erosion can be quite variable over the time dependent on the volume, velocity and duration of the flows. For example, a heavy rainfall or rapid snowmelt event may increase the potential magnitude or rate of erosion as a result of a measurable increase in water flows or discharge into and through the *river and stream systems*. Areas which are particularly susceptible to erosion are those banks or valleys slopes on the outside of meanders or bends of the river or stream.

Erosion is also the result of the gradual and continuous removal of soil material through other processes which are not always easily discernible. For example, wind and ice action on a river bank or channel results in the weathering, dislodging and transport of soil particles. This constant, yet often slow removal, ultimately can lead to the undercutting and instability of an adjacent slope. The level or rate of toe erosion, in this instance, is a function of the amount of water flowing through the system, the presence, duration and force of the wind, and the varying influence of ice and other water related forces (e.g., ground water seepage, and piping).

The rate of erosion is also a function of the proximity of the river or stream channel to a valley wall or bank face. If the river or stream channel is in close proximity or abuts the valley wall the erosive forces of the flowing water will cause a steepening and then undercutting of the valley wall. The degree or severity of this erosive action is dependent on the soil composition (e.g., determines the strength or susceptibility of the slope) and the proximity and exposure of the slope to the channel or water flows.

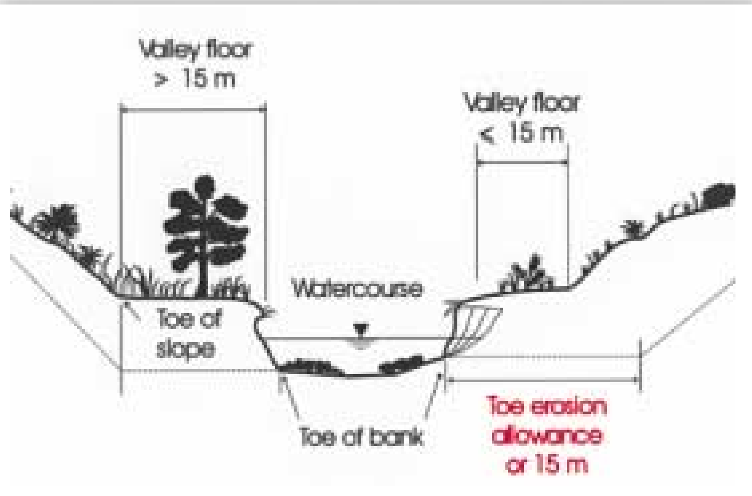


Figure 97 - 15 metre Toe Erosion Allowance

The **toe erosion allowance** or recession of the toe of the slope, which is normally applied only to confined systems and may be determined in one of four ways:

•use of the **average annual recession rate** applies only to confined and terrain-dependent systems consisting of cohesive materials. A minimum 25 years of record or data is required to provide a measure of reliability when determining average annual recession rate extended over a 100 year planning horizon. Data sources could include survey information, aerial photographs and through field monitoring and measurement using equipment having sufficient precision and accuracy to provide a reliable indication of recession.

•use of a **15 metre toe erosion allowance** measured inland horizontally and perpendicular to the toe of the watercourse slope (Figure 97) where the valley floor is less than or equal to 15 metres (i.e., distance between the watercourse and the base of the valley wall). The proximity of the watercourse to the base of the valley wall can be determined from aerial photography or site investigations.

•toe erosion allowance based on soil types and hydraulic processes based on visual observations or analytical studies and where the valley floor is less than or equal to 15 metres (i.e., distance between the watercourse and the base of the valley wall). Use of this option is guided by the information outlined in Table 3.

•use of a study using accepted geotechnical and engineering principles and based on a minimum of 25 years of record or data.

The first two options are straightforward and can be applied directly. Where the third option outlined above is selected (i.e., use of Table 3), there are a number of steps involved in determining the toe erosion allowance for a given location.

STEP 1:**The native soil structure or composition of the site should be confirmed**.

The native soil structure or composition of the site should be confirmed either through a site visit or previously generated information (e.g., borehole, auger hole or test pits). Select one of four general material types (i.e., hard rock; soft rock, cobbles and boulders; stiff/hard cohesive soils, coarse granular and/or tills; or soft/firm cohesive soil and/or fine granular) from Table 3.

For a further description and photo's of the general material types (i.e., hard rock, soft rock, cobbles and boulders; stiff/hard cohesive soils, coarse granular and/or tills; or soft/firm cohesive soil and/or fine granular) refer to Section 2.2 of this document.

Table 3: Determination of Toe Erosion Allowance

MINIMUM TOE EROSION ALLOWANCE - River Within 15 m of Slope Toe*

Type of Material Native Soil Structure	**Evidence** of Active Erosion** **OR** Bankfull Flow Velocity > Competent Flow Velocity*** RANGE OF SUGGESTED TOE **EROSION ALLOWANCES**	**No evidence** of Active Erosion** **OR** Bankfull Flow Velocity <Competent Flow Velocity***		
		Bankfull Width < 5m	5-30m	> 30m
1.Hard Rock (granite) *	0 - 2 m	0 m	0 m	1 m
2.Soft Rock (shale, limestone) Cobbles, Boulders *	2 - 5 m	0 m	1 m	2 m
3.Stiff/Hard Cohesive Soil (clays, clay silt), Coarse Granular (gravels) Tills *	5 - 8 m	1 m	2 m	4 m
4.Soft/Firm Cohesive Soil, loose granular, (sand, silt) Fill *	8 - 15 m	1-2 m	5 m	7 m

*Where a combination of different native soil structures occurs, the greater or largest range of applicable toe erosion allowances for the materials found at the site should be applied

****Active Erosion** is defined as: bank material is exposed directly to stream flow under normal or flood flow conditions where undercutting, oversteepening, slumping of a bank or down stream sediment loading is occurring. An area may have erosion but there may not be evidence of 'active erosion' either as a result of well rooted vegetation or as a result of a condition of net sediment deposition. The area may still suffer erosion at some point in the future as a result of shifting of the channel. The toe erosion allowances presented in the right half of Table 3 are suggested for sites with this condition. See Step 3.

*****Competent Flow Velocity** is the flow velocity that the bed material in the stream can support without resulting in erosion or scour. For *bankfull width* and *bankfull flow velocity*, see Section 3.1.2.

Where there is evidence of high variability in soil composition, the soil composition is not known, and/or evidence of high erosion activity, the 15 metre toe erosion allowance should be applied.

STEP 2: Determine whether or not there is evidence of active erosion OR if the bankfull velocity is greater than the competent flow velocity.

Visible on-site evidence of active erosion may include a bare or vegetation-free river or stream bank which is directly exposed to water flows, and where undercutting, over-steepening, slumping of the bank or high downstream sediment loading is occurring. Slumping, scars, and bare stream banks that are not directly exposed to river flows are slope stability issues and should not be considered as evidence of "active erosion".

If field investigations determine that active erosion is occurring and as long as the soils at the site can be identified, it may not be necessary to determine the bankfull or competent flow velocities at the site. The Toe Erosion Allowances from Table 3 can be applied directly without any further calculations.

Figure 98 - Determine Evidence of 'Active'

Figure 99 - Example of 'Active' Bank Erosion

However, if field observations are not undertaken and it is unknown whether active erosion is occurring at the site, then it may be necessary to determine the bankfull or competent flow velocities at the site.

Determination of whether the bankfull velocity is greater than the competent flow velocity can be confirmed through site investigations or the calculation of flow velocities (i.e., determined through the use of hydrologic studies involving an assessment of flow data and flow model calculations).

Using Table 3 will require some definitions which are presented at the bottom of the chart. One of the key components is the determination of the bankfull velocity and bankfull width.

Figure 100 - Example of 'Active' Erosion (Slumping)

3.1.1 Determination of Bankfull Characteristics

The bankfull flow is the maximum flow within a channel before spilling onto its floodplain. As the flow and energy per cross-sectional area is at its maximum at bankfull conditions, this flow performs the most work upon the channel boundary and has also been shown to be the most effective flow for transporting sediment.

Several definitions have been developed and are valid but lead to some confusion. These definitions include terms such as "channel defining flow", effective discharge, mean annual flood and dominant discharge. They all have slightly different meanings and can actually be the equivalent of bankfull flow.

A field procedure for determining bankfull width was developed by MNR as part of the "Stream Assessment Protocol for Ontario", 1998. This document and field assessment can be followed to obtain the bankfull width.

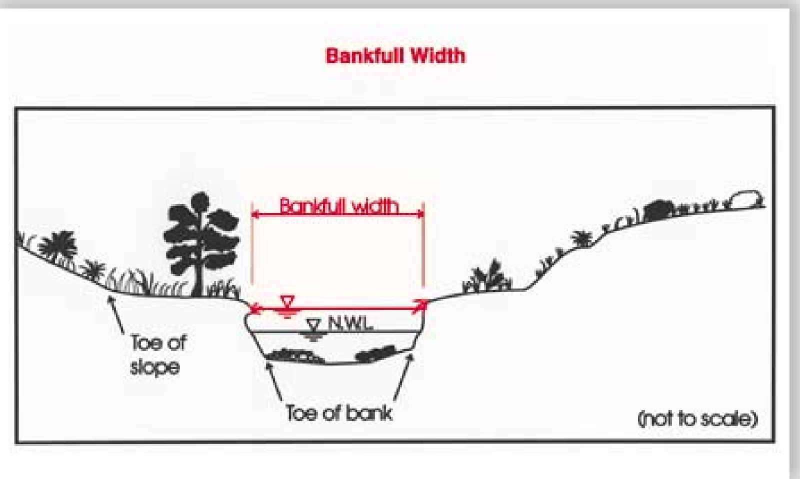


Figure 101 - Bankfull Width

Figure 102 - Examples of rivers at bankfull conditions

Physical indicators such as;

- a change in vegetation type; i.e., the lower limit of growth for perennial species (willow, alder, dogwood);
- a change in slope along the river bank;
- a change in the soil particle size of the bank;
- undercuts (erosion) in the bank;
- stain lines along the bank, or the lower limit of lichens on boulders;

are just some of the general indicators which can be helpful in identifying the bankfull width in the field. Refer to Section 2.3.3.1 for a bankfull discussion.

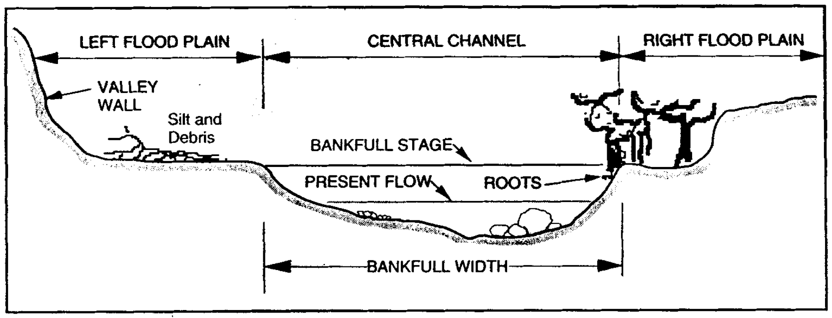
In the absence of field collected bankfull width data, the following charts (figures 104 - 107) may be used, provided they are used by qualified experts applying "accepted scientific and engineering principles".

The list of watercourses that were studied and measured in the field came from a study, "Database of Morphologic Characteristics of Watercourses in Southern Ontario", August, 1996 by W.K. Annable. Data was collected at 47 sites in larger systems, non-urbanized watersheds in Southern Ontario. It is very important to note that the data which was collected is only applicable to non-urbanized streams and rivers.

The detailed survey information for each of the first 47 sites is available in the above report and the "Morphologic Relationships of Rural Watercourses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology", August, 1996, by W.K. Annable.

If the drainage area is known for a site and the particular river system is on the list, the bankfull characteristics are provided. There may also be a river in a particular area that mimics one of the surveyed systems (i.e., same soil conditions, strata, hydraulics, gradient, etc.), then the information may be used with caution and the expertise to help interpret or predict bankfull conditions at the similar location.

Figure 105 is a plot of Newbury's data with all the 47 sites from the Annable study with the addition of 6 sites from the Don River. Figure 106 is a plot of the Newbury sites and all the Alluvial sites where the bedrock sites were taken out. Figure 107 indicates all the bedrock sites and Newbury's sites. This data may also be used to determine the "meander belt allowance" in the following sections.



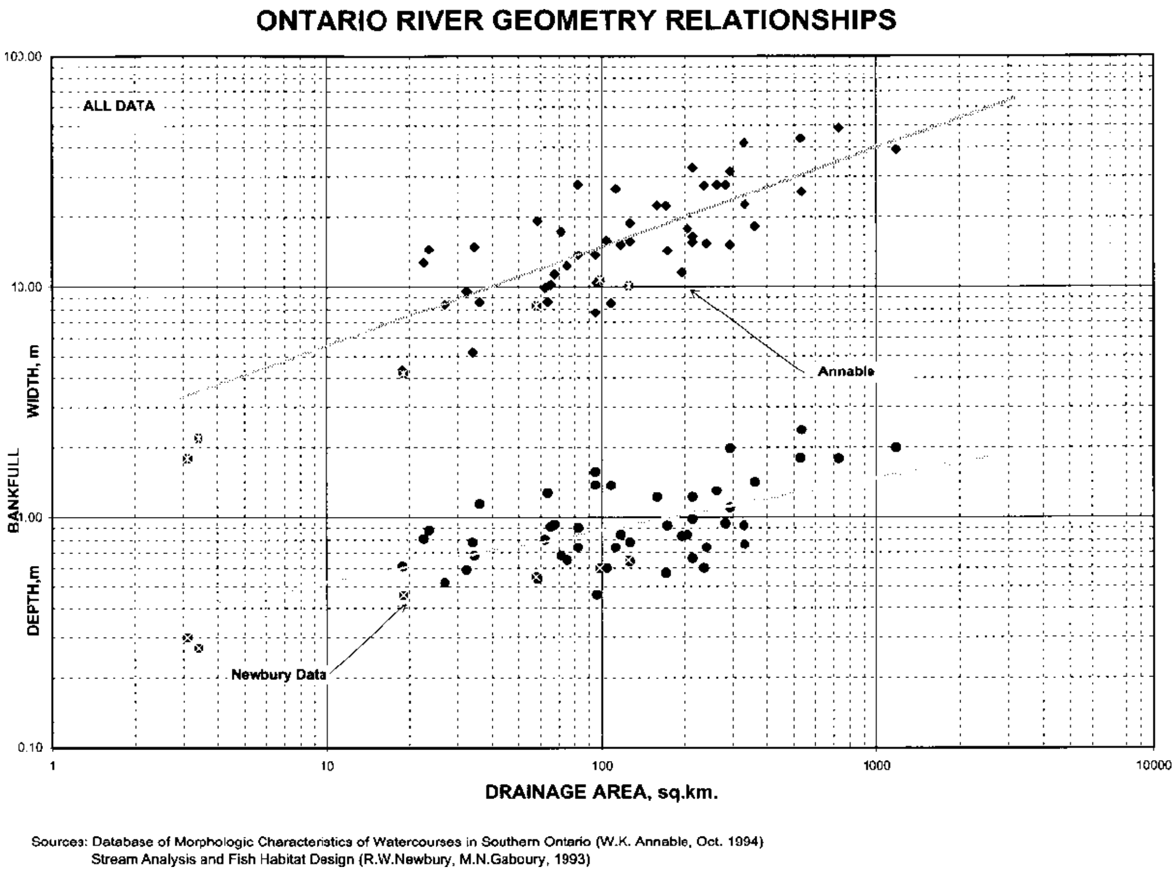
Cross section of stream valley with floodplains and a well-defined central channel and bankfull stage.

Figure 103 - Bankfull Stage

ALL DATA

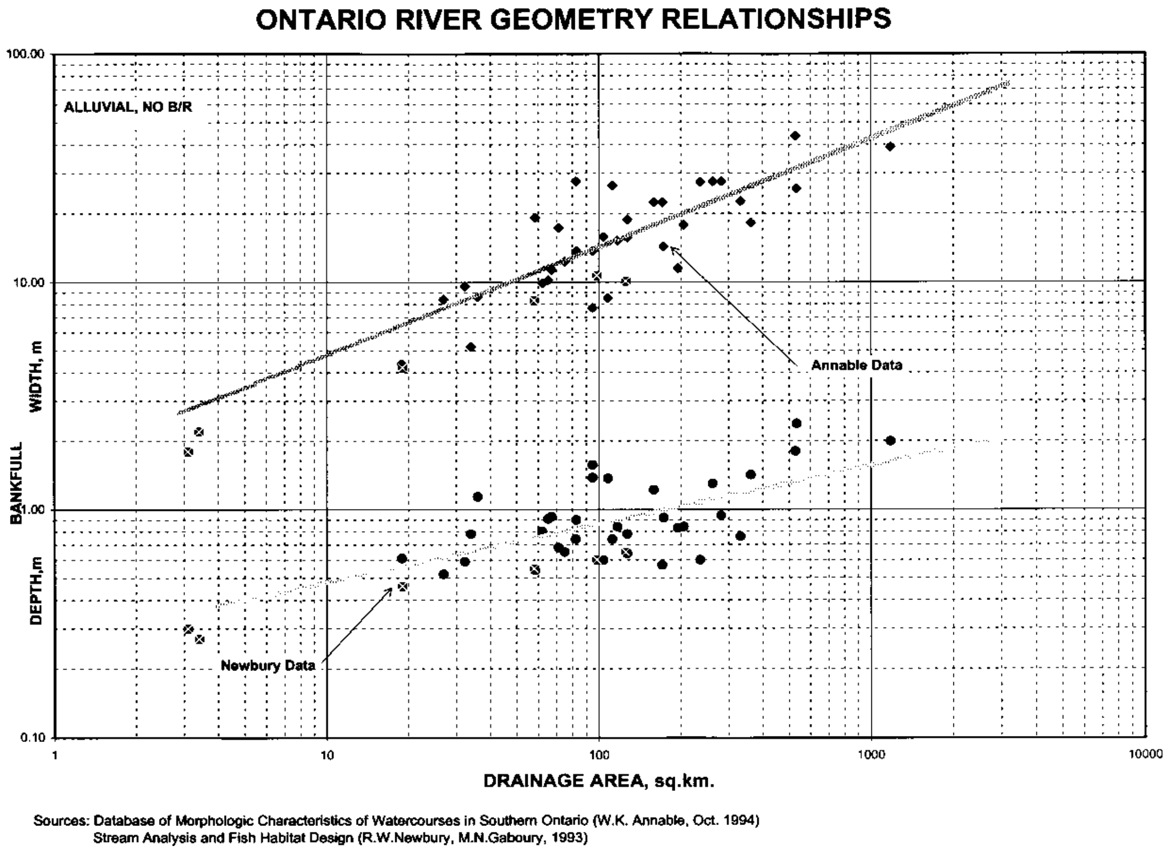
	Watercourse	DRAINAGE AREA (km2)	BANKFULL DEPTH (m)	BANKFULL WIDTH (m)	BANKFULL DISCHARGE cu.m/s	STREAM CLASS
ANNABEL DATA						
1	BEAR CREEK BELOW BRIGDEN	533.0	2.38	25.67	27.94	C6
2	BEAVERTON RIVER NEAR BEAVERTON	282.0	0.94	27.60	42.40	C4
3	BIG CREEK NEAR DELHI	362.0	1.42	18.20	29.73	F4
4	BLACK CREEK BELOW ACTON	18.9	0.61	4.36	2.27	E4
5	BOWMANVILLE CREEK NEAR ELMIRA	104.0	0.60	15.80	18.40	C3
6	BURNLEY CREEK ABOVE WARKWORTH	71.2	0.68	17.30	16.35	C4
7	CANAGAGIGUE CREEK NEAR ELMIRA	82.3	0.74	27.63	26.23	C4
8	COLD CREEK AT ORLAND	159.0	1.22	22.34	19.21	C4
9	COPELAND CREEK NEAR PENETANGUISHENI	26.9	0.52	8.40	3.61	C5
10	CREDIT RIVER AT BRIMSTONE	22.5	0.81	12.70	18.25	B3
11	CREDIT RIVER NEAR CATARACT	205.0	0.84	17.80	17.48	C4
12	CREDIT RIVER - ERIN BRANCH ABOVE ERIN	32.3	0.59	9.60	3.29	C5
13	WEST CREDIT RIVER ABOVE THE FORKS OF	96.0	0.46	10.40	9.64	B3
14	CREDIT RIVER NEAR ORANGEVILLE	62.2	0.80	9.90	6.72	C5
15	EAST HUMBER RIVER AT KING CREEK	94.8	1.38	7.70	13.70	E4
16	EELS CREEK BELOW APSLEY	241.0	0.74	15.40	21.68	B1
17	ERAMOSA RIVER ABOVE GUELPH	236.0	0.60	27.40	17.80	C3
18	FAREWELL CREEK AT OSHAWA	58.5	0.54	19.20	8.74	C4
19	GANARASKA RIVER NEAR DALE	262.0	1.30	27.60	49.87	C4
20	GANARASKA RIVER NEAR OSACA	67.3	0.93	11.30	14.26	E4
21	HOG CREEK NEAR VICTORIA HARBOUR	65.2	0.91	10.20	14.15	E4
22	HORNER CREEK NEAR INNERKIP	108.0	1.37	8.50	15.28	E5
23	HUMBER RIVER NEAR PALGRAVE	117.0	0.84	15.20	12.60	C4
24	IRVINE CREEK ABOVE SALEM	215.0	0.66	32.60	53.84	C1
25	IRVINE CREEK AT ELORA	215.0	1.22	16.50	53.84	F2
26	IRVINE CREEK AT SALEM	215.0	0.98	15.60	53.84	F1
27	MAITLAND RIVER AVOVE WINGHAM	528.0	1.80	43.60	96.40	C3
28	MAITLAND RIVER NEAR HARRISTON	112.0	0.74	26.50	24.67	C4
29	McKENZIE RIVER NEAR CALEDONIA	171.0	0.57	22.30	15.29	C5
30	NOTTAWASAGA RIVER AT HOCKLEY	172.9	0.92	14.30	20.00	C3
31	NOTTAWASAGA RIVER NEAR BAXTER	1180.0	1.99	39.00	98..73	C5
32	PEFFERLAW BROOK NEAR UDORA	332.0	0.76	22.60	18.45	C4
33	PINE RIVER NEAR EVERETTE	195.0	0.83	11.50	14.50	F4
34	PINE RIVER NEAR KILGORIE	75.0	0.65	12.30	9.97	B3
35	REDHILL CREEK BELOW ALBION FALLS	23.5	0.88	14.50	18.16	B3
36	SAUGEEN RIVER ABOVE DURHAM	329.0	0.92	41.70	73.50	C3
37	SILVER CREEK AT NORVAL (ROGERS CREEK	127.0	0.64	18.80	12.92	B4
38	SIXTEEN MILE CREEK BELOW HILTON FALLS	34.5	0.68	14.90	16.79	B3
39	SWAN CREEK NEAR ELORA	34.0	0.78	5.20	7.62	E4
40	SYNDENHAM RIVER AT ALVINSTON	730.0	1.79	48.70	84.90	C1
41	TROUT CREEK NEAR FAIRVIEW	36.0	1.14	8.60	16.93	F4
42	TWELVE MILE CREEK BELOW DECEW FALLS	63.5	1.27	8.60	19.25	A3
43	TWENTY MILE CREEK ABOVE BALLS FALLS	293.0	1.10	31.50	66.94	C1
44	TWENTY MILE CREEK BELOW BALLS FALLS	293.0	1.98	15.20	66.94	A2
45	WILLOW CREEK ABOVE LITTLE LAKE	94.8	1.57	13.70	22.65	E5
46	WILLOW CREEK AT MIDHURST	127.0	0.78	15.70	10.98	C4
47	WILMOT CREEK NEAR NEWCASTLE	82.6	0.90	13.71	18.00	C5
NEWBURY DATA						
48	DON RIVER	3.1	0.30	1.80		
49	DON RIVER	3.4	0.27	2.20		
50	DON RIVER	19.0	0.46	4.20		
51	DON RIVER	57.9	0.55	8.30		
52	DON RIVER	98.3	0.60	10.70		
53	DON RIVER	125.5	0.65	10.10		

Figure 104 - Ontario River Geometry Relationships List



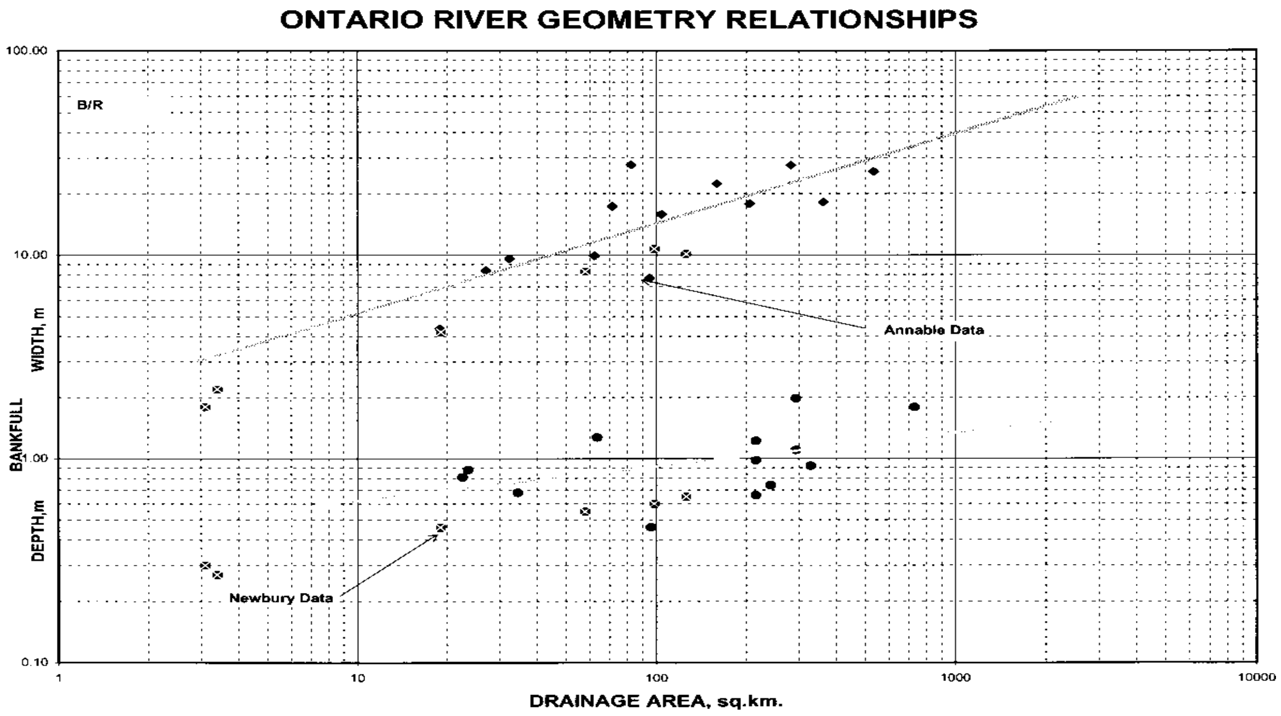
Sources: Database of Morphologic Characteristics of Watercourses in Southern Ontario (W.K. Annable, Oct. 1994)
Stream Analysis and Fish Habitat Design (R.W.Newbury, M.N.Gaboury, 1993)

Figure 105 - Ontario River All Data Chart 1



Sources: Database of Morphologic Characteristics of Watercourses in Southern Ontario (W.K. Annable, Oct. 1994)
Stream Analysis and Fish Habitat Design (R.W.Newbury, M.N.Gaboury, 1993)

Figure 106 - Ontario River , Alluvial Sites



Sources: Database of Morphologic Characteristics of Watercourses in Southern Ontario (W.K. Annable, Oct. 1994)
Stream Analysis and Fish Habitat Design (R.W.Newbury, M.N.Gaboury, 1993)

Figure 107 - Ontario River Data, Bedrock Sites

3.1.2 Competent Flow Velocity

For active erosion to take place, the flow velocity must increase and exceed the “competent” or “critical” velocity associated with the bed and bank material. Furthermore, the amount of erosion is then dependent on the frequency and duration of the erosive flow velocities.

Empirical methods have been used to assess the potential for vertical scour or erosion in rivers, for the purpose of **bridge foundation design (Ontario Highway Bridge Design Code, 1991)**. The OHBDC compiled numerous field data and case studies from Ontario, concerning scour and erosion. The **“competent mean velocity”** has been related to soil type or grain size (river bed and bank), for various depths of flow (regime) based on **bankfull discharge conditions**. This represents the minimum flow velocity which can cause active erosion based on the soil bed or bank materials.

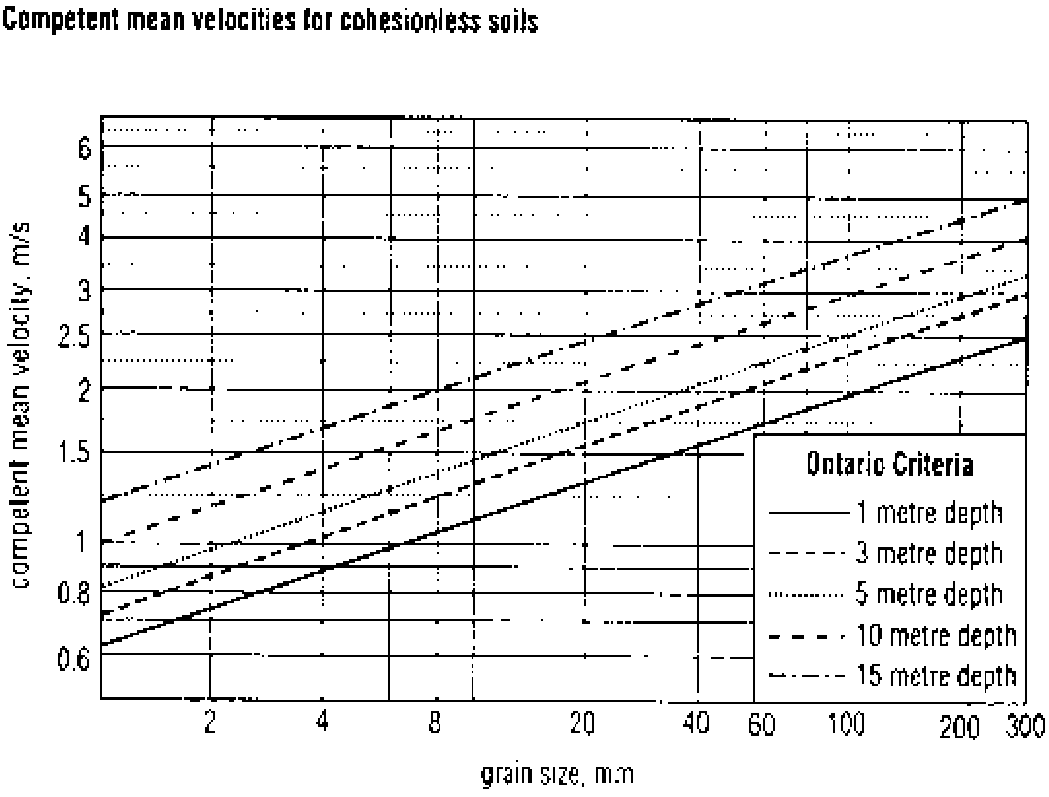
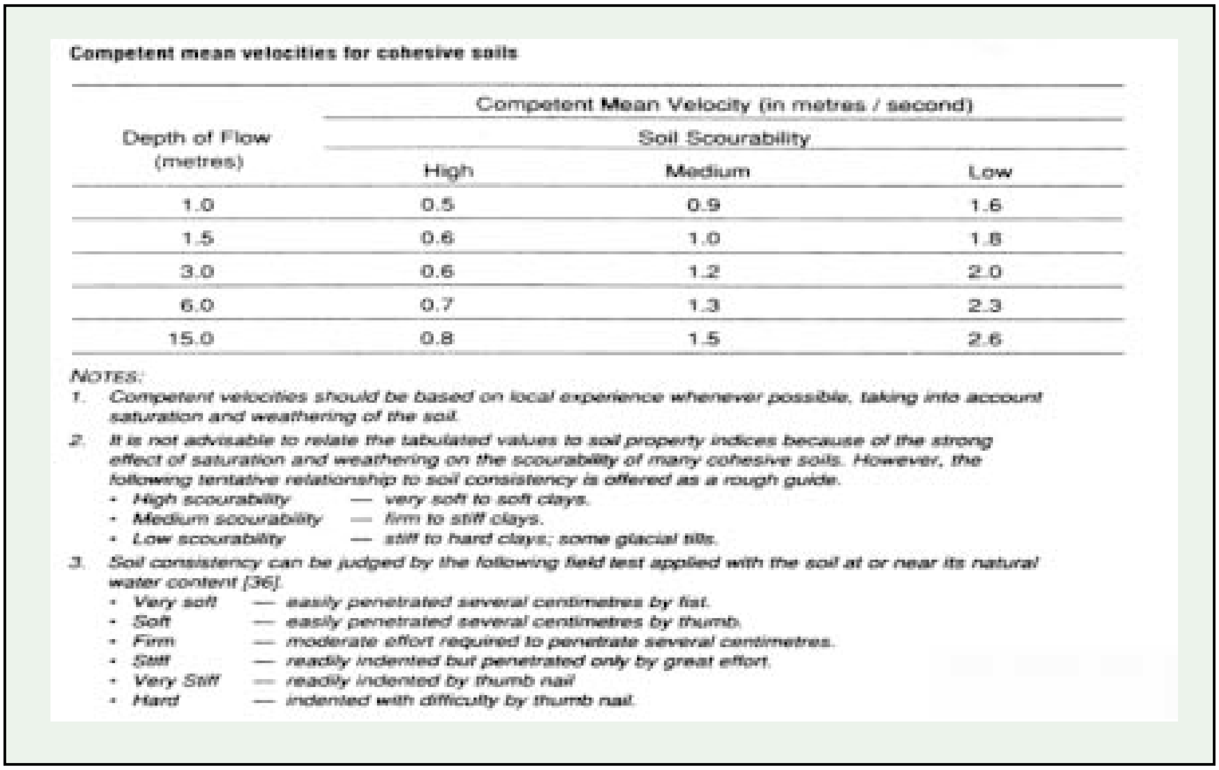


Figure 108 - Competent Mean Velocities for Cohesionless Soils



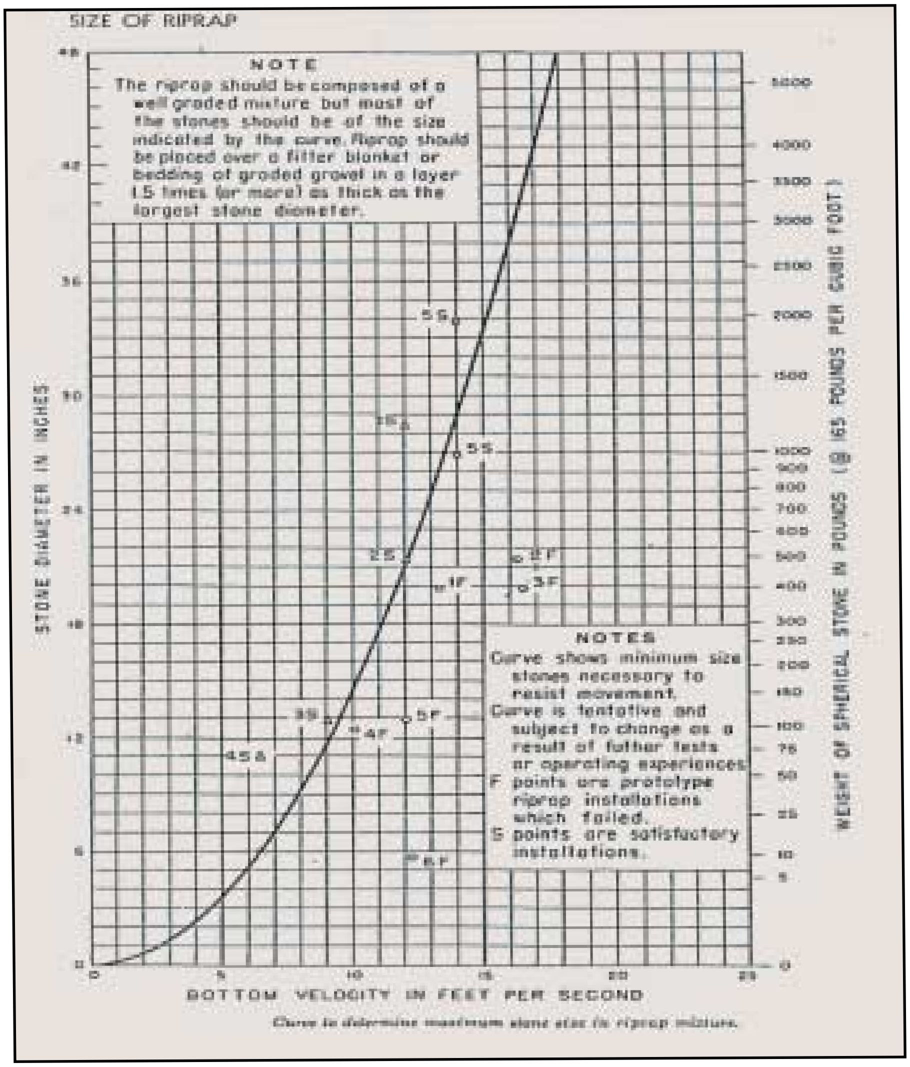
Competent mean velocities for cohesive soils

Depth of Flow (metres)	Competent Mean Velocity (in metres / second)		
	Soil Scourability		
	High	Medium	Low
1.0	0.5	0.9	1.6
1.5	0.6	1.0	1.8
3.0	0.6	1.2	2.0
6.0	0.7	1.3	2.3
15.0	0.8	1.5	2.6

NOTES:

1. *Competent velocities should be based on local experience whenever possible, taking into account saturation and weathering of the soil.*
2. *It is not advisable to relate the tabulated values to soil property indices because of the strong effect of saturation and weathering on the scourability of many cohesive soils. However, the following tentative relationship to soil consistency is offered as a rough guide.*
   - *High scourability — very soft to soft clays.*
   - *Medium scourability — firm to stiff clays.*
   - *Low scourability — stiff to hard clays; some glacial tills.*
3. *Soil consistency can be judged by the following field test applied with the soil at or near its natural water content [36].*
   - *Very soft — easily penetrated several centimetres by fist.*
   - *Soft — easily penetrated several centimetres by thumb.*
   - *Firm — moderate effort required to penetrate several centimetres.*
   - *Stiff — readily indented but penetrated only by great effort.*
   - *Very Stiff — readily indented by thumb nail*
   - *Hard — indented with difficulty by thumb nail.*

Figure 109 - Competent Mean Velocities for Cohesive Soils



NOTE
The riprap should be composed of a well graded mixture but most of the stones should be of the size indicated by the curve. Riprap should be placed over a filter blanket or bedding of graded gravel in a layer 1.5 times (or more) as thick as the largest stone diameter.

NOTES
Curve shows minimum size stones necessary to resist movement.
Curve is tentative and subject to change as a result of futher tests or operating experiences.
F points are prototype riprap installations which failed.
S points are satisfactory installations.

Curve to determine maximum stone size in riprap mixture.

Figure 110 - Competent Flow Velocity of Rip Rap

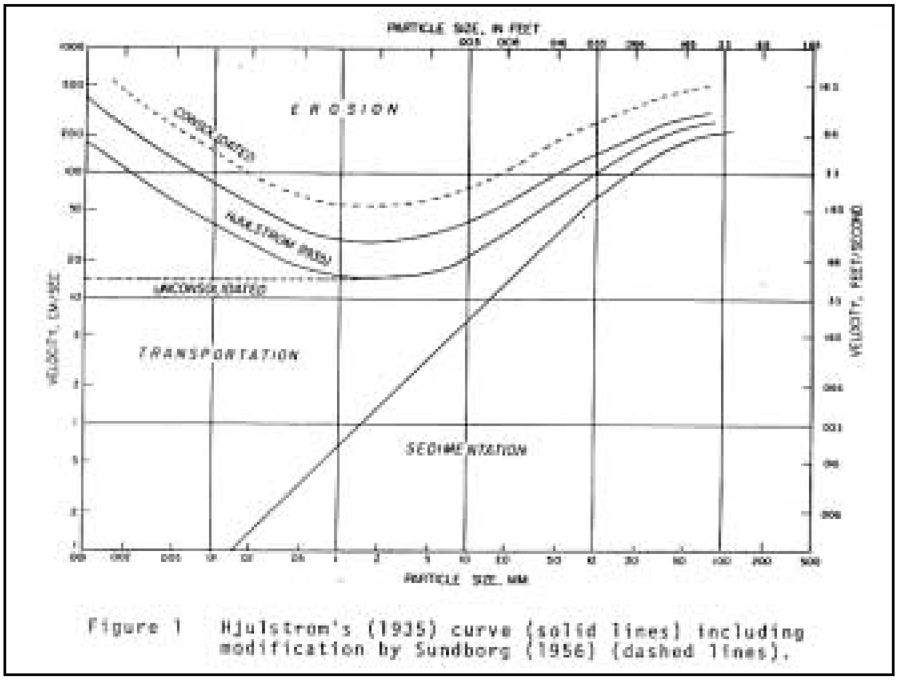


Figure 1 Hjulstrom's (1935) curve (solid lines) including modification by Sundborg (1956) (dashed lines).

Figure 111 - Modified Hjulstrom Curve (1935, 1994)

In very general terms, the flow velocity needed to cause “active erosion” is lowest for sand size particles, as shown on the **Hjulstrom Curve** (1935).fig 111. This graphical representation offers a simple description of flow velocity and particle size, in terms of **erosion, transportation, and deposition.**

STEP 3:Active Erosion has been Confirmed or the bankfull velocity is greater than the competent flow velocity

Figure 112 - Active Erosion

Figure 113 - No ‘Active Erosion

Where active erosion is confirmed (see Figures 112) **OR** the bankfull velocity is greater than the competent flow velocity, and the native soil structure or composition is known, Table 3 provides the range of toe erosion allowance that should applied (e.g., for soft/firm cohesive soils (# 4, left column) the toe erosion allowance should be within the range of 8-15 metres).

STEP 4: No active erosion or bankfull velocity is less than the competent flow velocity

Where there is no evidence of active erosion (see Figure 113, 114) **OR** the bankfull velocity is less than the competent flow velocity, water depths should be used to determine the toe erosion allowance (e.g., from Table 3, the area of stiff/hard cohesive soils (#3) and a bankfull width of 5 to 30 metres would result in the selection of a toe erosion allowance of 2 metres).

Where the use of any of the first four options suggests that the identified toe erosion allowance may be excessive or not sufficient enough to reflect location conditions, mechanisms should be incorporated into the planning process providing the flexibility to undertake a study using accepted geotechnical and engineering principles and a minimum of 25 years of record or data to determine the toe erosion allowance. Where the municipality or planning board approves the study using accepted geotechnical and engineering principles, the geotechnical/engineering toe erosion allowance should be applied only in the area studied.

In some locations studies of toe erosion allowances may have already been undertaken by local agencies. These allowances are generally unique to specific watersheds or regions and are usually based on the subsoil and ground water conditions characteristic of the area. Where local studies have been undertaken using accepted geotechnical and engineering principles they may be used to determine the toe erosion allowances for the area studied.

Figure 114 - No ‘Active Erosion’

3.2 STABLE SLOPE ALLOWANCE

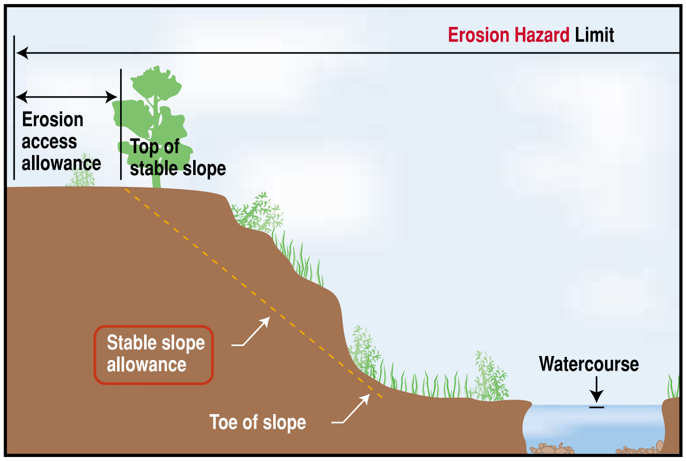


Figure 115 a - Stable Slope Allowance
(toe of valley slope >15m from watercourse)

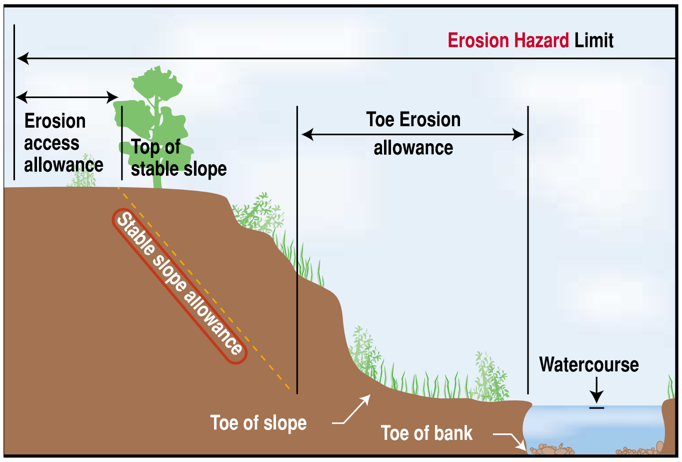


Figure 115 b - Stable Slope Allowance
(toe of valley slope ≤15m from watercourse)

The **stable slope allowance** is an important component of the *erosion hazard* limit for **confined** *river and stream systems.*

The stability or instability of slopes is governed by the interrelationships between a number of variables associated with surface and subsurface conditions. These include, but are not limited to, soil composition, slope steepness or inclination, water content and movement through and over the slope, load or pressures on the slope, and the presence or proximity of flowing water. Slope movement or instability can occur in many ways. The most common causes of slope movement include:

- changes in slope configuration (e.g., steepness, inclination);
- increases in loading on a slope (e.g., placement of buildings, structures or fill at or near the crest of the slope);
- changes in surface/subsurface drainage of the soil resulting in higher levels of flows and erosive action or higher water pressures (e.g., heavy rainfall, blocked drainage); and
- loss or removal of stabilizing vegetation (e.g., weakening of the soil structure with the removal of the surface cover and root systems).

Naturally occurring erosion processes can also play an integral role in affecting the stability of a slope. This is particularly true where flowing water is involved (e.g., surface runoff over the slope, seepage zones associated with throughflow and ground water flow). Examples of the effects of flowing water on slope stability include, but are not limited to:

- slope failure caused by erosion at the toe of the slope as evidenced by the undercutting and steepening of the slope by river or stream flows or wave action at the base of the slope;
- saturation and resultant weakening of the strength of the soil structure (e.g., slope face) related to water seepage or the presence of ground water flow; and
- ”piping”, associated with springs or seepage areas, on the slope face which may cause erosion to occur in the weaker layer of soil (e.g., sand) overlying a less permeable soil type (e.g., clay).

Generally, development should not occur on or on top of valley walls because the long-term stability of the slope, and therefore public health and safety, cannot be guaranteed. Development should be set back from the top of valley walls far enough to avoid increases in loading forces on the top of the slope, changes in drainage patterns that would compromise slope stability or exacerbate erosion of the slope face, and loss of stabilizing vegetation on the slope face.

Where the valley wall is over-steepened or subject to active toe erosion, development should be set farther back from the top of the valley wall so that the development will also be safe from erosion and slope failure in the long term. This is likely the case when the slope is steeper than the suggested stable slope allowance (3 horizontal to 1 vertical distance) or when the toe of the slope is within 15 metres of the river or stream bank.

The determination and use of a **stable slope allowance** should apply only to confined systems to locate the top of stable slope and subsequently, the **erosion access allowance** (see section 3.4). By definition, unconfined systems do not have discernible valley or channel slopes and as such, do not usually have significant slope stability concerns.

The **stable slope allowance** means:

- Where the toe of the valley slope is located less than 15 metres from the river or stream bank, a horizontal allowance measured farther landward from the toe erosion allowance (i.e. horizontal and perpendicular from the toe of the watercourse) equivalent to at least 3.0 times the height of the slope. (see figure 115b)
- Where the toe of the valley slope is located more than 15 metres from the river or stream bank, a horizontal allowance measured from the toe of the valley slope equivalent to 3.0 times the height of the slope (see figure 115a)

OR

A stable slope allowance determined by a study using accepted geotechnical principles.

Where municipalities and planning boards determine that the 3:1 (h:v) stable slope allowance is excessive or not sufficient enough, mechanisms should be incorporated into the planning process providing the flexibility to undertake a study using accepted geotechnical principles to determine the stable slope allowance and the top of the stable slope.

Where studies using accepted geotechnical principles are approved by the municipalities or planning boards, the engineered stable slope allowance should be applied only in the area studied. For further recommendations on what specifically should be addressed by these studies please refer to Chapter 4, Mapping and Studies and Geotechnical Principles for Stable Slopes, 1998 report.

3.3 FLOODING HAZARD LIMIT ALLOWANCE AND MEANDER BELT ALLOWANCE

In determining the *erosion hazard* limit of **unconfined** *river and stream systems*, either the flood hazard limit or the meander belt allowance are applied along with the **erosion access allowance** (see section 3.4).

Approaches to determine the extent of flooding, or the *flooding hazard* limit are outlined in the Technical Guide - River and Streams Systems, Flooding Hazard Limit and are based on either storm centred events (i.e. Hurricane Hazel, Timmins Storm) or a flood frequency based event (i.e. 100-year flood), or an observed event.

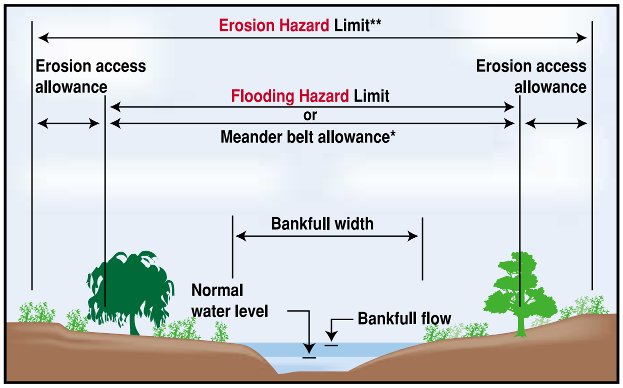
The general intent of defining the *flooding hazard* limit or meander belt allowance of unconfined river and stream systems is to ensure that the flow of water and its associated natural processes, including erosion, are maintained.

As unconfined systems are generally found within relatively flat terrains it is important to recognize that natural hazards associated with these fluvial systems may extend well beyond the immediate channel under conditions such as heavy or rapid runoff or spring snowmelt. During these times of increased flows, water flow may overtop banks of channels, create new channels and/or cause flooding and erosion.

Where the *flooding hazard* limit plus the erosion access allowance is used to determine the *erosion hazard* limit, the existence and availability of applicable data normally limits its use to drainage basins of greater than 125 hectares.

•Meander Belt Allowance

In any fluvial system, the morphology or change of the channel is a result of the dynamic balance of energy (e.g., flow or discharge of water) and the resistance of material comprising the channel perimeter (Morisawa 1985). As such, the channel form (e.g., shape, size, configuration) is governed by its need to carry sediment load (e.g., bed, suspended and dissolved) using the availability of water flows or discharge. A change in any of the variables (e.g., discharge, load, resistance) will result in a change in the channel form. One result of this change may be a shifting of the watercourse channel causing a change in the meander or channel orientation or form.



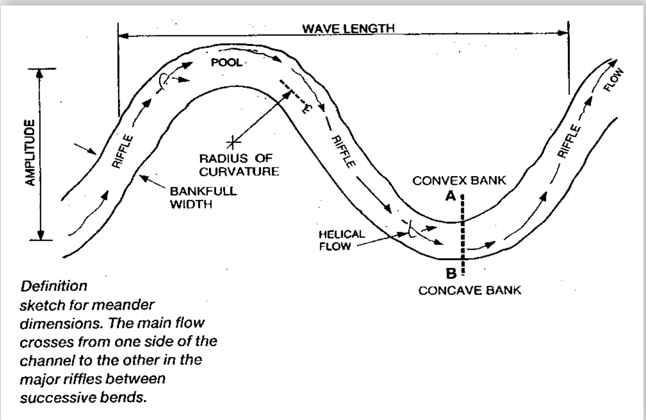
(NOT TO SCALE)

* The bankfull channel width with the largest amplitude meander in the reach is used to determine Meander Belt Width.

** Erosion access allowance is also added to the flooding hazard limit, when known, to define the erosion hazard limit.

Figure 116 - Flooding Hazard Limit for Unconfined Systems

Figure 117 - unconfined System



Definition sketch for meander dimensions. The main flow crosses from one side of the channel to the other in the major riffles between successive bends.

Figure 118 - River Terminology

Unconfined *river and stream systems* are located within relatively flat terrain. They normally contain perennial (i.e., year round) or ephemeral (i.e.,seasonal or intermittent) flows which have a tendency to constantly shift or meander (i.e., laterally and downstream) in response to the continuous changes associated with the natural influence of discharge and load.

The term **meander belt allowance**, for the purposes of defining the “area of provincial interest”, is essentially the maximum extent that a water channel migrates. The term meander belt is derived from terminology used to describe meandering systems such as amplitude, wavelength, bend radius, bankfull width, point bars, pools, riffles and concave and convex banks.

A meandering system is comprised of a series of interconnected reaches. A reach is defined as a length of channel over which the channel characteristics are stable or similar. See Chapter 2 for a further description of reach. For each reach, the meander belt can conceptually be centred on a line or axis drawn through the middle of the meanders or riffle zones, a line that essentially divides each of the meanders in half (Figure 119).

Bankfull width can be established. Please see the previous Section 3.1.1 - Determination of Bankfull Characteristics.

Numerous technical sources have indicated that the bankfull discharge is the main type of flow that determines channel morphology or change. As such, the width of the meander belt is derived from an analysis of the bankfull channel width of the largest amplitude meander in the reach. Bankfull channel width may be determined through either field investigations or through aerial photograph interpretation. Based on available data and information the **meander belt allowance** should be defined as **20 times the bankfull channel width of the reach** and centred on the meander belt axis (Figure 120).

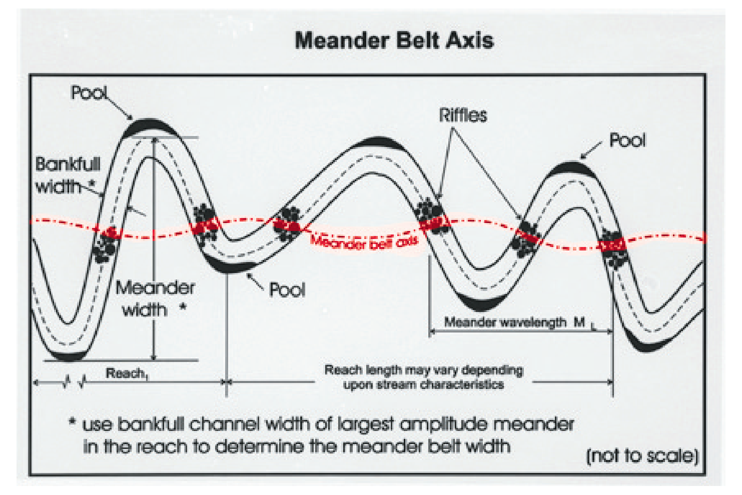


Figure 119 - Meander Belt Axis and Reach

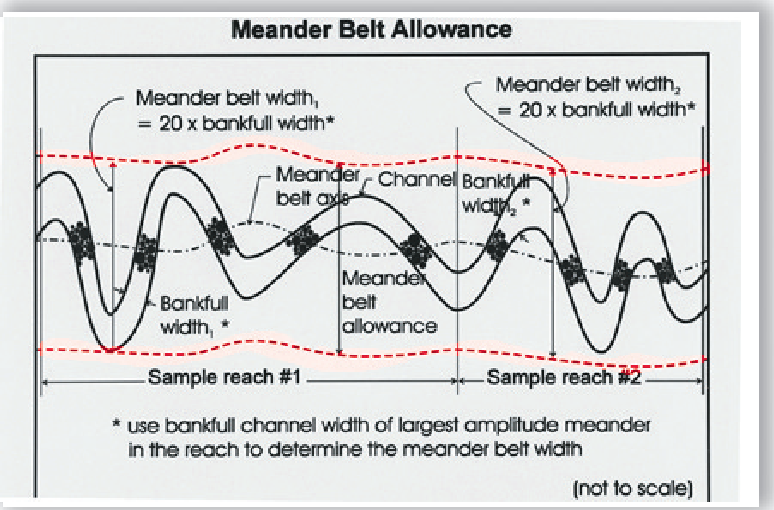


Figure 120- Meander Belt Allowance

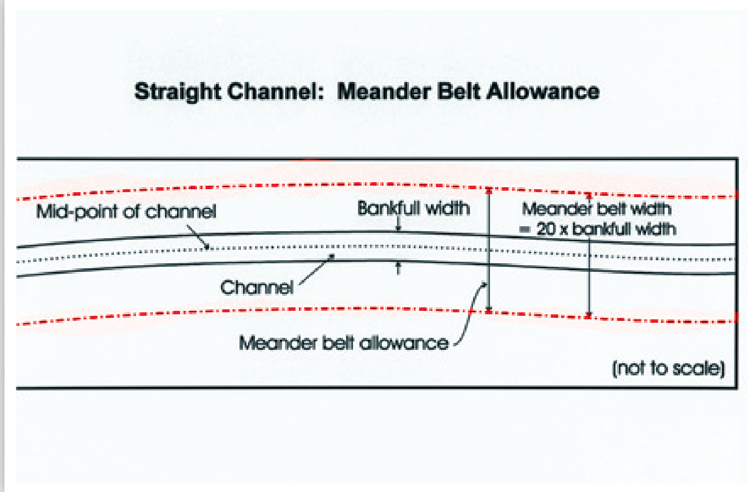


Figure 121 - Straight Channel

For those reaches where the channel appears to be straight (Figure 121), numerous factors combine to influence the size, shape and location of the meanders or the channel. For example, the "straightness" of the channel may result from the channel bed being located in a less erosive soil structure. Over time, flows within the channel bed may expose a more erosive soil structure and the channel may again begin to form meanders. When applying the meander belt allowance of 20 times the bankfull channel width for a reach that appears to be relatively straight, the meander belt should be centred on the mid-line of the channel.

Combining all of the calculated meander belt widths for each reach together along the entire length of channel will provide the overall meander belt allowance for the unconfined system.

Where municipalities and planning boards determine that 20 times the bankfull channel width of the reach is excessive or not sufficient enough in determining the meander belt allowance, mechanisms should be incorporated into the planning process providing the flexibility to undertake a study using accepted scientific, and engineering principles to determine the meander belt allowance. This flexibility may not be warranted or desired where a more precise definition of the meander belt allowance or *erosion hazard* limit is not necessary, where there is sufficient area within the development lot to site any proposed development outside of the *erosion hazard* limit (i.e., meander belt allowance plus the erosion access allowance), where development pressure is low and alternative development sites exist, or where the staff, administrative and financial resources within the municipality may preclude the ability of the municipality to support such studies. For those situations where a study is used to determine the "meander belt allowance", the study should be undertaken using "accepted engineering principles". For further recommendations on what should be addressed by these studies please refer to Chapter 4 - Field and Site Investigation.

Some studies of meander belt allowances have already been undertaken by local agencies. These allowances are generally unique to specific watersheds or regions. Where local studies have been undertaken using accepted engineering principles they may be used to determine the meander belt allowance for the area studied.

3.4 EROSION ACCESS ALLOWANCE

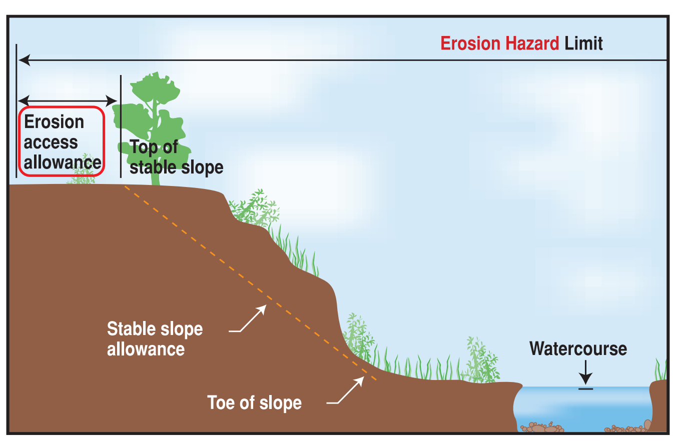


Figure 122 - Erosion Access Allowance: Confined Systems

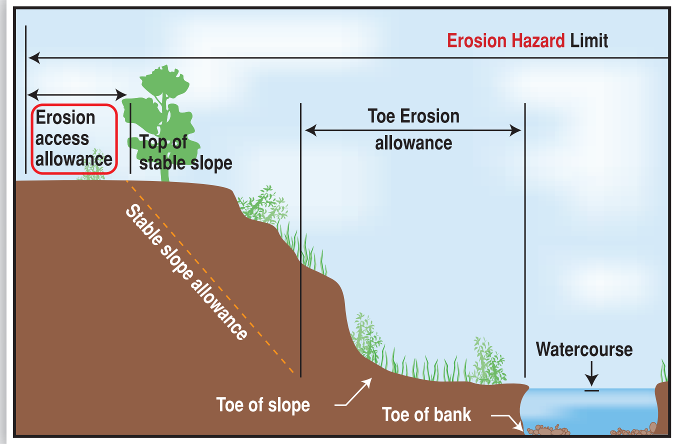


Figure 123 - Erosion Access Allowance: Unconfined Systems

Figure 124 - Erosion Access Allowance

The erosion access allowance is the last component used to determine the landward limit of the *erosion hazards* and should be applied within all confined, unconfined and terrain-dependent *river and stream systems*.

Three main principles support the inclusion of the erosion access allowance:

- providing for emergency access to erosion prone areas;
- providing for construction access for regular maintenance and access to the site in the event of an erosion event or failure of a structure; and
- providing protection against unforeseen or predicted external conditions which could have an adverse effect on the natural conditions or processes acting on or within an erosion prone area of provincial interest.

Study results using available data and information suggests that the **erosion access allowance** for *river and stream systems* should be **6 metres** (see Figures 122 and 123).

Where municipalities and planning boards determine that the suggested 6 metre erosion access allowance is excessive or not sufficient enough to provide the required public safety and site access, mechanisms should be incorporated into the planning process providing the flexibility to undertake a study using accepted scientific, geotechnical and engineering principles to determine the erosion access allowance. This flexibility may not be warranted or desired where a more precise definition of the erosion access allowance is not necessary, where there is sufficient area within the development lot to site any proposed development outside of the *erosion hazard* limit, where development pressure is low and alternative development sites exist, or where the staff, administrative and financial resources within the municipality may preclude the ability of the municipality to support such studies.

For those situations where a study is used to determine the “erosion access allowance”, the study should be undertaken using “accepted scientific, geotechnical and engineering principles”. Where studies using accepted scientific, geotechnical and engineering principles are approved by the municipality or planning boards, they should be applied only in the area studied.

Some studies of erosion access allowances have already been undertaken by local agencies. These allowances are generally unique to specific watersheds or regions. Where local studies have been undertaken using accepted scientific, geotechnical and engineering principles they may be used to determine the erosion access allowances for the area studied.

4.0 SITE INVESTIGATION AND STUDIES

If the proponent has decided that the generic setbacks are not appropriate for their purposes and would like to do a detailed study, then the following section will outline the procedure which should be followed.

The initial investigation for the site should be carried out by first carrying out the Step process outlined in the AMSC[9] in Ontario document. The following key questions should be answered as part of the initial erosion study:

- Where is the channel in its process of evolution?
- What is the disturbance?
- What future disturbances are likely to occur?
- What are the channel dynamics today?
- What is the streams response to the disturbance?
- What is the ultimate configuration of the channel?

This procedure will determine the potential future channel configuration and therefore assist in determining what areas are potentially safe to develop on or which areas are in danger of erosion in the future. The details of what is required in order to address each of these questions can be found in the AMSC[10] document. Additional investigations are the erosion, meandering and geotechnical investigations. These will assess the scale, nature, and extent of the natural erosion and slope stability process at the site and are covered under Section 4 of this document. The geotechnical procedure determines the surface, subsurface conditions (e.g., soil, rock, groundwater) and their potential for future slope instability. The erosion and meandering refers to the natural ongoing process in the river and stream system.

4.1 GENERAL INVESTIGATION FOR CONFINED AND UNCONFINED SYSTEMS

A site and field investigation may be carried out to assess the potential requirements for the confined or unconfined system (i.e., meander belt allowance, toe erosion allowance, stable slope allowance, and/or erosion access allowance). Depending on the landform type confined or unconfined, the type of study will vary significantly.

4.1.1 Site Investigation

The “site investigation” should involve a review of available records and a site visit to permit review of the type, scale and extent of the site hazard, the consequent risk to life, property and structure.

4.1.2 Review of Mapping

Regional geology should be considered at the outset of any slope stability investigation, along with any records of past slope instability situations. MNR geological mapping (bedrock geology and bedrock topography or drift thickness, Quaternary geology and MOE water well records) is available for many areas of the province, including most urbanized centres. Other sources include the Ministry of Development and Mines, and the Geologic Survey of Canada.

Many urbanized areas have had topographic mapping prepared from air photography interpretation and this is often available from the Engineering or Public Works Department in the municipal level government offices. The mapping should preferably be at a scale of 1:500 or 1:1000 in order to show sufficient detail of the slope profile.

These government offices sometimes also possess records of historical air photographs which may document conditions of erosion, slope instability, land development, or land filling. The Metropolitan Toronto Archives has such air photographs for the Toronto-centred area which are available from 1947 on almost an annual basis. These air photographs are at a scale of about 1:4800. Conservation Authorities also have files which document past reports of slope failures or erosion.

4.1.3 Review of Aerial Photographs

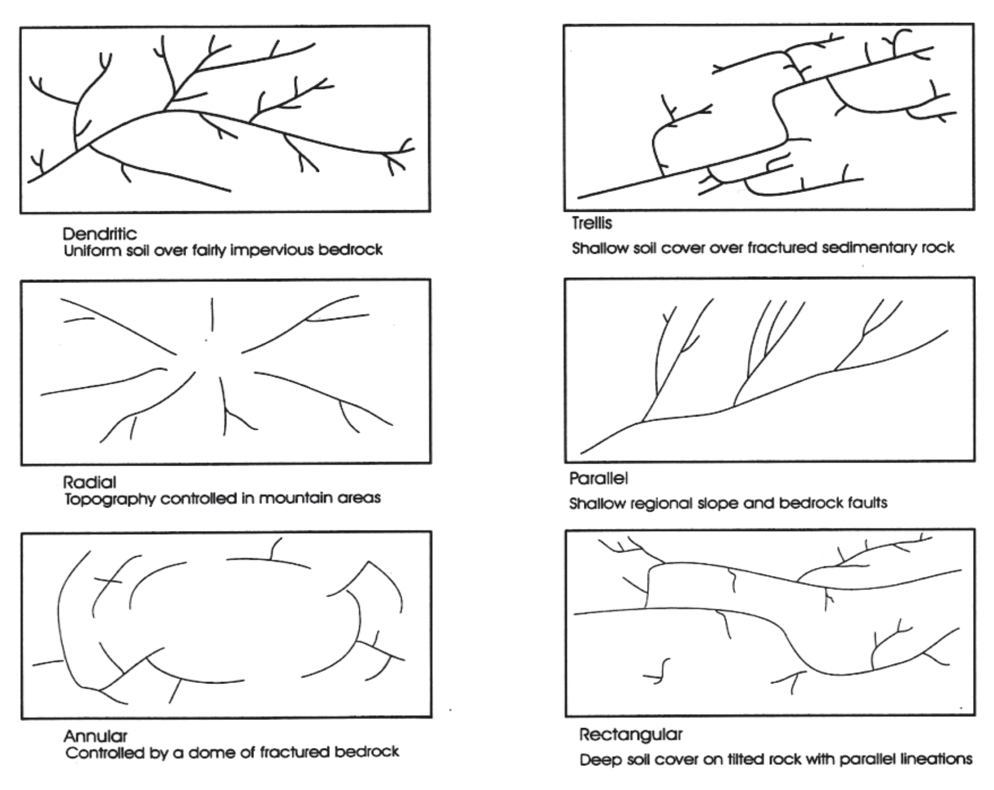


Figure 125 - Basic Drainage patterns (Mitchell, R.J., 1983)

Air photos provide detailed geological and topographic information over a relatively large area (watershed, subwatershed, reach and site scales) and are used to detect conditions that are difficult to observe/evaluate from a surface investigation (i.e., previous landslides, river meandering, landforms, drainage patterns). The elements evaluated by air photo interpretation include topographic features, drainage, erosion, soil tones, and vegetation.

The density and pattern of drainage channels in a given area, directly reflect the nature of the underlying soil and rock. Drainage patterns are better developed within the relatively impervious soils which promote surface runoff. For example, a closely spaced drainage system denotes relatively impervious materials; a tree-like drainage pattern develops in flat lying beds and relatively uniform materials; a parallel stream pattern indicates the presence of a regional slope. The basic patterns and their relationship to soils and bedrock are shown on Figure 125.

An important aerial photographic element is soil tone that can indicate moisture condition on the ground. A dark tone of soil generally indicates a high moisture condition on the ground (i.e., high ground water level). The sharpness of the tonal boundary between dark and light tone of soils, aids in determination of soil type. Well-drained coarse-textured soils show distinct tonal boundaries, while poorly drained fine-textured soils show irregular unclear tonal boundaries. Vegetation pattern is connected with soil moisture conditions and reflects local and regional climatic conditions. Typically a small difference in soil moisture condition is detected by a corresponding change in vegetation conditions on the ground.

The following features (discernible on aerial photographs) are typical of landslide or landslide-susceptible terrain (Rib, H.T. and Liang, T.);

•land masses undercut by streams,
•steep slopes having large masses of loose soils,
•sharp line of break at the scarp and/or tension cracks,
•hummocky surface of the sliding mass below the scarp,
•unnatural topography, such as spoon-shaped depressions in the terrain,
•seepage zones,
•closely spaced drainage channels,
•accumulation of debris in drainage channels or valleys,
•distinctive change in vegetation and tone, indicative of changes in soil moisture,
•inclined trees, displaced fences, distress to roadway.

Details of aerial photographic terrain evaluation are contained in Transportation Research Board Special Report No.176, “Landslides, Analysis and Control”, 1978.

4.3 Confined Systems : Determination of Toe Erosion and Slope Stability Issues

Toe Erosion Rates:

Toe erosion rates are best determined through long term measurements. Site measurements may not always be available for the site and aerial photography may be the best source of information. A minimum of 25 years of data is recommended for erosion assessment rates.

Slope Stability Requirements:

The following section describes the reasoning and basis for a suggested method of site evaluation to assist in determining the level of geotechnical investigation required to assess slope stability. In all cases, the responsibility for providing the geotechnical investigation is that of the proponent who might be a land developer, a pit operator, or a government agency. Part of the proposed development may be located close to a slope crest and there may be concerns about risks of ground loss in the event of a slope slide.

The level of geotechnical investigation required to determine the stability of a slope involves an understanding of:

- the physical and hydrological site conditions; and
- the type of development or land-use proposed,

which may be put at risk.

4.3.1 Site Investigation

Slope stability analysis and the calculation of Factors of Safety, requires certain basic information that can be determined in several manners or can be estimated with reasonable accuracy;

a)the slope configuration; height and inclination or shape. These can be estimated visually, or determined from topographic mapping, or measured by on-site survey of slope cross-sections (profiles).

b)the subsurface conditions within the slope; soil stratigraphy (types and layering), soil strengths (density and shear strength), groundwater levels. These can be determined in a general manner by visual inspection of exposed soil on the slope, or on the basis of geologic mapping. More specific information can be obtained by drilling boreholes (unlimited depth), or digging test pits (max. depth 3 to 5 m), or hand auger holes (max. 1 to 2 m depth).

c)any external loadings to the slope; structures, traffic, earthquakes,

d)site drainage and erosion conditions; surface run-off, ditches, channels, seepage, creeks, rivers, lakes,

e)vegetation cover.

The decision to use simple investigation (based on site inspection only) versus a detailed investigation (including boreholes, surveys or mapping) depends mostly on:

- the slope height; and
- the consequence of slope failure on the adjacent land-use.

4.3.2 Tools: Slope Inspection Record and Slope Rating Chart

A site inspection is always required when assessing slope stability, which produces an extensive basis of factual information for relatively little cost. The following tools are useful when assessing any site. The recommended procedure is to fill in the Slope Inspection Record and then the Slope Rating Chart.

a)Slope Inspection Record

The completion of the **Slope Inspection Record** (Table 4.1) from a field investigation is very important because it establishes vital factual information on the slope height, slope inclination, exposed soil stratigraphy (if visible), vegetation cover, structures near the slope, and other important features which are relied on by the stability analysis in attempting to model or simulate the actual forces and strength resistance conditions at a site. A photographic record (still or video) should also be taken of the site slope conditions.

•File No.
record date and time of inspection, including weather conditions and visibility, site accessibility

•Site Location
describe site location with respect to major roads or regional features; provide sketch

•Watershed
record name of watershed site is located in

•Property Ownership
obtain name and address of property owner, and legal description for property; describe current land-use of site and adjacent properties

•Slope Data
record vertical height of slope from toe to crest; describe slope inclination (horiz. to vert. or angle from horizontal) and shape (also provide sketch at end of report and take photographs), whether slope angle is uniform or composite

•Slope Drainage
describe locations and amounts of any seepage on the slope face or near the slope crest or toe; note location of any 'piping' if occurring, also provide sketch at end of report and take photographs

•Slope Soil Stratigraphy
where visible or exposed, describe soil stratigraphy (location, thickness, colour of soil layers) and soil types (sand, clay, rock) if possible, also show on sketch and take photographs

•Water Course Features
indicate location and proximity of any nearby drainage features or water bodies (marshy ground, swale, channel, gully, springs, stream, creek, river, pond, bay, lake), show on sketch

•Vegetation Cover
describe location, amount, and types of vegetation cover on the slope (crest, face, toe) and on adjacent properties; show sketches, take photographs; grasses, weeds, shrubs, saplings, trees

•Structures
describe location, types, and size of any man-made structures on the slope face or near the slope crest or slope toe; show on sketches, take photographs; buildings, retaining walls, fences, roads, stairs, decks, towers, bridges, buried utilities

•Erosion Features
describe location, types, and size of any erosion features on the slope face or near the slope crest or slope toe; show on sketches, take photographs; bare exposed soil, rills, gully, toe erosion, scour, undercutting, piping

•Slope Slide Features
describe location, types, and size of any past slope movements on the slope face or near the slope crest or slope toe; show on sketches, take photographs; tension cracks, scarps, slumps, bulges, ridges, bent tree trunks or stands of dead trees

•Comments
record any other general observations

•Plan View Sketch
show locations of slope crest, toe, structures, vegetation, stratigraphy, seepage, erosion, water course features

•Profile Sketch
show slope height, inclination, and shape

The Site Inspection Record (see next page) can be taken out to the site and has the following components to be recorded about the site. Further description is found in Chapter 7 of the Geotechnical Principles for Stable Slopes, 1998 report.

TABLE 4.1 - Slope Inspection Record

1. FILE NAME / NO.
INSPECTION DATE (DDMMYY):
WEATHER (circle):
• sunny • partly cloudy • cloudy
• calm • breeze • windy
• clear • fog • rain • snow
• cold • cool • warm • hot
estimated air temperature:
INSPECTED BY (name):

2. SITE LOCATION (describe main roads, features)

SKETCH

3. WATERSHED

4. PROPERTY OWNERSHIP (name, address, phone):

LEGAL DESCRIPTION
Lot
Concession
Township
County

CURRENT LAND USE (circle and describe)
• vacant -field, bush, woods, forest, wilderness, tundra,

• passive -recreational parks, golf courses, non-habitable structures, buried utilities, swimming pools,

• active -habitable structures, residential, commercial, industrial, warehousing and storage,

• infra-structure or public use - stadiums, hospitals,
schools, bridges, high voltage power lines, waste management sites,

5. SLOPE DATA

HEIGHT • 3 - 6 m • 6 - 10 m • 10 - 15 m • 15 - 20 m
• 20 - 25 m • 25 - 30 m • > 30 m
estimated height (m):

INCLINATION AND SHAPE

• 4:1 or flatter 25 % 14°	• up to 3:1 33 % 18 °	• up to 2:1 50 % 26 °
• up to 1:1 100 % 45°	• up to :1 200 % 63 °	• steeper than :1 > 63 °

6. SLOPE DRAINAGE (describe)

TOP

FACE

BOTTOM

7. SLOPE SOIL STRATIGRAPHY (describe, positions, thicknesses, types)

TOP

FACE

BOTTOM

8. WATER COURSE FEATURES (circle and describe)

SWALE, CHANNEL

GULLY

STREAM, CREEK, RIVER

POND, BAY, LAKE

SPRINGS

MARSHY GROUND

9. VEGETATION COVER(grasses, weeds, shrubs, saplings, trees)

TOP

FACE

BOTTOM

10. STRUCTURES(buildings, walls, fences, sewers, roads, stairs, decks, towers,)

TOP

FACE

BOTTOM

11. EROSION FEATURES(scour, undercutting, bare areas, piping, rills, gully)

TOP

FACE

BOTTOM

12. SLOPE SLIDE FEATURES(tension cracks, scarps, slumps, bulges, grabens, ridges, bent trees)

TOP

FACE

BOTTOM

13. PLAN SKETCH OF SLOPE

14. PROFILE SKETCH OF SLOPE

Slope Stability Rating Chart To Determine The Level of Investigation Required

To assist in determining the suggested level of investigation required, a "Slope Stability Rating Chart" is provided (Table 4.2). This Rating Chart can used by either those reviewing proposals or by a proponent, however a site visit is required to complete the Chart. The Rating Chart <u>must</u> be completed for all slope assessments and be retained by the reviewer. The Rating Chart has 7 components that together provide a reasonable assessment of the slope stability. Some calibration may be required of the values in the chart, on the basis of extensive experience with its use. The 7 components are;

1. Slope Inclination

- The angle from the horizontal of the slope face, measured from the toe to the crest. If the slope is comprised of several different inclinations, provide details on each. Estimate visually, or use hand inclinometer to measure approximate inclination, or survey (also refer to available mapping).

2. Soil Stratigraphy

- Soil layering and soil types composing the slope. Confirm if visible in bare exposed areas. Refer to previous nearby boreholes or well established local geology. <u>If several soil layers are present, provide details on each</u>.

3. Seepage from Slope Face

- The quantity and location of groundwater on the slope face. Visually inspect slope for surface seepage (springs, streams, creeks).

4. Slope Height

- Measurement of the vertical height between the toe (bottom) and the crest (top) of the slope. Estimate visually, or measure by surveying, or refer to available mapping.

5. Vegetation Cover on Slope Face

- Indication of the type and extent of vegetation cover (trees, grass).

6. Table Land Drainage and Gullies

- Indication of surface infiltration and run-off over the slope face, which may cause a potential for surface erosion. Describe whether table land drains towards slope and whether drainage/erosion features are present.

7. Previous Landslide History

- Indicates past instability. Visually inspect slope for evidence or indicators of past instability (scarps, tension cracks, slumped ground, bent or bowed or dead trees, leaning structures such as walls etc.).

Toe Erosion

. Recognizes the presence of and potential for continued slope instability. Toe erosion must be addressed prior to solving slope instability.

The Rating Chart provides a general indication of the stability of a slope. Based on this chart, the level of investigation required, can be assessed. The chart is a guideline or tool only. In all cases, the consequences of slope failure must be carefully considered and may be an over-riding factor. The chart is not intended as a replacement to the judgement of experienced and qualified geotechnical engineers. The chart was prepared, to help in assessing the level of geotechnical investigation which would be appropriate for the site conditions. The Slope Rating Chart was based on important slope stability factors; slope inclination, soil stratigraphy, seepage, slope height, vegetation, drainage, and previous land slide activity.

The chart is used by circling the rating value of the most appropriate descriptions for the key factor observed on the slope, based on visual inspection. The circled values are totalled at the bottom, and the total value is used as a guide to determine the appropriate level of investigation, from a choice of 3 levels listed at the bottom of the chart. Further details on use of the chart are provided in "Geotechnical Principles for Stable Slopes", 1998.

TABLE 4.2 - SLOPE STABILITY RATING CHART

Site Location:	File No.
Property Owner:	Inspection Date:
Inspected By:	Weather:

1. SLOPE INCLINATION

	degrees	horiz. : vert.	
a)	18 or less	3 : 1 or flatter	0
b)	18 - 26	2 : 1 to more than 3 : 1	6
c)	more than 26	steeper than 2 : 1	16

2. SOIL STRATIGRAPHY

a)	Shale, Limestone, Granite (Bedrock)	0
b)	Sand, Gravel	6
c)	Glacial Till	9
d)	Clay, Silt	12
e)	Fill	16
f)	Leda Clay	24

3. SEEPAGE FROM SLOPE FACE

a)	None or Near bottom only	0
b)	Near mid-slope only	6
c)	Near crest only or, From several levels	12

4. SLOPE HEIGHT

a)	2 m or less	0
b)	2.1 to 5 m	2
c)	5.1 to 10 m	4
d)	more than 10 m	8

5. VEGETATION COVER ON SLOPE FACE

a)	Well vegetated; heavy shrubs or forested with mature trees	0
b)	Light vegetation; Mostly grass, weeds, occasional trees, shrubs	4
c)	No vegetation, bare	8

6. TABLE LAND DRAINAGE

a)	Table land flat, no apparent drainage over slope	0
b)	Minor drainage over slope, no active erosion	2
c)	Drainage over slope, active erosion, gullies	4

7. PROXIMITY OF WATERCOURSE TO SLOPE TOE

a)15 metres or more from slope toe	0
b)Less than 15 metres from slope toe	6

8. PREVIOUS LANDSLIDE ACTIVITY

a)	No	0
b)	Yes	6

SLOPE INSTABILITY RATING VALUES INVESTIGATION RATING SUMMARY	**TOTAL**

SUMMARY OF RATING VALUES AND RESULTING INVESTIGATION REQUIREMENTS

1. Low potential	< 24	Site inspection only, confirmation, report letter.
2. Slight potential	25-35	Site inspection and surveying, preliminary study, detailed report.
3. Moderate potential	> 35	Boreholes, piezometers, lab tests, surveying, detailed report.

NOTES:
a) Choose only one from each category; compare total rating value with above requirements.
b)If there is a water body (stream, creek, river, pond, bay, lake) at the slope toe; the potential for toe erosion and undercutting should be evaluated in detail and, protection provided if required.

The Rating Chart identifies 3 levels of stability and associated investigation requirements. The three levels are:

1. Stable / Site Inspection Only

A rating of 24 or less, suggests stable slope conditions,

- no toe erosion,
- good vegetation cover
- no evidence of past instability
- no structures within   (slope height) of the crest

and that no further investigation (beyond visual inspection) is needed. This should be simply confirmed through a visual site inspection and estimate of the slope configuration and slope stratigraphy and drainage (i.e. no measurements). Confirmation of the slope stability should be provided in the form of a letter (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer. The letter should include a summary of the site inspection observations which could be recorded on a Slope Inspection Form (see enclosed) and should clearly identify;

- slope height and inclination,
- vegetation cover on slope face,
- toe erosion, or surface erosion on slope,
- structures near slope crest or on slope,
- drainage features near slope crest, on slope face, or near slope toe.

2. Slight Potential / Site Inspection, Preliminary Study

A rating between 25-35 suggests the presence of several surface features that could create an unstable slope situation. The stability of the slope should be confirmed through a visual site inspection only, without boreholes. In addition to recording the visual observations outlined in the section above, some direct measurements of site features are required.

The slope height and inclination should be determined either with a hand inclinometer, or by 'breaking slope', or from mapping, or by surveying. As well, more information about the soil stratigraphy of the slope, should be obtained (without drilling boreholes) based on either previous or nearby subsurface investigations, or geologic mapping, or hand augering or test pits to determine shallow depth soil type(s). Measurements should be taken (by hand tape or surveying) of the locations of structures relative to the crest, and other features such as vegetation, past slide features (tension cracks, scarps, slumps, bulges, ridges), and erosion features. If available, historical air photographs should be examined for evidence of any past instability over the long-term. Confirmation of the slope stability should be provided in the form of a detailed report (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer.

This report will include:

- Slope Inspection Record (Appendix)
- a Site Plan and a Slope Profile indicating the positions of the various measurements taken on site (slope crest, slope toe, location of structures relative to crest, drainage features, erosion features, vegetation cover, indicators of past instability or movements)
- photographs of the site and slope conditions
- a discussion of the site inspection and measurements taken, review of previous information
- preliminary engineering analysis of slope stability (i.e., calculation of Factor of Safety) based on the above information and measurements, but utilizing conservative soil strength parameters and groundwater conditions since boreholes were not carried out.

3. Moderate Potential / Borehole Investigation

A rating of more than 35 suggests a moderate potential for instability. This may result if the slope is either steep, high and/or has several features that could create an unstable slope situation. The stability of the slope should be assessed more precisely through topographic survey of slope configuration and boreholes for slope stratigraphy and penetration resistance tests. Piezometers must be installed in the boreholes and measurements must be taken for groundwater levels. Laboratory testing on the borehole samples must be conducted to measure Basic Index Properties (water contents, unit weights, grain size distribution, Atterberg Limits) described in Appendix D, or other properties as required.

A detailed engineering stability analysis must be conducted to determine if the Factor of Safety for the original slope conditions equals or exceeds a design minimum Factor of Safety. The analysis should be based on the information obtained from the site survey and the borehole information. Historical data such as air photographs should also be reviewed. Confirmation of the slope stability or instability (and the stable slope inclination) should be provided in the form of a detailed report (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer. This

report will include:
- Slope Inspection Record (Appendix)
- a Site Plan and a Slope Profile indicating the positions of the various measurements taken on site (slope crest, slope toe, location of structures relative to crest, drainage features, erosion features, vegetation cover, indicators of past instability or movements)
- photographs of the site and slope conditions
- a discussion of the site inspection and measurements taken, review of previous information
- borehole logs and piezometer monitoring data
- laboratory test results (water contents, unit weights, grain size distribution, Atterberg Limits)
- the results of the detailed engineering Stability Analysis (Factors of Safety, failure surfaces, assumed slope data), stabilization alternatives, long-term stable slope inclination.

Where the local geology is well known (exposed stratigraphy or nearby boreholes), the requirement for numbers or depths of boreholes should be reviewed and possibly reduced.

Costs for the various Levels of Biotechnical Investigation

If a site slope is higher than 2 m and steeper than 3 to 1 (horiz. to vert.), an assessment of slope stability is warranted. Three basic levels of investigation have been identified, to be used in evaluating slope stability of sites. The Slope Rating Chart above is an aid to determine the appropriate level of investigation for a site, based on the physical features of the site slopes which are important to slope stability (height, inclination, groundwater, etc.).

The results of carrying out a Level 1 or Level 2 investigation may be that a Level 3 investigation is required. In general terms, the levels of investigation have been chosen on a basic premise that low height or gentle slopes can be analyzed sufficiently by general or observational methods, and that as slopes become higher and steeper more rigorous and intensive methods are required. The amount of field investigation increases with each level as follows:

Level 1	- site visit and inspection by engineer;
Level 2	- site visit and inspection, mapping and site survey/measurements of physical features;
Level 3	- site visit/inspection, mapping/surveying, borehole drilling.

For purposes of comparison only, the approximate engineering fees (2000 $Cdn.) for evaluating a single house lot on a slope site is estimated as follows;

Level 1	$ 500 - 1,500
Level 2	$ 2,000 - 4,500
Level 3	$ 5,000 - 12,000 and up.

Some complex site conditions may result in higher costs for investigation than indicated above.

4.3.3 Slope Stability Engineering Analysis

The engineering analysis of slope stability should be conducted with a recognized method (Bishop's, Janbu, Morgenstern-Price, Spencer, Sarma) in accordance with guidelines provided in "Geotechnical Principles for Stable Slopes", 1998. The geotechnical report should provide details on the analysis method, the model basis and all assumptions made, and the extent of calculations with an overall summary. Both in the report text and on suitable figures or drawings the following basic information and discussion should be provided:

a) slope height, slope inclination,
b) location of structures near slope,
c) assessment of erosion risks,
d) soil stratigraphy and strength,
e) ground water conditions and drainage,
f) vegetation cover and species,
g) Factor of Safety calculations,
h) potential causes of instability,
I) alternative slope stabilization methods, and comparison of benefits,
j) discussion of erosion on or near the site; locations, extent, severity, rates, suitable protection alternatives
k) discussion of potential impacts on surrounding properties
l) if required, discussion of cost-benefit analysis of stabilization measures including
- 'do nothing'
- partial stabilization
- full stabilization

m) long-term stable slope crest position and inclination, based on engineering analysis.

4.3.3.1 Design Minimum Factors of Safety

A table of recommended minimum Factors of Safety for design, has been prepared by reviewing the current practice in different areas around the world. The common range of minimum Factor of Safety for design is 1.2 to 1.5.

The recommended minimum Factors of Safety have been prepared on the basis of land-use above or below the slope. This table recognizes the consequences or risks to land-use or life by the occurrence of a slope slide. In general, the recommended minimum Factor of Safety for design, increases as the land-use intensifies or as publicly-owned resources and utilities become at risk.

Table 4.3

	LAND-USES	DESIGN MINIMUM FACTOR OF SAFETY
A	**PASSIVE**; no buildings near slope; farm field, bush, forest, timberland, woods, wasteland, badlands, tundra	1.10
B	**LIGHT**; no habitable structures near slope; recreational parks, golf courses, buried small utilities, tile beds, barns, garages, swimming pools, sheds, satellite dishes, dog houses	1.20 to 1.30
C	**ACTIVE**; habitable or occupied structures near slope; residential, commercial, and industrial buildings, retaining walls, storage/warehousing of non-hazardous substances	1.30 to 1.50
D	**INFRASTRUCTURE and PUBLIC USE**; public use structures or buildings (i.e., hospitals, schools, stadiums), cemeteries, bridges, high voltage power transmission lines, towers, storage/warehousing of hazardous materials, waste management areas	1.40 to 1.50

4.3.4 Field Investigation

If there is insufficient existing topographic mapping on a site (at 1:500 scale or better), then detailed topographic surveying will be necessary to establish positions of <u>surface features</u> (slope crest, toe, structures and fences, vegetation and trees, drainage or seepage, scarps, ridges), as well as to measure slope profile (cross-section) or configuration (inclination). The plan should also show the locations of boreholes, auger holes, or test pits. The profile should show the soil stratigraphy (see enclosed examples).

The subsurface conditions of the slope should be investigated with boreholes and piezometers, to accurately establish the soil types, soil stratigraphy, soil relative density or consistency, ground water levels, and obtain soil samples. Boreholes are more suitable for investigation than test pits, because excavated test pits are limited by the equipment to maximum depths of 3 to 5 m. Conventional boreholes can be drilled to depths of 30 m or more.

One or two boreholes may be sufficient for many small and simple sites, while many boreholes may be required for larger sites or complex site conditions. For example, boreholes for other engineering projects are often spaced as follows:

Road Pavements and Sewers	50 to 150 m
Buildings	15 to 30 m.

<u>For uniform slope conditions</u>, a reasonable maximum spacing of boreholes along the slope crest would be about <u>100 m</u> (a closer spacing may be necessary for complex sites).

Generally the ground conditions should be established for the full height of the slope. Some judgement can be used where previous information is available, or where rock or other competent material is found at a shallower depth.

There are several methods of advancing boreholes,

- hand augers
- wash boring
- rotary auger (continuous flight)
    - solid stem
    - hollow stem.

The borehole is usually advanced by continuous flight solid-stem augers which are extracted at each depth interval to permit the insertion of a sampling device or test apparatus. These <u>solid-stem augers</u> typically result in borehole sizes of about 125 mm diameter. <u>Hollow-stem augers</u> (continuous flight) do not require extraction at depth intervals because a central hollow core serves as a casing to support the borehole. Sampling and testing equipment can be inserted through the augers to the bottom of the borehole. In very deep boreholes, the torque required to turn the augers may not be available and other means of borehole advancement are required.

Another standard method of advancing boreholes (through very slow) is "wash boring" which involves the insertion of pipe casing to support the hole and the use of a chopping bit on drill rods to dislodge the soil at the bottom of the borehole. Water is pumped under pressure through the drill rods and chopping bit to wash out the dislodged soil. The casing is driven to the bottom successively as required.

Portable tripod equipment can be used in difficult access areas (i.e., on slope face), to advance boreholes to moderate depths such as 5 to 10 m. This is very slow work.

Boreholes can also be drilled off-shore in standing water (lake, river, pond, bay) with the aid of a barge or platform to carry the drilling equipment.

Shallow hand auger holes can also be carried out (1 m depths) on steep slopes or in difficult access areas, but these are of limited value due to the shallow depth.

The most common test in the borehole is the Standard Penetration Test (S.P.T.) which consists of driving a standard split-spoon sampler (50 mm diameter, 600 mm long) into the bottom of the borehole with a falling weight of 67 kg dropping over a height of 0.75 m.

In soft cohesive soils, thin-walled Shelby tubes are used for the extraction of relatively undisturbed samples. The field vane apparatus is also used in soft, cohesive soils, in order to obtain shear strength values of the soil. The field vane consists of a vane-like device on the end of drill rods, which is inserted into the soil at the borehole bottom and then turned at the ground surface. The torque required to turn the vane is measured. The measured torque can be related to undrained shear strength based on the shape and size of the field vane.

Other types of penetration resistance testing can be carried out (dynamic cone, static cone) and these are summarized on the following table (ref. Cdn.Fdn.Man.),

For further information on the type of available testing, see Appendix 4, Borehole Test Methods.

Ground water conditions are often measured by standpipe piezometers consisting of hollow plastic pipe or tubing (10 to 50 mm diameter), which are installed in the boreholes on completion of drilling. Monitoring of ground water levels is conducted after borehole drilling.

The most common standpipe installation consists of small diameter tubing which extends down to a filtered porous (or perforated) tip that is surrounded with granular material (sand or fine gravel). Ground water is allowed to enter the standpipe through the filtered porous or perforated tip, and to rise to its static hydrostatic or piezometric level inside the piezometer tubing or piping. The ground water level inside the tubing can be measured by lowering a calibrated coaxial cable with low electrical current (or other device) down to the water level.

4.3.5 Laboratory Testing

In the geotechnical laboratory, the soil samples should all be subject to tactile examination by an experienced engineer who confirms the field descriptions on the borehole log, and who selects representative samples for detailed testing. There are several common laboratory tests to establish index properties of soils. The behaviour of soils types are often estimated on the basis of their measured index properties.

The most common laboratory tests and their recommended testing frequency for samples are:

A. Water contents, all samples
B. Atterberg Limits, cohesive strata
C. Grain size distribution, all strata
D. Soil unit weight, as required
E. Specific gravity, as required
F. Direct shear test, sand strata, as required
G. Triaxial compression test, cohesive strata, as required.

The Bore Hole testing methods are summarized on the following Table 4.4.

TABLE 4.4 - Borehole Test Methods

Type of Test	Type of Soil			Properties Obtainable	Remarks References
	Best For	Not For			
1.Standard Penetration Test	Sand	Clay	Qualitative evaluation of compactness; comparison of subsoil stratification.	(See Section 4.5.1.1)	1) CSA A119.1 2) ASTM D1586 3) Fletcher (1965) 4) Peck et al (1963) 5) Tavenas (1971) 6) ISSMFE (1977)
2. Dynamic Cone Test	Sand and Gravel Sand	Clay	Qualitative evaluation of compactness; comparison of subsoil stratification.		1) ISSMFE (1977)
3. Static Cone Test	Sand		Continuous evaluation of density and strength of sands and gravel; undrained shear strength in clays.	Test is best suited for design of piles in sand. Tests in clay only reliable with vane tests.	1) Sanglerat (1972) 2) Schmertmann 1970) 3) Ladanyi & Eden (1969) 4) ISSMFE (1977)
4. Plate Bearing Test	Sand		Modulus of subgrade reaction. Ultimate bearing capacity.	Strictly applicable in uniform deposits. Size effects must be considered in other cases.	
5. Vane Test	Clay	Silt Sand Gravel	Undrained shear strength c_u.	Test should be used with care particularly in fissured, varved and highly plastic clays.	1) ASTM D 2573 2) Bjerrum (1972) 3) Aas (1965) 4) Lo (1972) 5) Schmertmann 1975) 6) Lemasson (1976)
6. Pressure - meter Test	Soft rock Sand	-	Ultimate bearing capacity and compressibility	(See Section 4.5.1.3)	1) Menard (1965) 2) Eisenstein (1973) 3) Tavenas (1971) 4) Baguelin 1978)
7. Permeability Test	Sand and Gravel	Clay	Evaluation of co-efficient of permeability	Variable head tests in BH's have limited accuracy. Results reliable to one order of magnitude obtained only from long term large scale pumping tests.	1) Hvorslev (1949) 2) NAVFAC DM7 3) Sherard

4.4 UNCONFINED SYSTEMS - RECOMMENDED STUDY ISSUES TO BE ADDRESSED

For those situations where a study is used to determine the "meander belt allowance", the study should be undertaken using "accepted engineering and scientific principles". These studies usually involve a range of study areas such as geomorphology, engineering, ecology, biology. The variables involved in the study include some of the following but are not limited to:

- discharge regimes;
- slope, sinuosity, width-to-depth ratios, particle size of sediment in river/stream beds and banks, stream entrenchment ratios, and landform feature/stability class;
- drainage areas and patterns of the system;
- determination of the meander pattern (e.g., amplitude, radius of curvature, meander length, concave and convex banks, spacing of pool and riffle zones, and the presence or remnant meanders or oxbow lakes);
- bedload, suspended load and dissolved loads;
- channel roughness and shear stress required to move sediment loads;
- bankfull discharge and channel determination; and
- potential for lateral or downstream migration of the meander belt allowance.

A study of the river system characteristics may be required in order to determine the meander belt allowance. For further details on how a complete study encompassing all of the appropriate disciplines please review in detail the 9 step process outlined in AMSC[11]. This report outlines the various engineering, geomorphology and biology technical requirements when conducting a study. The bankfull characteristics are critical for determination of the meander belt. The procedure outlined in Chapter 3 of this document should be referenced when conducting any study.

4.4.1 Field Investigation

Within each of the reaches identified in the initial studies of the drainage basin, a field study should be undertaken to measure the stream geometry, flood capacity, and characteristics. The observations may also be used to determine the hydraulic characteristics of preferred habitats. Biological sampling may be carried out at the same time.

There are various methods available to carry out field investigations ensuring all of the required information is taken at the site. Depending on the desired outcome and criteria, different information and data may be collected.

There is no standard field sheet available which covers all aspects of the full set of geomorphology, engineering and biological information requirements so we have included sample sheets in Appendix 3 which focus on these areas. The first set of field sheets in Appendix 3A which have been provided are from Newbury & Gaboury, 1994, Stream Analysis and Fish Habitat. These sheets are the ones which focus on collecting the required engineering criteria. The next data field sheets in Appendix 3B are from J. Parish, 1999 of Parish Geomorphic with an emphasis on the fluvial geomorphology aspects. A very thorough assessment protocol was developed by MNR, 1998 entitled, "Stream Assessment Protocol for Ontario". This documents a detailed procedure which assesses the fish habitat suitability in Ontario streams. The protocol is designed to improve the repeatability (precision) of stream habitat assessments at a practical level. Objective data are collected in the field which then become a baseline for all future interpretations. The field sheets can be found in Appendix 3.

4.4.2 Recommended Analysis

The study procedure in the AMSC[12] document for the channel should be followed and the engineering, geomorphology and biology aspects should be analyzed as indicated. A question which needs to be answered in order to determine the meander belt width is what will the ultimate configuration of the channel be in the future? Once this has been addressed, then considerations can be made as to where, and what type, if any, of development can be considered at the particular site in question.

Determination of the bankfull width can be referred to Section 3.1.1 of this document. If the proponent determines that the recommended 20 times bankfull is not appropriate for their location, they must then provide the appropriate information, an analysis of the meander belt width which can be determined through accepted scientific and engineering study. In 1998, the "TRCA Meander Belt Width Delineation Procedure" was developed for the TRCA and may be a useful reference when assessing the meander belt width. The reference has been included for your information. This document discusses a method in determining the meander belt width. It suggests more than one method be used when attempting to predict the width. “Therefore, by developing only one belt width delineation procedure that is applicable for a range of flow regimes and floodplain settings, only a crude approximation of the actual belt width can be obtained. By examining various features of a floodplain, properties of both the floodplain and valley materials, and by understanding the flow regime of a river, a general belt width delineation procedure can be modified to yield reliable estimates of the belt width for any given river.”, [Page 9, TRCA Meander Belt Width Delineation Procedure, 1998][13]. This document explains the difficulty and importance of attaining good data for site analysis, and presents some practical methods for delineating the meander belt width.

A field procedure and protocol for assessing river characteristics (and fish habitat) which includes determining the bankfull width has been developed by MNR. This procedure is entitled “Stream Assessment Protocol for Ontario, 1998” and was designed to improve the precision and repeatability of stream assessments at a practical level.

5.0 ADDRESSING THE HAZARD

5.1 Introduction

Human responses to erosion concerns have primarily involved the construction of various forms of protection works. Unfortunately, these responses have often included works which were not designed within the appropriate context (e.g., watershed, subwatershed, reach, site). The works were usually designed with only the particular site in mind and more often than not incompatible with neighbouring installations, physical and biological processes. These works were often installed in an ad hoc fashion and largely ignored watershed processes and the resulting environmental impacts.

For certain *development* and *site alteration* to be permitted within *hazardous lands*, the Policy 3.1.3 states that all of the following requirements must be fulfilled:

- the hazards can be safely addressed, and the *development* and *site alteration* is carried out in accordance with *established standards and procedures* (Policy 3.1.3(a));
- new hazards are not created and existing hazards are not aggravated (Policy 3.1.3(b));
- no adverse environmental impacts will result (Policy 3.1.3(c));
- vehicles and people have a way of safely entering and exiting the area during times of flooding, erosion and other emergencies (Policy 3.1.3(d)); and
- the *development* does not include *institutional uses* or *essential emergency services* or the disposal, manufacture, treatment or storage of *hazardous substances* (Policy 3.1.3(e)).

In ensuring that these requirements are met, the intent of this Technical Guide is to provide direction on how to “address the hazards”. This includes assessing whether or not protection works for *development* and *site alteration* within the *hazardous lands* interest appropriately address the *erosion hazards* on-site. This outlines considerations that help determine the ultimate success of protection works including, but not limited to, hazards typically associated with the various types of structures. This is accomplished by identifying the potential impacts of protection works on the physical environmental processes.

5.2 Policies

Erosion is a natural phenomena evident on many watershed systems. This phenomena, or natural process, only becomes a problem, or hazard, when development is located in close proximity to the hazard. This Technical Guide has discussed the characteristics of this process and the delineation and mapping of *hazardous lands* adjacent to river and stream systems which are impacted by the *erosion hazards*. This chapter builds on this information and examines the watershed management approaches that may enable the *erosion hazard* to be safely and appropriately addressed in an environmentally sound manner.

In Ontario, addressing the *erosion hazard* has typically involved one or more of three watershed management approaches: prevention, protection works (non-structural or structural) and emergency response. Prevention is essentially the orderly planning of land use and the regulation of *development* and *site alteration* along watersheds subject to *erosion hazards* (i.e., generally directing *development* and *site alteration* to areas outside of *hazardous lands* as stated in Policy 3.1.1(a)).

By definition, *development*

“means the creation of a new lot, a change in land use, or the construction of buildings and structures, requiring approval under the Planning Act; but does not include activities that create or maintain *infrastructure* authorized under an environmental assessment process; or works subject to the Drainage Act.” (Provincial Policy Statement, 1996)

Site alteration means activities, such as fill, grading and excavation, that would change the landform and natural vegetative characteristics of a site." (Provincial Policy Statement, 1996)

Prevention approaches are the preferred approach for management of the *riverine* hazards as they reduce or minimize hazard losses by modifying the loss potential (e.g., hazard allowances and property acquisition).

Protection, as an alternative to prevention, involves non-structural and structural protection works which are essentially engineered methods for protecting *development* and *site alteration* located within the erosion susceptible areas. Some non-structural protection approaches are; relocation, bluff measures or soil bioengineering techniques. Some structural protection approaches which include but are not limited to the following; biotechnical stabilization methods, natural channel design techniques, revetments. These protection works may help to reduce the hazard losses by modifying the *erosion hazards* in the river or stream system. One must recognize that any changes to the natural physical process will have an impact on the biological and ecological processes and functions within the system.

While prevention is clearly the preferred choice for management, protection works are not to be considered as inherently negative. In a number of locations and situations, erosion protection works are necessary and may be the only realistic option. For example, protection works may be necessary at hazard prone areas where a large investment has already been made in the existing development, at parks in highly urbanized areas where recreational space is very limited, or in areas of very significant historical or social importance. In cases like these, it may be appropriate to proceed with protection works if the impacts that result from the works can be identified and mitigated or compensated.

Proper protection works, in combination with the appropriate allowances to address the stable slope and *erosion hazards* (i.e., *established standards and procedures*, Policy 3.1.3(a)), may provide sufficient "protection" to warrant consideration of *development* and *site alteration* within the limit of the *erosion hazard*. With the exception of the situations noted later (i.e., Policies 3.1.2(a) and (b)), *development* and *site alteration* may be permitted within the least hazardous portions of the *hazardous lands* provided that all of the following can be achieved:

- the hazards can be safely addressed, and the *development* and *site alteration* is carried out in accordance with *established standards and procedures* (Policy 3.1.3(a));
- new hazards are not created and existing hazards are not aggravated (Policy 3.1.3(b));
- no adverse environmental impacts will result (Policy 3.1.3(c));
- vehicles and people have a way of safely entering and exiting the area during times of flooding, erosion and other emergencies (Policy 3.1.3(d)); and
- the *development* does not include *institutional uses* or *essential emergency services* or the disposal, manufacture, treatment or storage of *hazardous substances* (Policy 3.1.3(e)).

The inclusion of these requirements is intended to provide flexibility to recognize local conditions. When applying this flexibility, care must be taken to ensure that the magnitude or degree of risk(s) is clearly understood, and that the potential or feasibility for *development* and *site alteration* to safely locate within certain portions of the *hazardous lands* is sound, reasonable and can be implemented in accordance with the *established standards and procedures*. Care must also be taken to ensure that the interests and intent of other policies addressing the same riverine areas are not compromised. Where all of these conditions cannot be fulfilled, the *development* and *site alteration* is to be directed to areas outside the *hazardous lands*.

The intent of these conditions (i.e., Policy 3.1.3 (a) to (e)) is to promote public safety and to minimize risks to life, property damage, adverse environmental impacts and social disruption. Ecological, geomorphological and socio-economic elements are concentrated along the riverine system and are uniquely defined by their interactions within the environment. A delicate, dynamic balance exists between these elements, a balance which can easily be altered or upset. It is imperative that any protection works consider both the immediate and the broader ecological, geomorphological and socio-economic contexts, as no part of the system operates independently of any other part. The proponent should also consider whether or not the protection works are justified from a benefit-cost perspective and are in keeping with any objectives for public access, recreation and aesthetics.

There are areas where protection works may be inappropriate and unacceptable as they would not meet all of the requirements of Policy 3.1.3. These areas may include, but are not limited to: locations where the active erosion of the site provides an essential sediment source downstream and imperative to maintaining the geomorphological processes; sites where the proposed protection works would result in unacceptable environmental impacts (e.g., adjacent wetland or fish habitat is significantly impacted); areas where the protection works create or aggravate hazards at upstream/downstream properties (e.g., structures trapping or deflecting sediment transport resulting in a significantly reduced quantity of sediment at adjacent properties thus increasing *erosion hazards*).

Although the policies governing natural hazards do provide the flexibility for municipalities and planning boards to consider *development* and *site alteration* within the least hazardous portions of the *hazardous lands*, care must be taken to ensure that *development* and *site alteration* are not permitted within those areas identified in Policy 3.1.2, namely:

- institutional uses;
- essential emergency services
- disposal, manufacturing, treatment or storage of hazardous substances.

When applying Policy 3.1.3, a number of complicating planning issues may arise. For example, municipalities and planning boards may need to develop strategies to deal with existing lots of record, *residential infilling*, *residential intensifica-*

tion, or with additions and alterations to existing development. In some municipalities, development applications involving structures or buildings which by the nature of their use are normally located in close proximity to or within the water (e.g., weirs, utilities, etc.) may also require a more detailed evaluation. In each of these cases, consultation with the local Conservation Authority and the Ministry of Natural Resources may assist municipalities and planning boards in determining the potential risks associated with the various municipal land use planning strategies that may be under consideration or applied. In all of these situations, regardless of the planning issue being evaluated, the overall intent of the Policy, to minimize the potential risk to life and property, is to be preserved.

5.2.1 Established Standards and Procedures

Where the potential for environmentally sound development to safely occur does exist, the *development* and *site alteration* should be carried out in accordance with the *established standards and procedures* (Policy 3.1.3(a)) that apply. *Established standards and procedures* means the following:

- "**Protection works standard**, which means the combination of non-structural or structural works and allowances for slope stability and erosion to reduce the damages caused by *erosion* and to allow access for their maintenance and repair."

- "**Access standard**, which means a method or procedure to ensure safe vehicular and pedestrian movement, and access for the maintenance and repair of protection works, during times of *erosion*."

It must be recognized that there are no guarantees that protection works will offer protection for the 100 year planning horizon. In fact, protection works installed to address erosion hazards typically have a design life of only 25 to 50 years. This is due to limitations in current knowledge of the natural processes and their interaction with structures, the limited durability of structures and materials in the environment, the natural erosional sediment processes, possible inadequate quality control during design and construction, and insufficient maintenance.

Protection Works Standard

In addressing the natural hazards (i.e., *flooding* and/or *erosion hazards*, including unstable slopes), so as to considered development within the least hazardous portions of the *hazardous lands* for *river and stream systems*, the following *protection works standards* should be applied:

- for **confined systems**

protection works (non-structural, structural)	+	**toe erosion allowance*** (from Table 3 OR 100 times the average annual recession rate of the toe) **OR** a study using accepted geotechnical and engineering principles	+	**allowance for stable slope** 3:1 (h:v) **OR** as determined by a study using accepted geotechnical principles	+	**erosion access allowance** 6 metres **OR** as determined by a study using accepted scientific, geotechnical and engineering principles

* Note: *where the soil type is not known, Table 3 recommends the use of a 15 m toe erosion allowance; and when using average annual recession rates to determine the toe erosion allowance a minimum of 25 years of reliable information is recommended.*

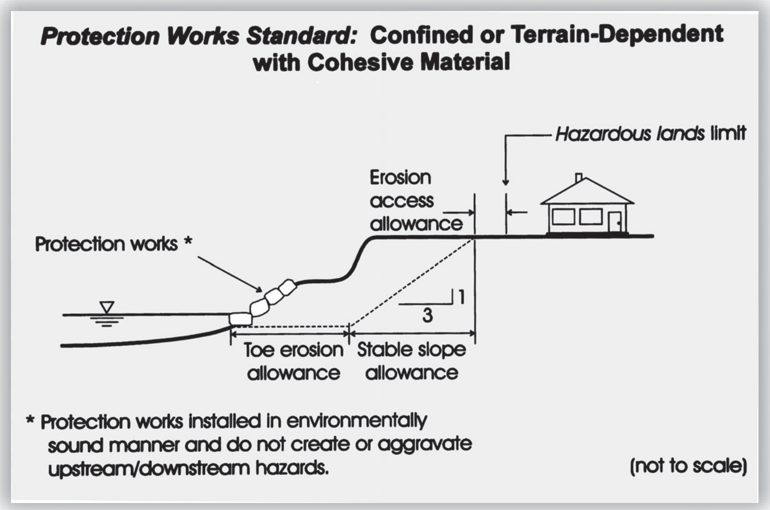
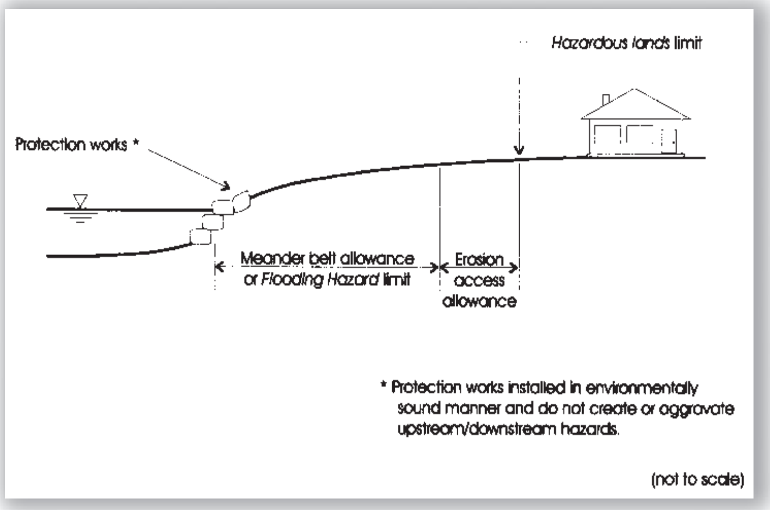


Figure 126 - Protection Works Standard: Confined Systems

Figure 127- Protection Works for Confined System (example)



128 - Protection Works Standard : Unconfined Systems

Where the *protection works standard* is deemed too excessive or insufficient to address the severity of the natural hazards impacting on a particular site, mechanisms should be incorporated into the planning process providing the flexibility to undertake a study using accepted scientific, geotechnical and engineering principles to determine the *protection works standard*.

Where the municipality or planning board approves the study (studies) using accepted geotechnical, scientific and/or engineering principles, where applicable and appropriate, to determine the toe erosion, meander belt, stable slope and/or erosion access allowances, the *protection works standard* should then consist of the protection works plus the approved allowances and applied only in the area studied.

Access to the development in times of erosion emergencies is necessary for safety. Access to the protection works is also required for maintenance and repairs.

- for **UNconfined systems**

protection works
(non-structural, structural works)

+

allowance for the *flooding hazard* limit OR meander belt allowance
20 times the bankfull channel width centred over the meander belt axis **OR** as determined by a study using accepted engineering principles

+

erosion access allowance
6 metres **OR** as determined by a study using accepted scientific, geotechnical and engineering principles

5.3 WATERSHED MANAGEMENT APPROACHES FOR ADDRESSING THE HAZARDS

Ensuring that the hazards can safely be addressed, as required by Policy 3.1.3(a), essentially means that any measures or actions intended to minimize or reduce the *erosion* must not place the safety of people or property and developments at risk. This section provides an overview of the various watershed management approaches that may be considered to address *erosion hazards*.

It is extremely important to note that before any watershed management approaches are considered the process outlined in the AMSC[14] in Ontario should be part of the evaluation process and should be followed when undertaking any site assessment.

There is a wide variety of watershed management approaches and they can be classified or grouped in many ways according to different criteria. For the purpose of this Technical Guide, the management approaches have been classified as being either a prevention or a protection approach.

5.3.1 Prevention

Prevention is the orderly planning of land use and the regulation of development in erosion susceptible areas. Prevention approaches reduce hazard losses by modifying the loss potential they are hazard allowances and property acquisition. It is better to manage a functional natural river and stream system than to design a new one. Siting new urban developments adequately away from the watercourse to ensure the continuation of a functional floodplain and stream system, will in most cases achieve public safety and environmental objectives. Prevention is the preferred approach when making decisions on watershed management alternatives although it may not always be possible.

5.3.2 Non-structural protection works

Protection approaches are engineered methods for protecting development located within the erosion susceptible areas and they reduce hazard losses by modifying the erosion hazards along the river and stream system. Protection approaches can be further classified as non-structural or structural. **Non-structural protection works** are activities that do not involve the construction or placement of significant additional structures or material along or in the river or stream system. Non-structural protection works include: relocation and some soil bioengineering techniques.

5.3.2. Relocation

Relocation is an effective means of mitigating erosion hazards by moving the building or service (e.g., roadway, utility) to a different site further inland or to a more landward location within the existing site. Relocation often proves to be less costly than protection, especially in areas of high to severe erosion. It is an effective practice to mitigating erosion hazards. Virtually any structure can be relocated but whether or not the cost of relocating is justified depends on several factors. The major limitations are the size and construction style of the building (and therefore the actual feasibility of moving) and the availability of a site for relocation. The actual moving costs for a typical single family dwelling can often be quite feasible in comparison to the costs of providing adequate, effective, environmentally sound works. Generally the width and height of the house are the limiting factors. The width must be less than the clearance along the roadways (i.e., between trees, hydro poles) and the height lower than the overhead clearance (i.e., under overhead wires, bridges). Houses with slab foundations, concrete block walls, extensive brick or stone work, or large unusual shapes are often impractical to move. The greatest costs associated with relocation may be acquiring an additional parcel of land if setbacks do not permit relocation on the same property. When a building or service is relocated it should be placed landward of the hazardous lands.

5.3.2.2 Soil Bioengineering Techniques

Soil bioengineering is the utilization of vegetation through live construction. Live construction entails the use of conventional planting's alone (e.g., grasses and shrubs).

For the purposes of this policy non-structural protection works defines soil bioengineering techniques as those which use vegetation to control surface drainage, runoff and/or groundwater flow. Soil bioengineering techniques may also involve regrading of the slope but only if a minor amount of material used, if a significant amount of material is used then the works would be considered structural protection works. Other sources of water which need to be controlled and not allowed to discharge freely down the face of the slope are; lawn sprinkling, swimming pool drainage and leaks, and possibly septic systems. In a high flow river or stream system, soil bioengineering techniques are insufficient to address the 'active' erosion which is occurring but can be used to address the surface erosion problems. In order to address the 'active' erosion structural measures may need to be added resulting in what is referred to as biotechnical stabilization techniques. It is important to note however, that in very low or intermittent flow zone soil bioengineering techniques may be appropriate to address the surface erosion problems. The following section outlines some examples of non-structural methods including some soil bioengineering techniques. For details on soil bioengineering techniques refer to Biotechnical and Soil Bioengineering, A Practical Guide for Erosion Control, 1996.

Soil bioengineering refers to the use of living plant materials to also protect against erosion (brush layering or contour wattling). These approaches are most effective as surface erosion protection and are not very effective for improving overall stability against deep rotational slides or slides which extend deeper than the root reinforcement. As erosion protection, biotechnical slope protection approaches may be more appropriate stabilization measures. They may require less site access and disturbance to install.

Vegetation by itself is vulnerable to frost action, trampling, and moisture or nutrient deficiencies. Further, it does not address the hazards of slope instability or toe erosion.

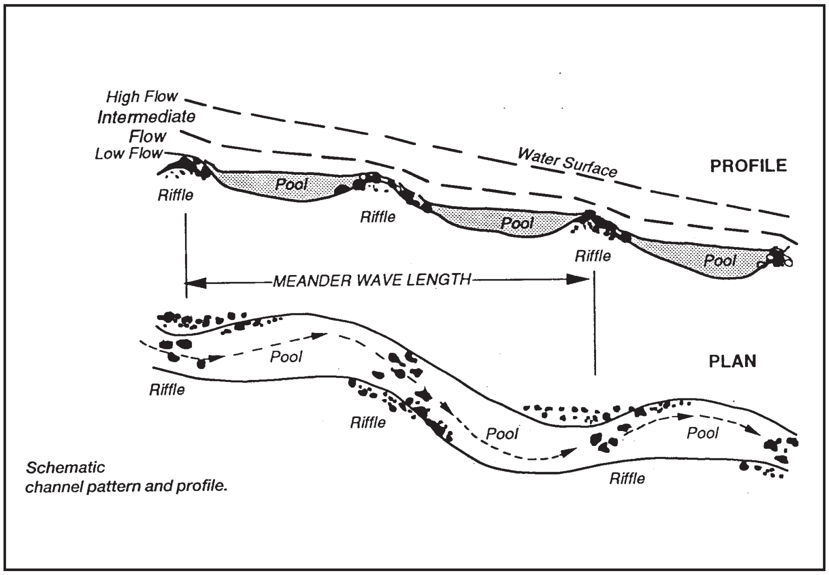
Empirically it has been found that a **2 to 1 inclination** (26°) is the **steepest upon which vegetation can be established and maintained satisfactory**. However a slightly flatter inclination of **3 to 1** (17°) is required to achieve **maximum vegetative stability**. Steeper inclinations cannot be suitably stabilized by vegetation alone and additional reinforcing or support is required.

5.3.3 Structural Protection

Structural protection works involve the construction and/or placement of significant additional structures and/or materials along the river or stream system. Some structural protection approaches which include but are not limited to the following; biotechnical stabilization methods, natural channel design techniques, revetments. Table 5 presents a summary and schematic view of the primary types of stabilization measures.

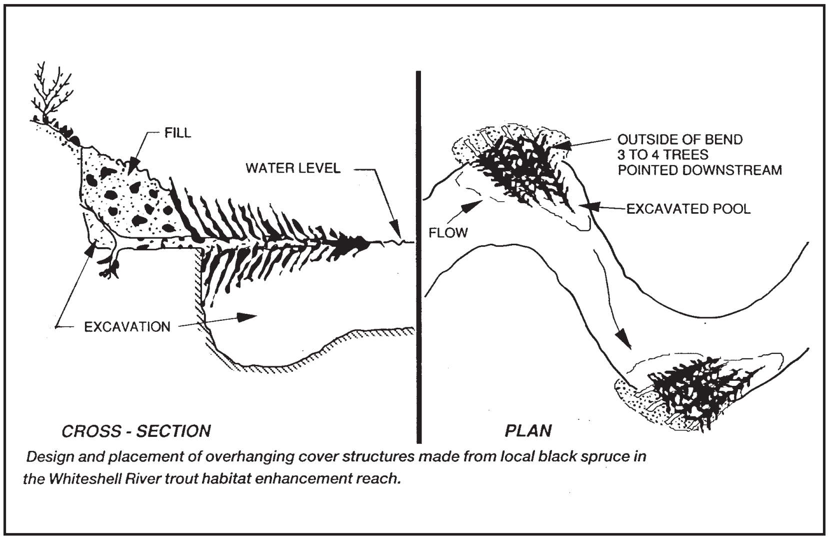
5.3.3.1 Natural Channel - Riffle, Pool Sequence Design Techniques

Natural channel (i.e., riffle, pool sequence) designs should be considered as the first alternative to structural protection works. Successful designs must re-create many natural conditions encompassing hydraulics, fluvial processes and aquatic requirements. The key is to mimic the natural geometry and materials of the stream. Inherent in these types of designs is that some level of instability will be anticipated and knowledge of the desired ecosystem is applied in the design. In contrast, the "hard engineered" channels are designed to be stable with fixed geometries, usually built in concrete or lined with protective materials, and for the single purpose of efficient water conductance. [Pg. 196 "Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour", Robert Newbury, Marc Gaboury, Freshwater Biology (1993) 29, Pg. 195-210.][15]



Schematic channel pattern and profile.

Figure 129 - Riffle and Pools (Newbury, 1993)



Design and placement of overhanging cover structures made from local black spruce in the Whiteshell River trout habitat enhancement reach.

Figure 130 - Log Anchors (Newbury, 1993)

Figure 131 - Back/side channels

Figure 132 -Riffle Design

Included in these types of designs are often the log-anchors as seen in Figure 135 and back and side channel areas which may be important in addressing the overall biological needs depending on the ecosystems. For detailed information and the procedure to be followed to carry out these designs, please refer to Newbury & Gaboury, "Stream Analysis and Fish Habitat Design", 1993.

Figure 133 -Installation of Log Crib

Figure 134 - Log Crib Works

5.3.3.2 Biotechnical Stabilization Techniques

Structural works such as biotechnical stabilization techniques and natural channel designs (e.g., vegetated mesh and grids, vegetated crib, rip rap, armour stone and tiered walls) although they significantly impact the existing system, if designed properly can often provide an opportunity to enhance environmental conditions.

If vegetation is used in combination with structural elements then the works are referred to as structural and called biotechnical stabilization techniques. The term biotechnical is used to describe methods which consist of both structural and vegetative elements working together in an integrated manner (e.g., brush layering, vegetated crib, rip rap or armour stone walls). The vegetation plays an important functional roll that will vary depending on the structural elements involved.

For further details on the application of biotechnical techniques please refer to the following: Appendix 4 and (Grey and Sotir) Biotechnical and Soil Bioengineering Slope Stabilization, A Practical Guide for Erosion Control, 1996.

5.4 Application of Approaches for Addressing the Hazard

The following chart lists the main river and stream management practices that may be appropriate to address the hazards at a given site. The individual application will depend on the different processes governing the erosion at the particular site. The chart does not endorse a particular type of management practice, it only provides an initial indication of whether or not a particular approach may be appropriate for addressing the various types of hazards on site.

The site should be thoroughly assessed following the procedure outlined in theAMSC[16] in Ontario document. Natural channel, riffle, pool design, soil bioengineering, biotechnical stabilization alternatives should all be fully evaluated. A complete assessment and identification of the potential impacts the selected practices will have on the natural river or stream processes should be followed. The identification of the impacts are then evaluated with respect to creating or aggravating any upstream/downstream impacts. As well, the impacts must be examined to ensure the selected practice is environmentally sound. An appraisal of the impacts on the fisheries and terrestrial wildlife habitat should be carried out. It is possible that the initially selected practice is appropriate for addressing the hazard on-site, but that it does NOT meet the other equally important requirements:

1 new or existing hazards can not be created and/or aggravated;
2 no updrift/downdrift impacts result; and
3 the practice must be environmentally sound.

See the procedure outlined in Chapter 6 of this document, Environmentally Sound Management which outlines these requirements.

5.4.1 Procedure

The chart indicates the management practice that may be appropriate to address the hazard. The management practices are grouped under the categories: **prevention, non-structural protection** and **structural protection**.

The use of the chart then requires that you identify the type of hazard you are addressing (i.e., river toe erosion, slope instability or surface erosion). The check marks indicate the type of hazard which is being addressed and which management method is the most appropriate for addressing that specific hazard. The following rating has been used:

✔✔✔ - Recommended to address the hazards
✔✔ - Generally will address the hazards
✔ - May be considered but may not provide the proper level of protection to address the hazards.
✖ - Will not address the hazard

The proponent should still address the concerns outlined in Section 5.4 and carry out the procedure outlined in the AMSC[17] document.

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[16] Work in Progress: Adaptive Management of Stream Corridors in Ontario, 2000

[17] Work in Progress: Adaptive Management of Stream Corridors in Ontario, 2000

Table 5 - Methods for Addressing Hazards - Provention and Protection Measures

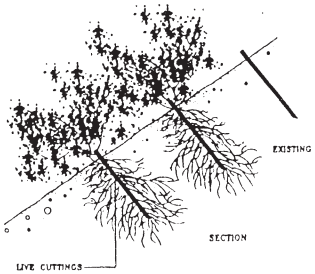
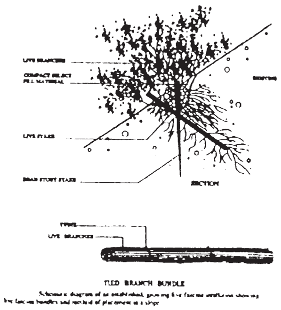
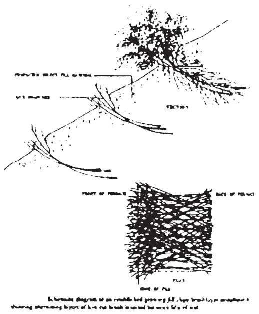
	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY			NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides	Surface Runoff		
PREVENTION	1. Prevention	Hazard Allowance Set-backs; stay away from the potential problems	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	requires no work in river, stream or on slope	
	2. Relocation	Move building or service (e.g., utility or roadway)	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	requires no work in river, stream or slope	
SOIL BIOENGINEERING NON-STRUCTURAL	3. Live Staking	insertion of live plant cuttings in rows or clusters (willow stakes, ½ to 1 m long)			✓		✓✓	suitable for repair of small shallow earth slumps, gullies	 Schematic diagram of an established growing live stake installation

Table 5 - Methods for Addressing Ha Provention and Protection Measures

	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY			NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides	Surface Runoff		
SOIL BIOENGINEERING NON-STRUCTURAL	4. Live Fascines, Contour Wattling	bundles of rootable plant stems and branches (willow, dogwood, alder) buried in shallow trenches across slopes and anchored with wood stakes, 1 to 2 m spacing			✓✓		✓✓✓	suitable for control of surface runoff erosion and shallow slides, cut slopes, embankments, max. Steepness 1½ to 1, improves drainage	
	5. Brush Layering, Branch Packing	layers of live cut branches (up to 3½ m long, sticking out and criss-crossed) buried across a slope, rows every 1 to 2 m (willow, dogwood, alder)			✓✓✓		✓✓✓	best suited where slope fill is added; protects against surface erosion and shallow slides, improves drainage, max. Steepness 1½ to 1	

Legend:

✓✓✓ Recommended to address hazards

✓✓ Generally will address hazards

✓ May be considered but may not provide proper level of protection to address hazard

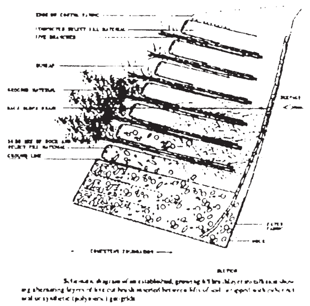
▲ does not address environmental concerns

Notes: 1) Filter cloth & drainage design is not indicated on the drawings, but MUST be included in the design of any protection works.

2) The Adaptive Management Evaluation Approach should be followed as part of the design procedure.

3) Tables are not intended to be inclusive of all structural techniques available. The tables are general in nature and are intended to serve as a guide. They are not exhaustive and site-specific conditions may differ.

Table 5 - Methods for Addressing Hazards - Provention and Protection Measures

	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
SOIL BIOENGINEERING NON-STRUCTURAL	6. Vegetated Mesh and Grids	plant brush layers and plastic mesh/grid layers back into slope; provide reinforcing	✓✓	✓✓	✓✓✓			suitable for very steep slopes; effective against periodic scour, improves drainage, max. Steepness 1 to 1	

Legend:

✓✓✓ Recommended to address hazards

✓✓ Generally will address hazards

✓ May be considered but may not provide proper level of protection to address hazard

▲ does not address environmental concerns

Notes:

1) Filter cloth & drainage design is not indicated on the drawings, but MUST be included in the design of any protection works.

2) The Adaptive Management Evaluation Approach should be followed as part of the design procedure.

3) Tables are not intended to be inclusive of all structural techniques available. The tables are general in nature and are intended to serve as a guide. They are not exhaustive a[illegible]te-specific conditions may differ.

Table 5 - Methods for Addressing Haz Provention and Protection Measures

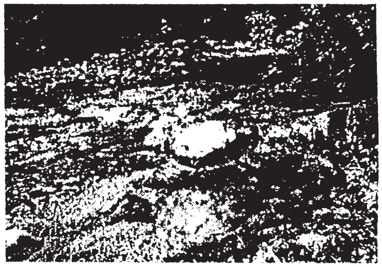
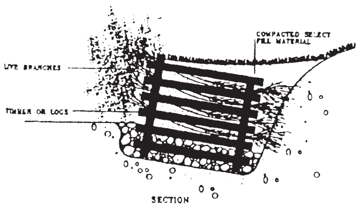
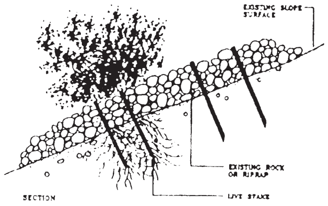
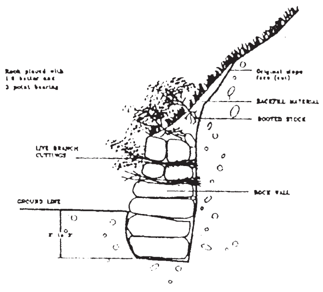
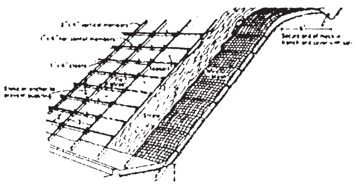
	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
BIOTECHNICAL STABILIZATION STRUCTURAL	7. Natural Channel Assessment and Design	channel designed with variations of Riffle/Pool sequence	✓✓✓	✓✓✓	✓✓✓		✓✓✓	requires work in river, stream or slope, effective on erosion. When vegetation is used in combination with harder materials, shallow slides and surface runoff is addressed.	
	8. Vegetated Crib Walls	near-vertical retaining wall formed by box of stacked timbers filled with earth and layers of live branch cuttings	✓✓✓	✓✓✓	✓✓✓			effective as a toe wall on slopes, and against scour, near-vertical wall, max. Height 2 m	 Schematic illustration of an established, growing vegetated (live) crib wall
	9. Vegetated Rip Rap	(joint planting) live willow cuttings inserted through rip rap	✓✓✓	✓✓	✓		✓✓✓	flexible, suitable for repair of localized slump areas, along stream banks, max. Steepness 1½ to 1	 Schematic illustration of an established, growing vegetated riprap revetment.

Table 5 - Methods for Addressing Hazards - Provention and Protection Measures

	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
BIOTECHNICAL STABILIZATION STRUCTURAL	10. Vegetated Rock Walls, Crib Walls	live branch cuttings inserted into openings of rock breast wall and crib wall	✓✓✓	✓✓✓	✓✓✓			effective as low toe walls, protects against scour, max. Height 2 to 3 m	 Schematic illustration of an established growing vegetated rock wall
	11. Vegetated Cellular Grids	lattice-like array anchored to slope and planted in openings	✓✓✓	✓✓	✓		✓✓✓	flexible, permits vegetation on steep slopes up to 1 to 1, requires little fill * this option may address toe and meander erosion if scour protection such as rip rap is added to the toe of the structure	 Anchored timber grid used to hold topsoil and slope plantings
	12. Vegetated Tiered Walls	series of short stepped walls with plantings on the benches			✓✓✓	✓✓		suitable for high slopes, max. Height 1½ m per bench this option may address toe and meander erosion if scour protection such as armour stone or rip rap is added to toe of structure	

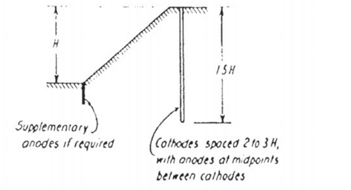
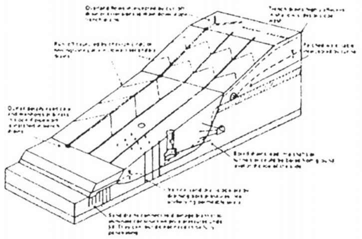
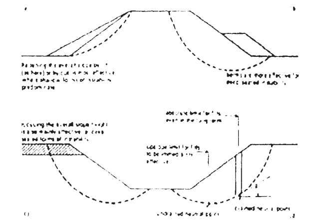
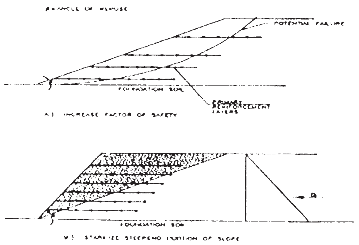
	ON MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		LOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
INERT CONSTRUCTION STRUCTURAL	13. Improve Ground Properties	Grouting, electro-osmosis			✓✓	✓✓✓		dependant on soil properties	 One arrangement of electrodes suitable for stabilizing slope by electro-osmosis.
	14. Reduce External Loads on Slope	Move traffic, remove fill			✓✓	✓✓			
	15. Improve Slope Drainage	Gravel trenches, sand wicks, deep wells			✓✓✓	✓✓		effective where water levels influence stability	

Table 5 - Methods for Addressing Hazards - Provention and Protection Measures

	EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
			Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
INERT CONSTRUCTION STRUCTURAL	16. Alter Slope Geometry (cut/fill, height, inclination)	Reduce inclination, lower height, provide toe berm			✓✓✓	✓✓✓		Major earthworks	 Types of regrading to improve stability. Although these are trivial illustrations, the same principles apply to slopes with complex shapes and internal details. There are quite clearly some situations in which some of the alternatives are impractical, or where some are more valid than the others
	17. Ground Anchors / Reinforcement	Metal cables drilled and grouted, plastic geogrid layers			✓	✓✓✓		Corrosion risk, not flexible	 Role of reinforcement in slopes

Legend:

✓✓✓ Recommended to address hazards

✓✓ Generally will address hazards

✓ May be considered but may not provide proper level of protection to address hazard

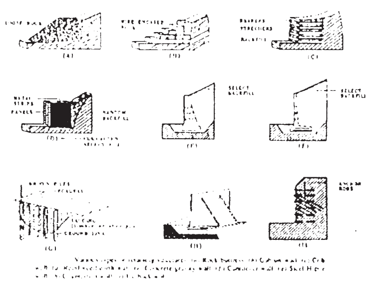
▲ does not address environmental concerns

Notes: 1) Filter cloth & drainage design is not indicated on the drawings, but MUST be included in the design of any protection works.

2) The Adaptive Management Evaluation Approach should be followed as part of the design procedure.

3) Tables are not intended to be inclusive of all structural techniques available. The tables are general in nature and are intended to serve as a guide. They are not exhaustive a ite-specific conditions may differ.

Table 5 - Methods for Addressing Ha Provention and Protection Measures

EROSION MANAGEMENT	DESCRIPTION	RIVER FLOW EROSION		SLOPE INSTABILITY		Surface Runoff	NOTES	SKETCH
		Toe Erosion	Meander Erosion	Shallow Slides	Deep Slides			
18. Retaining Walls / Structures; crib walls, but does not address environmental concerns.	Stacked Blocks, Concrete, Reinforced Backfill, Soldier Piles & Lagging	✓✓▲	✓✓▲	✓✓▲	✓		Cantilever walls feasible up to 9 m height, Counterfort walls suitable for heights more than 8 m	

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Notes: 1) Filter cloth & drainage design is not indicated on the drawings, but MUST be included in the design of any protection works.

2) The Adaptive Management Evaluation Approach should be followed as part of the design procedure.

3) Tables are not intended to be inclusive of all structural techniques available. The tables are general in nature and are intended to serve as a guide. They are not exhaustive and site-specific conditions may differ.

5.4.2 Monitor and Adjust Design

The evaluation phase of the project is often omitted from the overall process and budget. It is the only way to determine whether or not a project has been successful. The evaluation of the project depends on information which was gathered and gained from the monitoring. This information is used to measure or correct project performance, as well as to improve the knowledge base and technology for future projects.

Monitoring is needed to ensure that the project has met it's objectives and does not fail. A great deal of information now exists for the creation of effective monitoring programs. The following references outline many of the specific considerations for monitoring. These references come from initiatives such as the Ministry of Natural Resources guide, Stream Corridors, Adaptive Management In Progress, U.S. Department of Agriculture's Stream Corridor Restoration Handbook.

The specific goals of the project should be considered in order to determine whether the project was a success. The goals may vary depending on the habitat, aesthetics, uses, economics or stability issues. The fundamental elements of a monitoring program should be established at the onset of the project where measurable goals are outlined and baseline data is collected.

Measurable goals for example could set out that fish production in a dredging area be maintained after the project is completed. This would require that the baseline information be conducted to gain a knowledge of existing levels of production. It would also require an indicator of success such as a specific level of production or fishing success that can be measured after construction. The same would apply to a goal of improved bank stability, which requires knowledge of existing stability, migration or erosion rates (baseline), as well as some measurable indicator of success (bank erosion rate, cross sectional dynamics, etc.).

Stakeholders and proponents should ask at the initiation of the project how they will know if the project worked. One of the most important considerations is how to distinguish between change in the stream resulting from the project and a change resulting from activities elsewhere in the natural system.

Typical Monitoring Measures

The following factors may require consideration to ensure that the correct indicators are measured, practical and economically sound methods are used:

- duration and frequency of monitoring;
- relevance of parameters measured to the type of monitoring and goals;
- spatial extent and number of samples;
- technical expertise and need for ease of measurement, observation, understanding;
- repeatability and consistency;
- data management and reporting requirements;
- required level of scientific certainty and validity (level of detail, uncertainty in the project technology);
- clarity in baseline data (helps determine monitoring effort to detect a change)
- technical expertise of group carrying out monitoring;
- distinction between project changes and other natural processes which change in the physical system.

A major consideration in establishing a monitoring program is the timing and scale of project effects that must be measured. Will project effects be measured "before and after" at one location, or compared to reference sites or both? Monitoring should cover an appropriate sized area over which various project objectives should be achieved. There may be a lag period before project effects are measurable. The number of samples should reflect the degree of confidence desired in the data. Various monitoring parameters may be more susceptible to seasonal, annual patterns or activities.

In any proposed works, the systems should continue to be monitored and adjusted as outlined in "AMSC" and the "1998, U.S. Department of Agriculture's Stream Corridor Restoration Handbook".

6.0 ENVIRONMENTALLY SOUND MANAGEMENT WITHIN THE EROSION HAZARD: PHYSICAL AND ECOLOGICAL IMPACTS FOR RIVER AND STREAM SYSTEMS

Increasing pressure to develop along river and stream systems susceptible to flooding and erosion hazards has resulted in detrimental impacts to the shore and aquatic ecosystem. Effective river and stream systems management requires that implementing agencies manage not only the erosion hazards but that there also be a recognition and understanding of the potential impacts of any such actions on the river and stream systems environment or ecosystem and the mandates and objectives of other resource management programs (fisheries, wetlands, wildlife).

The purpose of Section 6 is to provide direction in considering the river and stream system environment. Through understanding the function and susceptibility of various river and stream system ecosystems to disturbance, the potential impacts that may occur as a result of proposed development or remedial works can be identified, and methods of reducing these impacts through design changes or mitigation measures can be implemented.

Environmentally sound management refers to principles, methods and procedures involved in addressing all of the issues that are part of the protection, management and enhancement of the river and stream system ecosystem. This includes but is not limited to the following; geology, geomorphology, hydrogeology, ecology, biology, landscape architect, natural heritage, planning, geotechnical, hydrology and hydraulics. We will introduce some methods associated with undertaking of hazard management in an environmentally sound manner when considering development proposals within the *hazardous lands* but have not attempted to cover all of the respective disciplines. The social and natural heritage issues are of equal importance but policies regarding this issues should be referred to directly. The application of the methods and procedures which are associated with the various disciplines and how they are applied in the study of river and stream system processes are outlined in detail in the AMSC[18] in Ontario, 1998. This document provides a procedure which should be followed when ever any type of protection works or study is being considered within the river or stream system. (see figure 135).

This procedure is designed to aid decision-makers in evaluating an area, or particular location, within an area of provincial interest and in ensuring that consideration is given to both the physical and ecological influences and impacts when selecting which, if any, natural hazard management response (e.g., prevention, non-structural protection works or structural protection works) would provide the "best management practice" given local site conditions. This includes:

- **Identify Hazards;**
- **Identify Development Proposed Within the Hazardous Lands or Hazardous Sites;**
- **Identify Appropriate Hazard Management Response;**
- **Determine Potential Impacts to Physical Processes and Characteristics;**
- **Assess Off-Site Physical Impacts;**
- **Assess Biological or Environmental Impacts; and**
- **Mitigate Minor Impacts of Preferred Hazard Management Response.**

The following procedure focuses on some basic questions and issues that must be addressed in any development decision-making process. It is recognized that some natural hazards may be more complex than others. As such the level of evaluation will be site specific and directly proportional to such factors as the size, severity, and type of risks and the potential physical, environmental and biological impacts that may result.

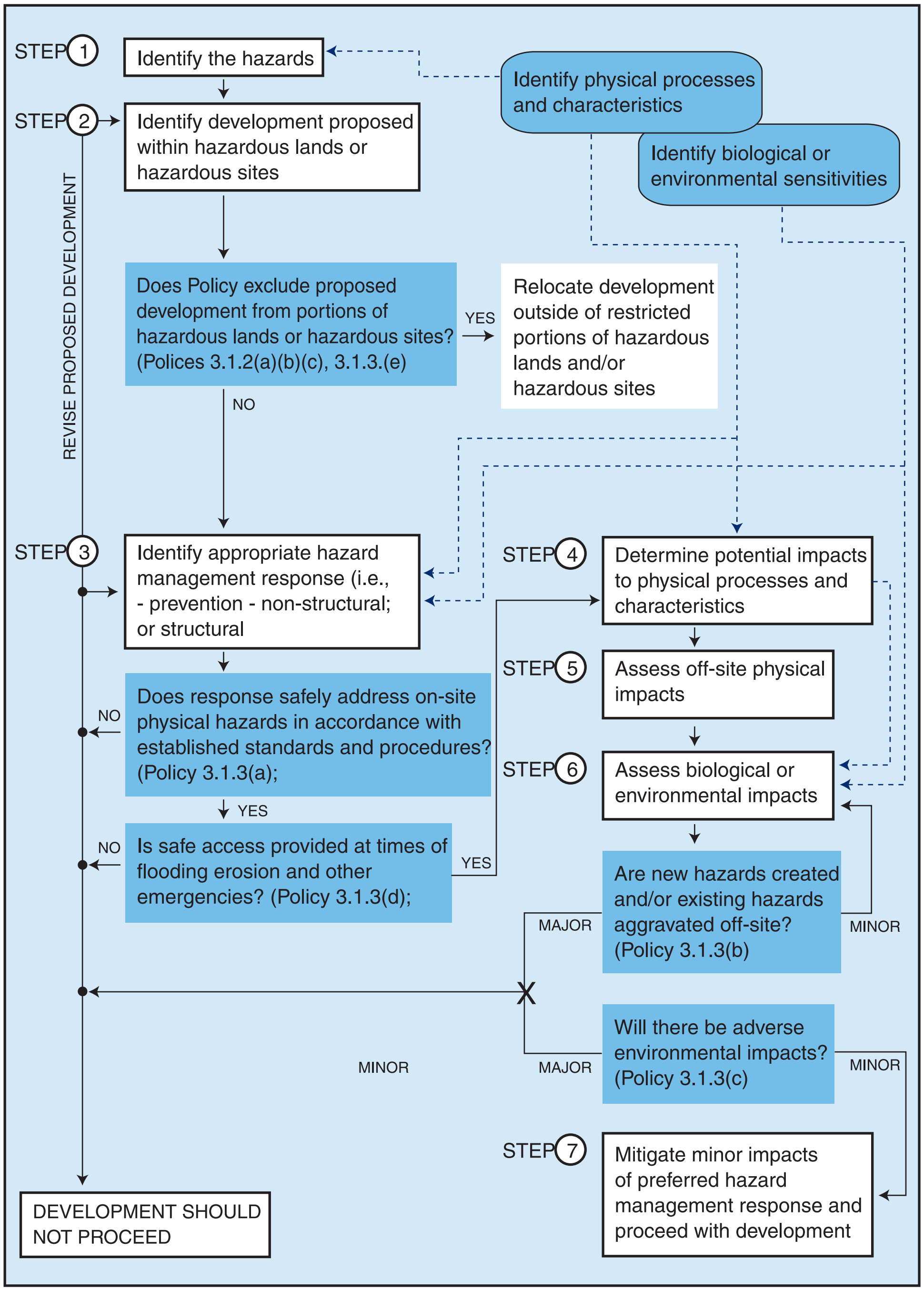


Figure 135 - Addressing the Hazards: 7 Step Procedure

An excellent summary of specific potential drainage impacts and causes as a result of drainage alterations has been prepared by the Ontario Ministry of Transportation, Chapter 2 Developing Drainage Objectives and Criteria, Drainage Management Manual 1997. Many of the applications in this manual are directly applicable to the river and stream systems. Summary charts have been included in Appendix 3 of this document for your information.

6.1 Identify Hazards

The Policy identifies *hazardous lands* adjacent to *river and stream systems* which are impacted by *flooding* and/or *erosion hazards*; and *hazardous sites*. The first step is to identify, or delineate, these four areas of provincial interest. If the standard allowances are not used to delineate the erosion hazards, this step may require a study to assess the existing processes within and beyond the specific site. A further level of understanding of the physical and ecological processes and how they fit into the overall watershed/subwatershed characteristics will be necessary. Reference should be made to the AMSC[19] and the recommended procedure followed.

6.2 Identify Development Proposed Within the Hazardous Lands

Except for certain restrictions (i.e., Policy 3.1.3), the Policy has the flexibility to permit *development* and *site alterations* to be located within the least hazardous portion of the *hazardous lands* and/or *hazardous sites*. The second step is to identify the size and nature of the development that is proposed within the *hazardous lands* and/or *hazardous sites*. The characteristics of the proposed development activity, or the resulting land use, can influence the type of hazard management response to be applied. For example, a high-density residential development will obviously require a greater degree of protection from hazards than non-habitable buildings. Development can generally be grouped into three major categories:

- multi-lot, large lot and large scale development;
- residential or habitable infilling, redevelopment, replacement, major additions/alterations, minor additions/alterations; and
- non-habitable buildings and structures.

Policy 3.1.2 does not permit *development* and *site alterations* within *defined portions of the dynamic beach*, *defined portions of the one hundred year flood level along connecting channels*, and a *floodway*. Also, Policy 3.1.3(e) excludes *institutional uses* or *essential emergency services* or the disposal, manufacture, treatment or storage of *hazardous substances* from the areas of provincial interest. Such uses should not be permitted within these areas and should be directed to areas outside the *hazardous lands* and/or *hazardous sites*.

6.3 Identify Appropriate Hazard Management Response

As discussed in Section 5, where development is to be considered within any of the four areas of provincial interest, the development must fulfil all of the *established standards and procedures* respecting:

- protection works; and
- access.

This involves an assessment of whether or not the selected hazard management response (i.e., prevention, non-structural or structural protection works) is required or considered to be appropriate, will it fulfil each of these standards and will it safely address the on-site physical hazards. This will require an extensive level of understanding of the physical processes and characteristics of the site.

If it is determined that these standards are not fulfilled, or if the proposed hazard management response does not in fact safely "address the on-site physical hazards" (e.g., erosion) (Policy 3.1.3(a)) or if safe ingress and egress is not provided at times of flooding, erosion and other emergencies (Policy 3.1.3(d)), then an alternative hazard management response should be selected and/or the proposed development revised.

6.4 Determine Potential Impacts to Physical Processes and Characteristics

In any application that requires some type of protection works should be evaluated within the appropriate context of the watershed. It is important to consider the appropriate scale to address the key issues as well as to understand how the stream and valley system functions and the impacts the works will have on the management of the system. One of the primary issues when considering protection works to address natural hazards is the need to assess the impacts of the selected protection works on the area's physical processes and characteristics.

Although a particular hazard management response may appropriately address the local or on-site erosion hazard(s), the physical characteristics of the protection works (e.g., structural form and slope, size of material, permeability, etc.), the methods used in construction, the methods of maintenance, and the post-design life measures may individually and/or collectively affect the characteristics and physical processes of a given location. The "affects" or impacts may in turn cause harm to the ecosystem and pose physical risk or harm by increasing or exacerbating hazards on surrounding properties.

The potential influences and impacts of the proposed hazard management response to the physical processes and characteristics must be identified. This will require a sufficient level of understanding of the physical processes and characteristics.

In addition to understanding and addressing the type and magnitude of impacts on the physical processes and characteristics on-site, consideration it is extremely important to also consider the spatial extent of the physical impacts in order to be able to assess the impacts off-site (e.g., how far upstream/ downstream the physical impact is determined to extend). Evaluation of the spatial extent (e.g., watershed, subwatershed, reach, site) of the physical impacts is dependent on such factors as the type, design, configuration and sometimes the timing of the installation of protection works. The resultant impact(s) on the physical processes is also dependent on the physical characteristics of the area in which the works are being installed. For example, is the native soil structure highly susceptible to disturbance, is the area exposed, is it partially sheltered, and what is the magnitude and duration of the forces (e.g., wind, waves, flood flows)? A general discussion outlining the scope, scale, and spacial extent concerns which should be addressed when evaluating the potential impacts has been provided in Section 2.3.1 of this document. A further discussion of this topic is provided in the "AMSC[20]".

Effective ecosystem and natural hazards management requires implementing agencies to manage not only the physical hazards (e.g., flooding, erosion, dynamic beaches, unstable soils, unstable bedrock), but to recognize and understand the potential impacts of any such actions on the local environment or ecosystem. Further reference to the AMSC[21] document outlines many of the biological, ecological and geomorphic impacts and concerns which should also be addressed.

6.5 Assessing Spacial Extent (Off-Site Physical) Impacts

Beyond the consideration of the range, magnitude and consequences of protection works on on-site physical processes and characteristics, one must also give consideration to the potential range, magnitude and consequences of the same protection works on off-site locations or surrounding properties (e.g., updrift/ downdrift river and stream system properties, upstream/downstream riverine properties).

Evaluations of potential physical impacts are often described in terms of **major** or **minor impacts**. For the purposes of this document, clarification and consistency, the following definitions specific to natural hazards will apply:

- **Minor physical impacts** are defined as being of short-duration, where the impact can be mitigated through alterations in design or the selection of an alternative form of protection work, where the impact can be addressed by a change in the timing of construction, where there is likely to be a high rate of recovery, and where there is a low potential for spin-off effects.
- **Major physical impacts** are defined as having long-term and permanent adverse impact on the on-site/off-site physical characteristics and/or processes, where the impact(s) cannot be mitigated through changes in design and/or timing, and where there is a high potential for spin-offs direct and/or indirect effects.

Where major off-site physical impacts result, the development is considered to not be fulfilling the conditions of the applicable policy (e.g., Policy 3.1.3(b), development is to not aggravate existing hazards, create new hazards). Where new hazards are created and/or existing hazards aggravated, one of three options should be implemented:

- an alternative method of “addressing the hazard” must be considered; or
- the development should be revised; or
- the development should not be permitted.

Where minor physical impacts are identified, a determination of whether this impact(s) can be further reduced using another form of protection works or an alteration to the design, installation method or timing should be considered.

6.6 Assess Biological and Environmental Impacts

The environmentally sound management of a particular location requires an understanding not only of the physical processes impacted by various protection works, but also of the effects that these physical processes, and any changes to them, have on the ecosystem. The more complex or diverse the physical characteristics and processes that are shaping and reshaping the development site, the more diverse the range of habitat types for plant and animal species. Although examination and understanding of these diversities, therefore, will help to ensure that potential adverse environmental impacts are addressed and minimized.

The gradual encroachment of development on sensitive ecosystems have in the past resulted in impacts which were frequently overlooked until it was too costly, practical or late to remedy or recover affected habitats. It is essential, therefore, in any decision-making process to ensure that environmental concerns are considered as an integral part of managing a particular location, and not as an isolated study component to be addressed at a later or last stage of the process. For environmental concerns to be duly recognized and properly evaluated and addressed, they must be considered at all stages of the land use planning process, from the formulation of alternative development strategies to the plan implementation and post-development monitoring stage.

To carry out a complete evaluation, it will necessary to identify the environmental sensitivities associated with a particular development site and to develop an understanding and recognition of their importance to the ecosystem as a whole. As well, it will be necessary to have as input, an understanding of the potential physical impacts and their spatial extent. An evaluation of how the biological, terrestrial, ecological elements and processes are impacted by the introduction of the development and any associated non-structural or structural works that may be proposed should be undertaken.

Habitat, in general, is the combination of living and non-living things which provide a particular species with the resources it needs to complete its life cycle. These may include soil, water, air, rocks, rain, heat and the other plants and animals which provide the food needed for survival. Maintaining a diversity of habitats is essential to accommodating the needs of many species and to ensuring the continued diversity of wild life. The term “wild life”, as defined in the Wild Life Strategy for Ontario (1991), includes all wild animals, birds, reptiles, amphibians, fish, invertebrates, as well as, plants, algae, bacteria, and other wild organisms. All species have different habitats, which collectively influence each other and function together as an ecological system or ecosystem.

When assessing the environmental sensitivities within natural hazard areas, one must also fully recognize that the use, existence and management of wild life species are not restricted to these "areas of provincial interest". As such, any decisions made relative to natural hazards should also consult the broader resource planning and management interests of the implementing agencies normally identified in ecosystem-based resource management plans (e.g., watershed, subwatershed management plans).

The biological component of the ecosystem encompasses all wild life and the habitat that supports it. Every wild life species has its own habitat requirements, which can change depending on the stage of its life cycle, the season or even the hour of the day. Areas involving water are particularly important in terms of wild life habitat. For example, areas surrounding wetlands, ponds, rivers and lakes are used by more wild life species than any other habitat type.

An analysis of the significance of the various biological elements of the ecosystem and their susceptibility to disturbance from the placement or design of various protection works is often very difficult due to the interconnections and linkages between these elements.

When evaluating the potential impacts of any proposed activities, one may undertake an assessment of the function and significance of the habitat, and secondly, an assessment on the susceptibility of the habitat to disturbance.

The function and significance of a habitat includes the interrelationships between it and other components of the ecosystem, the general importance of the habitat type in terms of its economic or social value, and its intrinsic values in providing habitat for endangered species. Discussions on the susceptibility of a habitat normally relate to the response of a particular habitat to stress or to changes being placed on it. In general, habitats that can withstand this stress, or which can adapt or recover quickly are considered to have a low susceptibility to disturbance. Conversely, where stress or change to the ecosystem can result in permanent or irreversible changes to the diversity and number of habitats and associated wild life species, such habitats are considered to have a high susceptibility to disturbance.

When discussing potential options for addressing natural hazards, earlier components of this document identified three general categories of management approaches:

- prevention
- non-structural
- structural

Prevention techniques such as the siting of buildings landward of the natural hazard limits and property acquisition and with some non-structural protection works such as building relocation measures normally do not require major alterations or disturbance to the local environments within areas of natural hazards. Where these measures are undertaken with minimal disturbance, the environmental impacts and potential for long-term disturbance to sensitive habitats with these measures may be considered to be negligible.

Conversely, there are some **non-structural** approaches to addressing natural hazards such as soil bioengineering techniques, (e.g., live staking, live facines, contour wattling, brush layering, branch packing) are often used to address a common problem of surface runoff erosion. These techniques often require that some alteration of the local environment is undertaken. See Summary Table 5 and Appendix 4 for examples.

Structural works such as biotechnical stabilization techniques and natural channel designs (e.g., vegetated mesh and grids, vegetated crib, rip rap, armour stone and tiered walls) although they significantly impact the existing system, if designed properly can often provide an opportunity to enhance environmental conditions. See Summary Table 5 and Appendix 4 for examples.

Although the magnitude of the impact is often directly proportional to the level of intrusion and disturbance, these measures may add new stressors and impacts on susceptible habitats but they may also provide an opportunity to improve conditions.

Of the three general categories of protection works, structural protection works have the potential to cause the greatest magnitude and range of spatial and temporal environmental impacts depending on the susceptibility of the biological communities and their associated habitats to disturbance.

The relative significance of the ecological impacts associated with various protection works may include the evaluation of some of the following criteria:

- importance
- spatial extent
- duration of effect
- recovery
- mitigation
- cumulative effects

6.6.1 Importance

This addresses the significance or the value attached to the potentially affected area as a result of such factors as its location, uniqueness or importance for wild life and society.

For example, there are many areas along river and stream systems that have been identified as having high value or significance due to the special functions or habitats which they provided to a diverse range of wild life. These include endangered species habitat, spawning areas, Areas of Natural and Scientific Interest, provincially and locally significant watersheds, Environmentally Significant Areas, and areas deemed to be of Natural Heritage. As such, these areas should be given special consideration and attention in planning for a protection works structure.

6.6.2 Spatial Extent and Scale

The environmental impacts associated with various protection works can occur within the immediate site or in the vicinity of the works (e.g., reach, upstream/downstream for riverine sites) and/or at a further distance from the site area (e.g., watershed, subwatershed).

Impacts in the immediate vicinity of the protection works can result from both large-scale (e.g., construction of an erosion structure) and small-scale activities (e.g., clearing of vegetation for access).

For example, typical on-site environmental impacts of protection works or related development activities may include but are not limited to:

- placement of fill material which covers aquatic plants and bottom substrates;
- changes to nearshore substrates on which fish species may spawn (e.g., cobbles);
- alteration of water levels in periodically flooded areas which may restrict spawning areas and waterfowl habitat;
- removal or clearing of river and stream system vegetation which provides shade, bank stabilization and habitat for wild life; and
- removal of material from the nearshore such as boulders, cobbles, and stumps affect fish feeding grounds by reducing the potential habitat for food organisms (prey species).

A few typical off-site environmental impacts for river and stream system areas may include:

- release of sediments into the water column;
- release of sediments upland, downland or inland of the site, disturbing terrestrial habitat, food supplies;
- disruption to the corridor from either noise or physical impacts affecting migration patterns of certain species;
- changes in sediment supply and alongshore sediment transport either increasing or decreasing erosion in the system; and
- change to substrates covering aquatic plants, bottom substrates, and plants.

Rarely are there environmental impacts which are limited to the immediate site of the activity or disturbance. For this reason, careful consideration and evaluation of on-site and off-site impacts must be addressed in any development decision-making process.

6.6.3 Duration of Effect

Evaluation of this criteria addresses the length of time associated with the activity and its possible environmental impacts. Such impacts are normally identified in terms of their short-term or long-term duration.

There are three key temporal phases associated with protection works:

- construction-related activities;
- operation and function of the protection works during its design life; and
- post-design life.

Short-term environmental impacts are generally associated with construction activities and may often be avoided through alterations and/or modifications in project design or through changes in construction practices (e.g., fencing of the access route to the site to minimize surrounding disturbance, use of silt screens/fencing).

Long-term environmental impacts are generally the result of the project design and occur following construction. For example, the direct loss of a fish spawning bed by the placement of a structure in the river and stream system would be considered a long-term impact.

During the post-design life phase, when the structure has failed or is no longer functioning as designed, environmental impacts may be more difficult to predict. Generally, however, these impacts will likely occur on-site and off-site in areas surrounding the development site.

6.6.4 Recovery

The susceptibility of habitat and its ability to recover following a stress placed on it must be considered. For example, the re-establishment of a small area of river and stream system vegetation when a construction road is no longer required, may be quick to recover and may require little input. Conversely, other environmental impacts, such as those associated with the alteration of a drainage pattern to a wetland may be irreversible.

6.6.5 Mitigation

The use of standard mitigation measures or practices are normally required to alleviate or reduce the environmental impacts associated with a particular development activity. Mitigation measures can be employed during the construction phase or in the actual design stage of a particular structure or activity to reduce associated environmental impacts.

When standard mitigation measures will not substantially reduce environmental impacts (e.g., loss of habitat will occur), compensation for the displaced habitat may be considered and/or required. As an example, compensation plans associated with the potential destruction of fish habitat must be approved by the Federal Department of Fisheries and Oceans.

6.6.6 Cumulative Impacts

Although the environmental impacts associated with a single development activity may be considered to be small or minimal, the addition of this impact to all others being placed on an already stressed ecosystem may have the cumulative impact of causing serious and potentially irreversible degradation. Careful consideration of the cumulative impact of any and all development activities should be assessed and determined through ongoing consultation with all agencies having an interest in the ecosystem.

For the purposes of this document the evaluation of these criteria has been based on the resultant major or minor biological impacts:

- **minor biological** are those which can be mitigated, that is, the proposed structure or or environmental activity will cause impacts which can be mitigated through changes in impacts the design and/or timing of the activity. Confining impacts to what is considered a minor level (as opposed to a major level impact) is contingent on having an impact of short duration, the availability of mitigation practices, a high rate of recovery, and a low potential for spin-off effects.

- **major biological** occur when the structure or activity has significant long-term **or environmental** permanent adverse environmental impacts on the net productivity of the **impacts** habitat on-site or off-site. A major impact can occur when the impact is of long-term duration, the rate of recovery of the habitat is low, there is a high potential for spin-off or indirect effects and/or the area affected is considered to be critical habitat.

The relative importance of each of these criteria and the rigour with which they are evaluated may vary with each project. As a standard evaluation procedure, implementing agencies should consider the type and size of the project, scope of the works and the sensitivity of the location when deciding on the level of study that is to determine whether or not the development is being undertaken in an environmentally sound manner. The procedure outlined in the AMSC[22] should be followed when conducting any type of study or assessment of potential protection works. Where the development cannot be undertaken in an environmentally sound manner (e.g., adverse environmental impacts result) alternative works should be considered or the development should not be permitted.

6.7 Mitigate Minor Impacts of Preferred Hazard Management Response

The proposed *development* and *site alteration* may proceed provided it meets all the requirements of Policies 3.1.2 and 3.1.2, as outlined in the above steps and any minor impacts are mitigated by alterations to the design and/or to the timing and method of installation. Please review Section 5.4.2 Monitoring and Adjust Design of this document and the AMSC [23] document for further details.

Appendix 1 - Soil Properties

APPENDIX 1 - SOIL PROPERTIES

In soil mechanics, three basic soil properties define the soil strength and the available resistance to sliding;

soil unit weight, gamma (kN/m^3)	**angle of internal friction,** phi, degrees	**cohesion** (kN/m^2)
γ	φ'	c'

The shearing resistance or **'strength'** of a soil is defined as the sum of the cohesive resistance and the frictional resistance.

Only fine-grained soils (clays, silts) have cohesive resistance which is the result of attraction or adhesion between soil particles.
Both fine-grained and coarse-grained soils have frictional resistance, caused by individual grains rubbing at their contact points. The frictional resistance is directly related to the contact pressure between the grains (i.e., a high contact pressure results in a high frictional resistance). The shear strength of a soil is defined by the following formula;

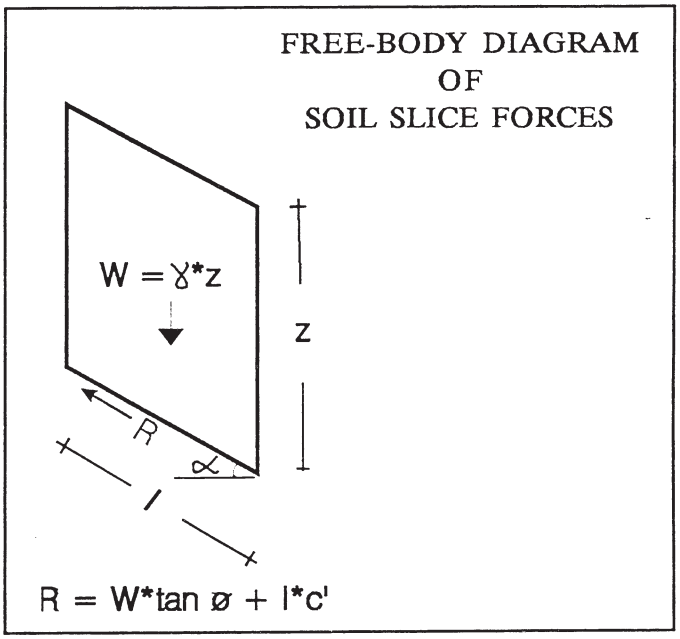


Figure 1-1

$$\tau = c' + (\sigma - \mu)\tan\varphi'$$

where τ = soil shear resistance
c' = soil cohesion
σ = normal stress (perpendicular to shear surface)
μ = soil pore pressure
φ' = soil angle of internal friction

For most **"cohesionless"** soils in Ontario such as sands (gravelly to silty) the following ranges of soil properties are considered typical;

- Cohesionless Soil, Typical Properties

c' = 0
φ' = 26° to 42°
γ = 17 to 19 kN/m^3.

For most "**cohesive**" soils in Ontario such as clays (clayey silt, tills), following are typical ranges;

Cohesive Soil, Typical Properties

$c' = 10 - 60$ kPa (kPa = kN/m^2)
$\varphi' = 26° \text{ to } 38°$
$\gamma = 17 \text{ to } 21$ kN/m^3.

Direct measurements of the angle of internal friction can be carried out in the laboratory using the **Direct Shear Test** or **Triaxial Compression Test**.

However, a good estimate of φ' for '**cohesionless soils**' (sands) can be obtained on the basis of **'N' Value** (Standard Penetration Test), routinely measured in boreholes.

The effective angle of internal friction is dependent on the **relative density** of the "cohesionless" soils and typically increases with density as shown on the adjacent graph and the table below.

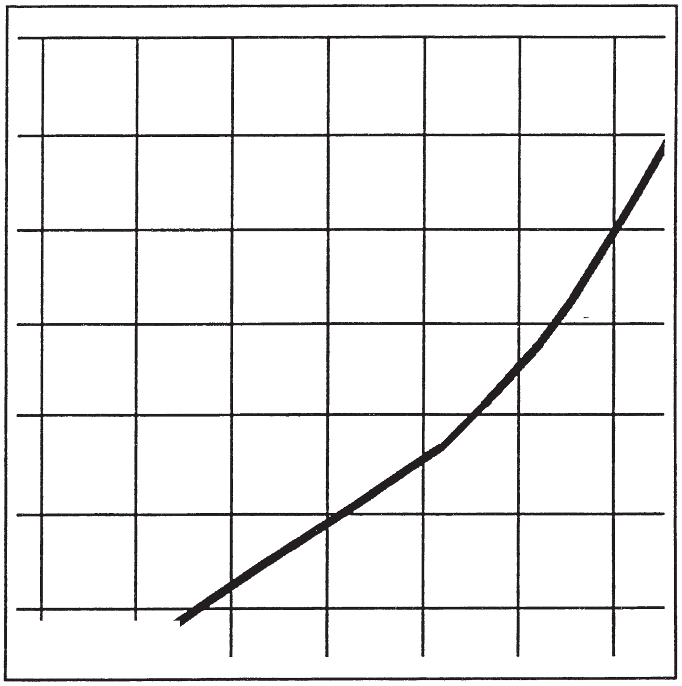


Figure 1-2

Table A 1.1 - Relative Density of Cohesionless Soils

Compactness	Very Loose		Loose	Compact	Dense	Very Dense
Relative Density, Dr	0	15%	35%	65%	85%	100%
'N' Value, Standard Penetration Resistance	1	4	10	30	50	
φ' (°), angle of internal friction		28	30	36	41	
Unit weight, γ moist, kN/m^3	15		16 - 19.5	17 - 20.5	17 - 22	20.5
submerged	9.5		8.5 - 10	9.5 - 11	10 - 13.5	12
Identification in the field	a reinforcing rod can be hand pushed into soil 1 m				difficult to drive 2" by 4" stake with sledge hammer	

Approximate estimates of '**undrained shear strength**' (c_u) can be made on the basis of Standard Penetration Tests (**'N' Values**).

Table A 1.2 - Consistency / Shear Strength, Cohesive Soil

Consistency Term	Approximate Undrained Shear Strength, c_u		'N' Value	Field Description
	kPa	psf		
Very Soft	< 12	< 250	< 2	easily penetrated several cm by fist
Soft	12 - 25	250 - 500	2 - 4	easily penetrated several cm by thumb
Firm	25 - 50	500 - 1000	4 - 8	moderate effort to penetrate by thumb
Stiff	50 - 100	1000 - 2000	8 - 16	readily indented by thumb, great effort
Very Stiff	100 - 200	2000 - 4000	16 - 32	readily indented by thumbnail
Hard	> 200	> 4000	> 32	very difficult to indent with thumbnail

Generally there are few stability problems with bedrock slopes in natural environments due to the high relative strength in comparison to soil. Shales however can be relatively weak in comparison to other rock types (limestones, granites) and can weather or deteriorate to a degree where their strength approaches that of strong soils.

Appendix 2 - Empirical Relationships

APPENDIX 2

Table A2.1 :Empirical Relations Between Size Parameters for Meanders in Alluvial Valleys

(Fluvial Process in Geomorphology by L.B. Leopold, M.G. Wolman, J.P. Millar)

Meander Length to Channel Width	Amplitude to Channel Width	Meander Length to Radius of Curvature	Source
$\lambda = 6.6W^{0.99}$	$A = 18.6w^{0.99}$	-----	Inglis (1949, pt. 1. p 144 Ferguson data)
-----	$A = 10.9w^{1.04}$	-----	Inglis (1949, pt. 1.p. 149 Bates data)
$\lambda = 10.9w^{1.01}$	$A = 2.7w^{1.1}$	$\lambda = 4.7r_m^{0.98}$	Leopold and Wolman (1960)

Table A2.2 - The Geometry of Meandering Streams from Model and River Data

(from M. Shahjahan, 'Factors Controlling the Geometry of Fluvial Meanders', Bull. Int. Ass. Sci. Hydrol., 1970, XV (3), 13 - 24

Area	Authority	Geometry of Meander Channel	Average Particle Size 'D' (mm)	Initial Valley Slope, S_v	Range of Discharge Q ft^3/sec
River Data U.S.A.	C.C. Inglis (1949)	$M_L = 6.6\ B^{0.99}$: $M_B = 18.65\ B^{0.99}$ $M_B = 1.7\ M_L^{1.06}$ $M_B = 10.9\ B^{1.04} = 14B$	-----	-----	-----
Orissa Rivers (India)		$M_L = 27.4\ Q_{max.}^{0.5} = \pm 14.33$	-----	-----	29,000 - 61,000
		$B = 4.88\ Q_{max.}^{0.5}$; $M_L = 6.46\ B$	-----	-----	-----
		$M_B = 57.8\ Q_{max.}^{0.5}$	-----	-----	-----
U.S.A.	C.W. Carlston (1965)	$M_L = 106.1\ Q_a^{0.46}$; $M_L = 80\ Q_{mm}^{0.46}$ $M_L = 8.2\ Q_b^{0.62}$; $M_B = 65.8\ Q^{0.47}$	-----	-----	31 - 562,800
U.S.A. and Australia	S.A. Schumm (1969)	$B = 2.3\ Q_{max.}^{0.58}$, $M^{-0.37}$ $M_L = 234\ Q_{max}^{0.48}$, $M^{-0.74}$	0.11 - 1.1	-----	580 - 48,000
River and Laboratory Data	L.B. Leopold and M.G. Wolman (1957, 1960)	$M_L = 36\ Q^{0.5}$; $M_L = 10.9\ B^{1.01}$ $M_L = 4.7\ R_m^{0.98}$; $S = 0.06\ Q_b^{-0.44}$	0.2 - 42.5	-----	0.021 - 1,000,000
Laboratory Experiments	J.F. Friedkin (1945)	$M_L = 14.0 - 34.0$ $M_B = 1.84 - 17.8$	0.20 - 0.45	0.006 - 0.009	0.05 - 0.30
	C.C. Inglis (1947)	$M_L = 36.4\ Q_d^{0.5}$; $M_B = 16\ Q_d^{0.5}$	0.20	-----	0.175 - 0.40
	N.E. Kondratév (1962)	(a) $M_L = 7.78$; $M_B = 3.52$	0.22	0.005	0.0339
		(b) $M_L = 12.5 - 19.7$; $M_B = 3.94 - 8.73$	0.30 - 0.45	0.006 - 0.008	0.05 - 0.141
		(c) $M_L = 9.76 - 13.9$; $M_B = 2.5 - 5.35$	0.27	0.005 - 0.008	0.035 - 0.071

Table A2.2 - **The Geometry of Meandering Streams from Model and River Data (cont'd)**
Contin'd

(from M. Shahjahan, 'Factors Controlling the Geometry of Fluvial Meanders', Bull. Int. Ass. Sci. Hydrol., 1970, XV (3), 13 - 24

Area	Authority	Geometry of Meander Channel	Average Particle Size 'D' (mm)	Initial Valley Slope, S_v	Range of Discharge Q ft^3/sec
	F.G. Charlton and R.W. Benson (1966)	$\frac{M_L}{D} = 27.2 \left[(Q^2/gD^5)^{0.235} \cdot \left(\frac{Q_s}{Q}\right)^{-0.033} \right]$	0.15 - 0.70	-----	0.0128 - 2
	H.S. Nagabhushaniah	$\frac{M_B}{D} = 0.76 \left[(Q - Q_c)\, D^{-3.0} \cdot S_v\, t \right]^{0.5}$	0.5	0.003 - 0.012	0.019 - 0.147
	S.N. Gupta et al. (1966)	$\frac{M_L}{M_B} = 44.78\, S^{0.55} = 3.71 \left[\left(\frac{Q_s}{Q}\right) \cdot F_r \right]^{0.09}$	0.23	0.0022 - 0.0040	1.0 - 3.0
	H.H. Hill (1964)	$M_L = 29.0 - 37.5$; $M_B = 10.0 - 16.4$	0.26	-----	0.820 - 0.875
	P. Ackers and	$M_L = 37.8\, Q^{0.506}$	0.16	-----	0.238 - 2.74
	F.G.Charlton (1970)	$M_L = 38.0\, Q^{0.467}$	0.15	-----	0.25 - 2.0

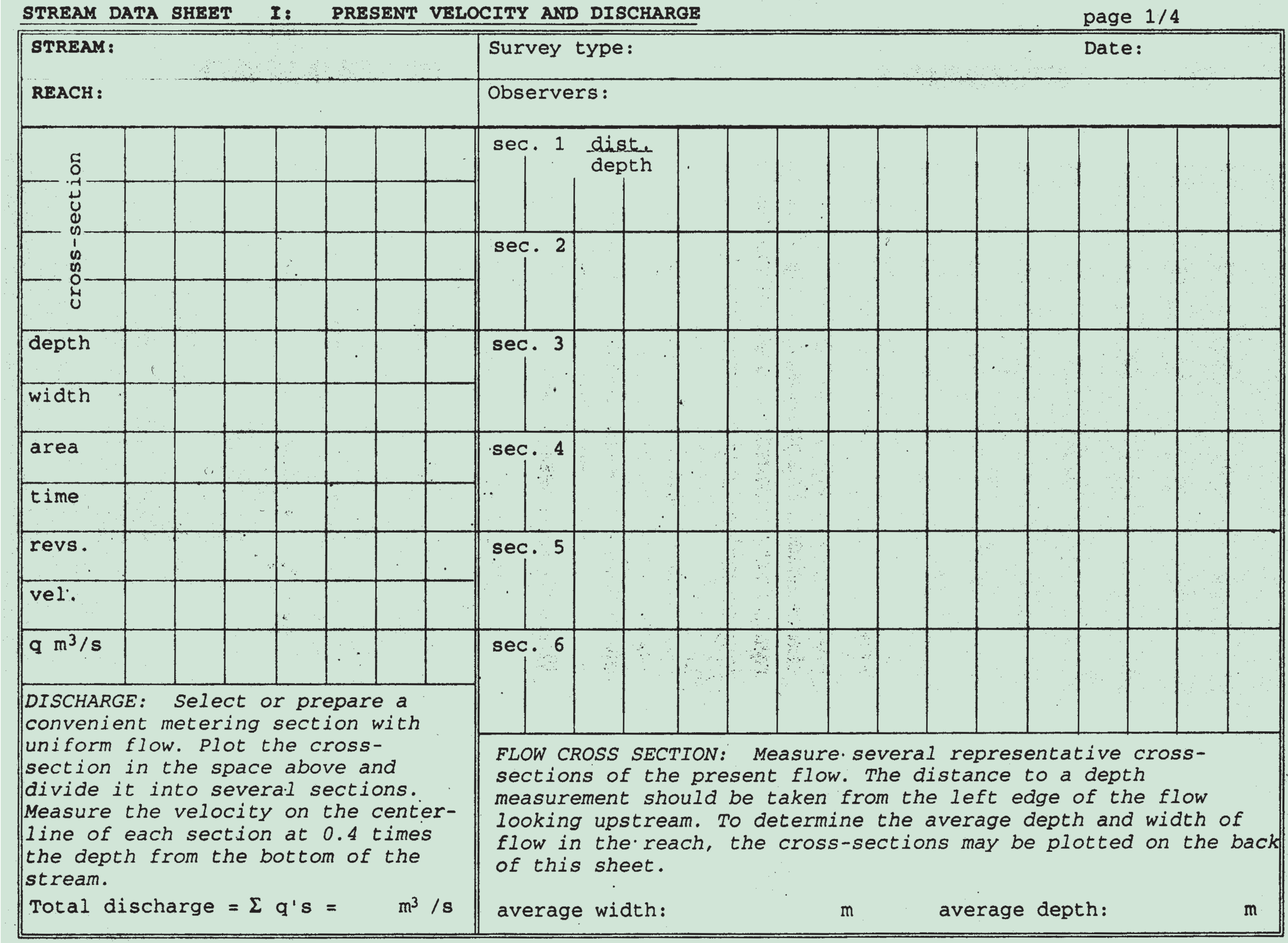
Where: B = channel width
M = percentage silt clay in perimeter of channel
Q = flume discharge
Q_a = mean annual discharge
Q_b = bank full discharge
Q_c = critical discharge at which critical shear velocity corresponding to 'D' exists

Q_d = dominant discharge
Q_{ma} = mean annual flood discharge
Q_{max} = maximum discharge
Q_{mm} = mean maximum monthly discharge
D = mean sediment size
g = acceleration due to gravity

S = channel surface slope
S_v = initial valley slope
t = time of run in hours
F_r = froude number

$\frac{Q_s}{Q}$ = *sediment charge (parts per million)*

Appendix 3 - Field Sheets for Data Collection



STREAM DATA SHEET I: PRESENT VELOCITY AND DISCHARGE page 1/4

STREAM: Survey type: Date:

REACH: Observers:

cross-section							
depth							
width							
area							
time							
revs.							
vel.							
q m³/s							

sec. 1	dist. depth														
sec. 2															
sec. 3															
sec. 4															
sec. 5															
sec. 6															

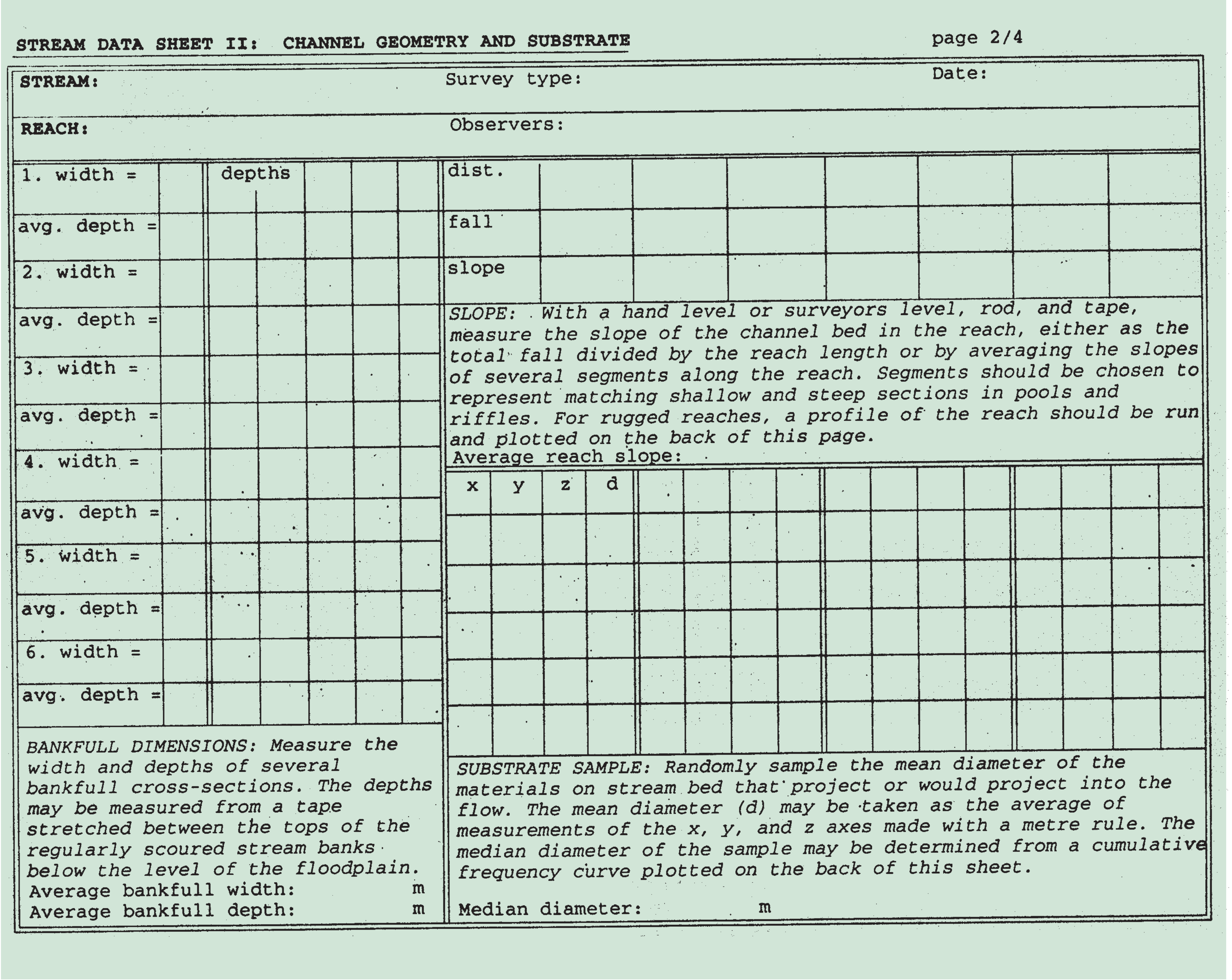
DISCHARGE: Select or prepare a convenient metering section with uniform flow. Plot the cross-section in the space above and divide it into several sections. Measure the velocity on the center-line of each section at 0.4 times the depth from the bottom of the stream.

Total discharge = Σ q's = m³ /s

FLOW CROSS SECTION: Measure several representative cross-sections of the present flow. The distance to a depth measurement should be taken from the left edge of the flow looking upstream. To determine the average depth and width of flow in the reach, the cross-sections may be plotted on the back of this sheet.

average width: m average depth: m

Figure 3-1: Present Velocity & Discharge



STREAM DATA SHEET II: CHANNEL GEOMETRY AND SUBSTRATE page 2/4

STREAM: Survey type: Date:

REACH: Observers:

1. width =		depths				
avg. depth =						
2. width =						
avg. depth =						
3. width =						
avg. depth =						
4. width =						
avg. depth =						
5. width =						
avg. depth =						
6. width =						
avg. depth =						

BANKFULL DIMENSIONS: Measure the width and depths of several bankfull cross-sections. The depths may be measured from a tape stretched between the tops of the regularly scoured stream banks below the level of the floodplain.

Average bankfull width: m

Average bankfull depth: m

dist.							
fall							
slope							

SLOPE: With a hand level or surveyors level, rod, and tape, measure the slope of the channel bed in the reach, either as the total fall divided by the reach length or by averaging the slopes of several segments along the reach. Segments should be chosen to represent matching shallow and steep sections in pools and riffles. For rugged reaches, a profile of the reach should be run and plotted on the back of this page.

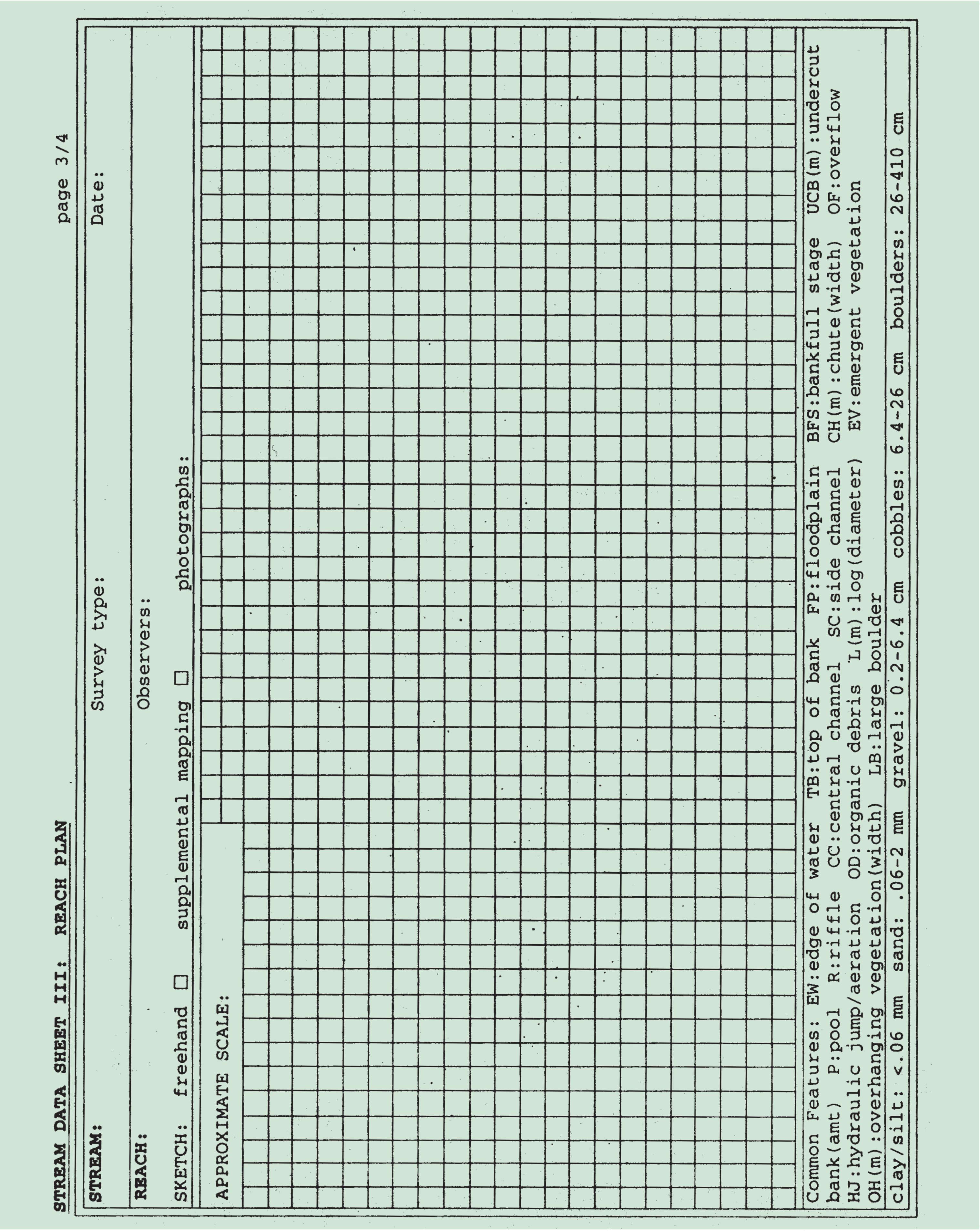
Average reach slope:

x	y	z	d												

SUBSTRATE SAMPLE: Randomly sample the mean diameter of the materials on stream bed that project or would project into the flow. The mean diameter (d) may be taken as the average of measurements of the x, y, and z axes made with a metre rule. The median diameter of the sample may be determined from a cumulative frequency curve plotted on the back of this sheet.

Median diameter: m

Figure 3-2: Channel Geometry & Substrate



STREAM DATA SHEET III: REACH PLAN page 3/4

STREAM: Survey type: Date:

REACH: Observers:

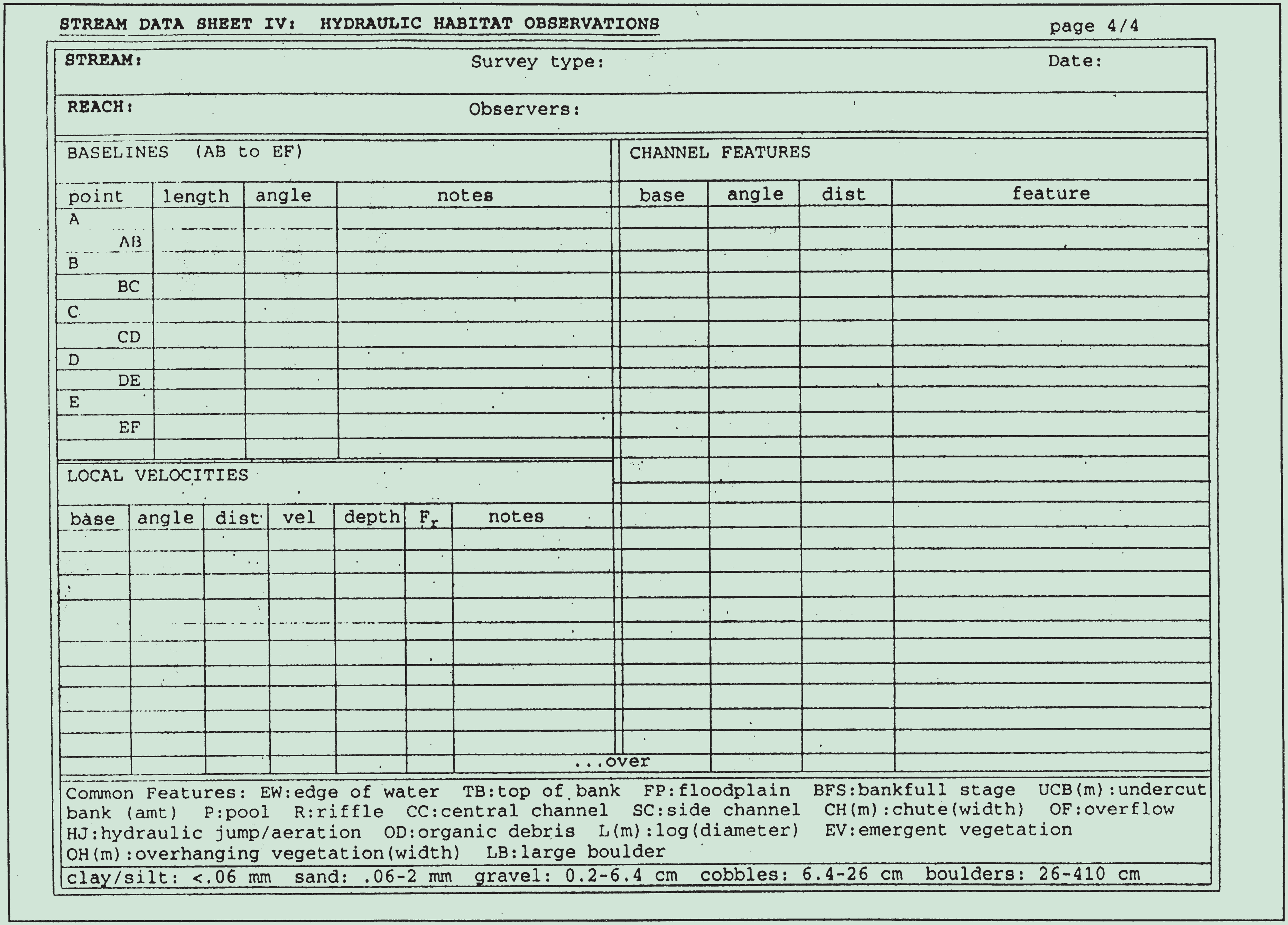
SKETCH: freehand ☐ supplemental mapping ☐ photographs:

APPROXIMATE SCALE:

Common Features: EW:edge of water TB:top of bank FP:floodplain BFS:bankfull stage UCB(m):undercut
bank(amt) P:pool R:riffle CC:central channel SC:side channel CH(m):chute(width) OF:overflow
HJ:hydraulic jump/aeration OD:organic debris L(m):log(diameter) EV:emergent vegetation
OH(m):overhanging vegetation(width) LB:large boulder

clay/silt: <.06 mm sand: .06-2 mm gravel: 0.2-6.4 cm cobbles: 6.4-26 cm boulders: 26-410 cm

Figure 3-3: Reach Plan



STREAM DATA SHEET IV: HYDRAULIC HABITAT OBSERVATIONS page 4/4

STREAM: Survey type: Date:

REACH: Observers:

BASELINES (AB to EF)

point	length	angle	notes
A			
AB			
B			
BC			
C			
CD			
D			
DE			
E			
EF			

LOCAL VELOCITIES

base	angle	dist	vel	depth	F_r	notes

CHANNEL FEATURES

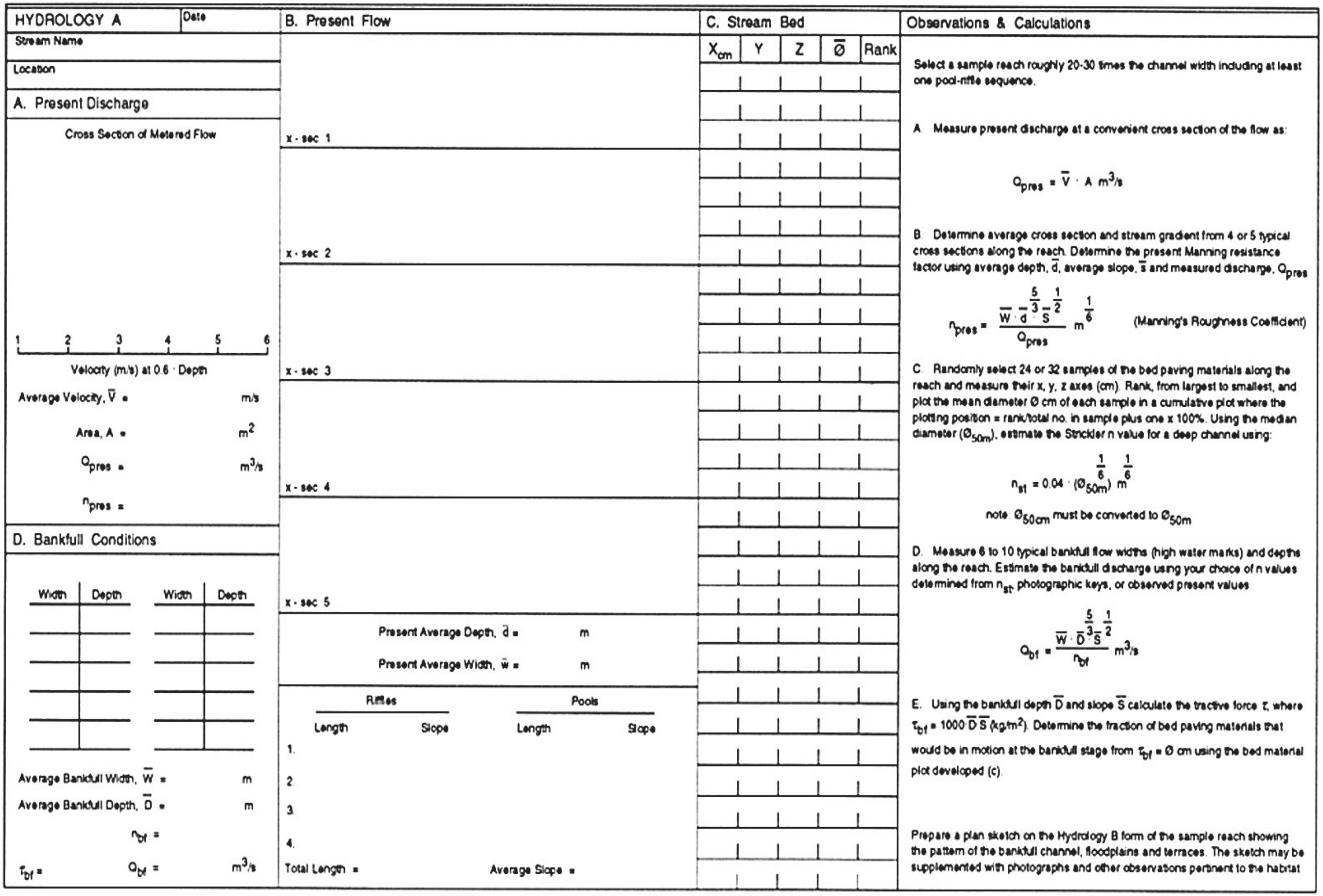
base	angle	dist	feature

...over

Common Features: EW:edge of water TB:top of bank FP:floodplain BFS:bankfull stage UCB(m):undercut bank (amt) P:pool R:riffle CC:central channel SC:side channel CH(m):chute(width) OF:overflow HJ:hydraulic jump/aeration OD:organic debris L(m):log(diameter) EV:emergent vegetation OH(m):overhanging vegetation(width) LB:large boulder

clay/silt: <.06 mm sand: .06-2 mm gravel: 0.2-6.4 cm cobbles: 6.4-26 cm boulders: 26-410 cm

Figure 3-4: Hydraulic Habitat Observations



HYDROLOGY A Date

Stream Name

Location

A. Present Discharge

Cross Section of Metered Flow

Velocity (m/s) at 0.6 · Depth

Average Velocity, $\overline{V}$ = m/s

Area, A = m^2

Q_{pres} = m^3/s

n_{pres} =

D. Bankfull Conditions

Width	Depth	Width	Depth

Average Bankfull Width, $\overline{W}$ = m

Average Bankfull Depth, $\overline{D}$ = m

n_{bf} =

τ_{bf} = Q_{bf} = m^3/s

B. Present Flow

x - sec 1

x - sec 2

x - sec 3

x - sec 4

x - sec 5

Present Average Depth, $\overline{d}$ = m

Present Average Width, $\overline{w}$ = m

	Riffles		Pools	
	Length	Slope	Length	Slope
1.				
2.				
3.				
4.				

Total Length = Average Slope =

C. Stream Bed

X_{cm}	Y	Z	$\overline{Ø}$	Rank

Observations & Calculations

Select a sample reach roughly 20-30 times the channel width including at least one pool-riffle sequence.

A. Measure present discharge at a convenient cross section of the flow as:

$$Q_{pres} = \overline{V} \cdot A \ m^3/s$$

B. Determine average cross section and stream gradient from 4 or 5 typical cross sections along the reach. Determine the present Manning resistance factor using average depth, $\overline{d}$, average slope, $\overline{s}$ and measured discharge, Q_{pres}

$$n_{pres} = \frac{\overline{W} \cdot \overline{d}^{\frac{5}{3}} \cdot \overline{S}^{\frac{1}{2}}}{Q_{pres}} \ m^{\frac{1}{6}} \qquad \text{(Manning's Roughness Coefficient)}$$

C. Randomly select 24 or 32 samples of the bed paving materials along the reach and measure their x, y, z axes (cm). Rank, from largest to smallest, and plot the mean diameter Ø cm of each sample in a cumulative plot where the plotting position = rank/total no. in sample plus one x 100%. Using the median diameter ($Ø_{50m}$), estimate the Strickler n value for a deep channel using:

$$n_{st} = 0.04 \cdot (Ø_{50m})^{\frac{1}{6}} \ m^{\frac{1}{6}}$$

note: $Ø_{50cm}$ must be converted to $Ø_{50m}$

D. Measure 6 to 10 typical bankfull flow widths (high water marks) and depths along the reach. Estimate the bankfull discharge using your choice of n values determined from n_{st}, photographic keys, or observed present values

$$Q_{bf} = \frac{\overline{W} \cdot \overline{D}^{\frac{5}{3}} \cdot \overline{S}^{\frac{1}{2}}}{n_{bf}} \ m^3/s$$

E. Using the bankfull depth $\overline{D}$ and slope $\overline{S}$ calculate the tractive force τ, where $\tau_{bf} = 1000 \cdot \overline{D} \cdot \overline{S}$ (kg/m²). Determine the fraction of bed paving materials that would be in motion at the bankfull stage from τ_{bf} = Ø cm using the bed material plot developed (c).

Prepare a plan sketch on the Hydrology B form of the sample reach showing the pattern of the bankfull channel, floodplains and terraces. The sketch may be supplemented with photographs and other observations pertinent to the habitat

Figure 3-5: Hydrology Charts

HYDROLOGY B	Stream Name	Location	Date

Sketch

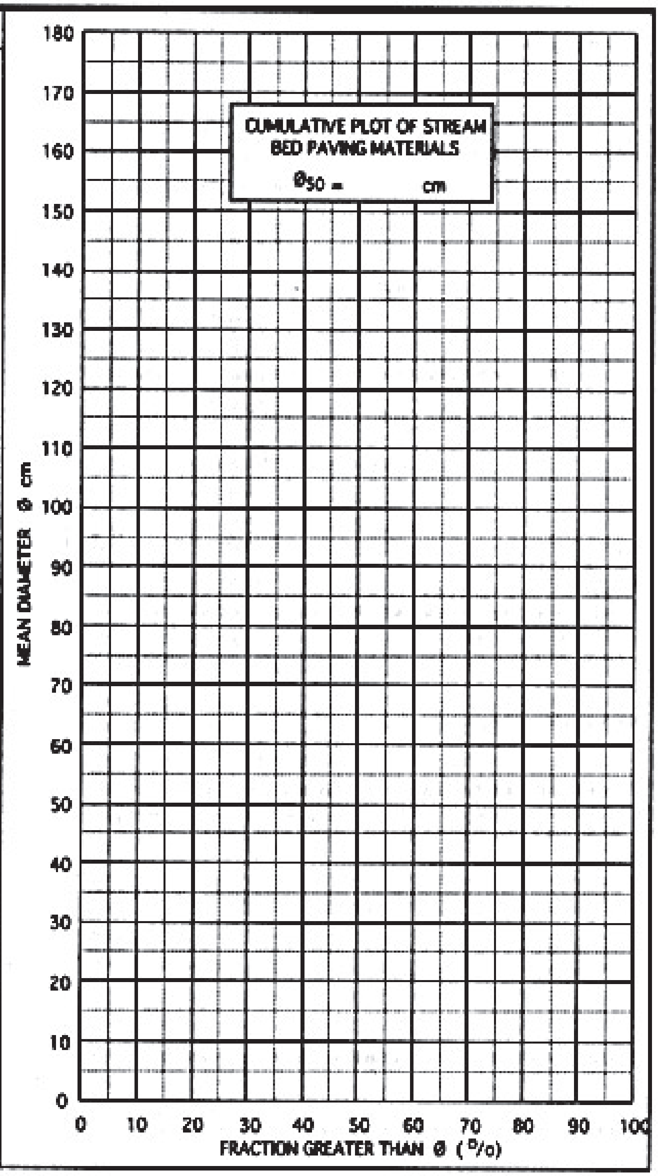


Figure 3-6: Hydrology Charts

APPENDIX 3 B - Field Sheets

Parish Geomorphic

PARISH
geomorphic

SURVEY DATA

Date:
Location:
Weather Description:

Crew:

Station:
Rod:
Recorder:

Station Height:

GPS Co-ordinates:

Elevation	Distance (m)	Angle (°)	H^2O Depth	Calc. Elev.	Comments

Survey Comments and Locations:

TR = Top of riffle
BR = Bottom of riffle

PMAX = Maximum pool depth
PT = Top of pool
PB = Bottom of pool

CC = Center channel
CC# = Center of Cross-section

LBF# = Left bankfull @ transect #
RBF# = Right bankfull @ transect #

TLJ = Top of Log Jam
BLJ = Bottom of Log Jam

BACKSIGHT = New station position

Planform Sketch:

Woody Debris Description:

Erosion Description:

Riparian Description:

Comments & Site Description:

PARISH geomorphic

FLOW DATA

Date: ***Site:*** ***Crew:*** ***Flow Meter:***
Location:
Weather Description: ***Recorder:***

Panel A Downstream Left

Distance from Bank (m): **Water Depth (m):** **Units:**

Height (cm)	Bed				Surface	0.6 of Depth
1						
2						
3						
4						
5						
6						
Mean						

***Avg Vel** (m/sec)*
***Panel Q** (m³/sec)*

Panel B

Distance from Bank (m): **Water Depth (m):** **Units:**

Height (cm)	Bed				Surface	0.6 of Depth
1						
2						
3						
4						
5						
6						
Mean						

***Panel Area** (m²)*
***Avg Vel** (m/sec)*
***Panel Q** (m³/sec)*

Panel C

Distance from Bank (m): **Water Depth (m):** **Units:**

Height (cm)	Bed				Surface	0.6 of Depth
1						
2						
3						
4						
5						
6						
Mean						

***Panel Area** (m²)*
***Avg Vel** (m/sec)*
***Panel Q** (m³/sec)*

Panel D

Distance from Bank (m): **Water Depth (m):** **Units:**

Height (cm)	Bed				Surface	0.6 of Depth
1						
2						
3						
4						
5						
6						
Mean						

***Panel Area** (m²)*
***Avg Vel** (m/sec)*
***Panel Q** (m³/sec)*

Panel E Downstream Right

Distance from Bank (m): **Water Depth (m):** **Units:**

Height (cm)	Bed				Surface	0.6 of Depth
1						
2						
3						
4						
5						
6						
Mean						

***Panel Area** (m²)*
***Avg Vel** (m/sec)*
***Panel Q** (m³/sec)*

Comments:

Total Q (m³/sec):

PARISH
geomorphic

BANK DATA

Date: **Site:** **Crew:**
Location:
Weather Description: **Recorder:**

RIGHT Bank - Downstream

Bank Type: Simple ☐ Complex ☐ Vertical ☐ Overhang ☐ Valley ☐ Other ☐ ____________

Height (m)

Vegetation
Trees ☐ Sp.
Shrubs ☐
Herbs: Tall ☐ Short ☐
Grasses: Tall ☐ Short ☐

Sketch

Materials

Rooting Depth (cm)

Torvane

% Protected by Vegetation

Undercut (cm) Height:
Amount:

Woody Debris Description

Surrounding Land Use

Bank Sample? Yes ☐ No ☐

LEFT Bank - Downstream

Bank Type: Simple ☐ Complex ☐ Vertical ☐ Overhang ☐ Valley ☐ Other ☐ ____________

Height (m)

Vegetation
Trees ☐ Sp.
Shrubs ☐
Herbs: Tall ☐ Short ☐
Grasses: Tall ☐ Short ☐

Sketch

Materials

Rooting Depth (cm)

Torvane

% Protected by Vegetation

Undercut (cm) Height:
Amount:

Woody Debris Description

Surrounding Land Use

Bank Sample? Yes ☐ No ☐

Site Description & Comments:

PARISH
geomorphic

CROSS-SECTION DATA

Date: **Site:** **Crew:**
Location:
Weather Description: **Recorder:**

Cross-section (cm)

Width	Bankfull Depth	Water Depth	Comments
			Downstream Left

Pictures? ☐ *Numbers:*

Site Description & Comments:

Bankfull Width (m)

Wetted Width (m)
Start: End:

Entrenchment (m)
Left: Right:

Undercuts:

Left	Major ☐	Right	Major ☐
	Minor ☐		Minor ☐
	None ☐		None ☐

Pebble Count (cm)

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

Particle Shape (cm)

X	Y	Z
X	Y	Z
X	Y	Z

Hydraulic Roughness (cm)

Max: Med: Min:

Embeddedness (%)

Sub-Pavement

Samples Taken:

Sub-Pvmnt ☐	Pavement ☐	Riffle ☐
Water ☐	Bank ☐	Deposit ☐

Distance to Next Site:

APPENDIX 4 -

Biotechnical & Soil Bioengineering Methods

APPENDIX 4
BIOTECHNICAL AND SOIL BIOENGINEERING

From a broader philosophical and functional context biotechnical and soil bioengineering honours the land by rebuilding functionality and in doing so connects people with living resources. It is a restoration, rehabilitation and reclamation technology which offers a reasonable, attractive, and integratable approach to “protection” and “living system” land stabilization and ecological restoration functions. From a “Protection” perspective, it serves as an erosion, shallow mass wasting, and flood control technology. It works to rebuild functionality and in the reestablishment of a balanced, living, native community capable of self-repair as it adapts to the land’s stresses. Soil bioengineering works with nature to restore the land to a self-supporting functioning state. It is always based on sound engineering practice with integrated ecological principles.

Soil bioengineering represents only one important integral component. It is not a stand-alone technology. Typically it is best accomplished through interdisciplinary team efforts. To produce a successful project with broad benefits, sites may require experts in wildlife, fisheries, and human habitat, landscape architecture, engineering, soil geology, economics, hydrology, horticulture, and fluvial geomorphology, as well as soil bioengineering. The work proceeds from careful on-site assessment, data review, and design documentation to exacting installation by a competent contractor and subsequent evaluation and monitoring. Care must be exercised to ensure that problems, not symptoms, are treated. All are critical to protecting and rebuilding the investment, and as in any other discipline, each step requires sound judgment. Expertise in soil bioengineering requires many years of specialized education, training, and experience.

By definition, soil bioengineering is an applied science which rebuilds functional systems using biotechnical stabilization in which either initially or over time the living plant material becomes the main structural component. This system becomes part of the complex functioning relationships which connect land, water, plant life, and habitat. Herbaceous and especially woody pioneer species (such as salix, cornus, and viburnum) that are able to root from cuttings form the initial living systems. Initially, the unrooted live branch material protects the soil, offering structural/mechanical function. As plants root and grow, they further reinforce and stabilize the site, strengthening through time. Other plants invade, creating a rich, diverse community that offers long-term site protection and enhancement. In certain areas and seasons and for specific purposes such as habitat, rooted plants are also used.

Live plants excel in stabilizing soils and in a very important way work to enhance and restore a diverse, healthy habitat. In riparian zones, as well as in wetland areas, they serve as filters to improve water quality. Top growth intercepts raindrops, filters sediments out of runoff, enriches the soil, and increases infiltration. Roots consolidate the soil and act as fibrous inclusions, reinforcing the soil mantle. They provide arching and buttressing units on upland structures and remove moisture through transpiration. Soil bioengineering works, being live, need not succumb to deterioration as non-living systems must.

These living structures establish foundations for reestablishment of functionality on upland watersheds and riparian zones which, again, as connected systems, enhance and support a diverse aquatic and terrestrial habitat, offering food, cover, shelter, transportation corridors, and nesting opportunities. They further offer a variety of recreational and aesthetic experiences for human enjoyment. Aesthetic improvements may also increase the economic value of the land and adjoining lands.

The living plant systems, such as the brushlayer, live fascine, brushmattress and live staking, are used in specific combinations and configurations to control surface erosion and shallow mass wasting (see Tables 1 and 2). The soil bioengineer must consider the mechanical/hydraulic and ecological/environmental parameters of the specific site before selecting the appropriate method technology requirements and methods.

Soil bioengineering is typically used in combination with conventional and other environmentally-based systems to reduce costs and increase effectiveness, permanence and aesthetic appeal. Most projects in which soil bioengineering solutions are incorporated provide broader, more complete, and more environmentally responsible products which tend to grow stronger and more diverse with age as their functionality is restored.

This technology, while it is only one important component in the overall broader context, offers integratable natural and effective solutions to problems of stability, water quality, and habitat enhancement along streams and rivers, highway cut and fill slopes, in highway/railway transportation, power, landfills, forestry logging operations, military installations, wetlands and on commercial, private, agricultural, and recreational sites. With reference to connected lands, the upland watersheds and the river and streambank riparian zones, floodplain corridors and wetlands need to be protected in order to ensure sustainable functionality.

For detailed descriptions of the various methods mentioned in the following 3 tables, please refer to Biotechnical and Soil Bioengineering Slope Stabilization, 1996, Gray & Sotir, and the U.S. Department of Agriculture (U.S.D.A.) Engineering Field Handbook; Chapter 16, Streambank and Shoreline Protection and Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction.

APPROPRIATE STREAMBANK PROTECTION MEASURES

(Adapted for the Second International Conference on Natural Channel Systems)

Erosion Process	**Structures Provided the Greatest Environmental Benefits Ranked In Order of Benefits**
Headcutting and General bed degradation	Erosion must be halted by installing grade control, runoff detention, and/or by armoring bed
Toe erosion and Upper bank failure	1. Brushmattress with rock toe 2. Live cribwall 3. Live boom 4. Rock toe with vegetation 5. Conventional riprap
Local bank scour	1. Branchpacking 2. Live cribwall 3. Live fascine 4. Joint planting 5. Tree revetment 6. Conventional vegetation 7. Conventional riprap
Local bed scour	1. Eliminate problem and armor bed scour hole
General scour of Middle and upper bank	1. Brushmattress with rock toe 2. Live boom 3. Live fascine 4. Live staking 5. Joint planting 6. Tree revetment 7. Conventional vegetation 8. Conventional riprap
Overbank runoff	Intercept and divert runoff and repair damage with: 1. Branchpacking 2. Live fascine 3. Live staking
Piping	Intercept and divert runoff. Fill existing pipes and repair damage with: 1. Branchpacking 2. Live staking

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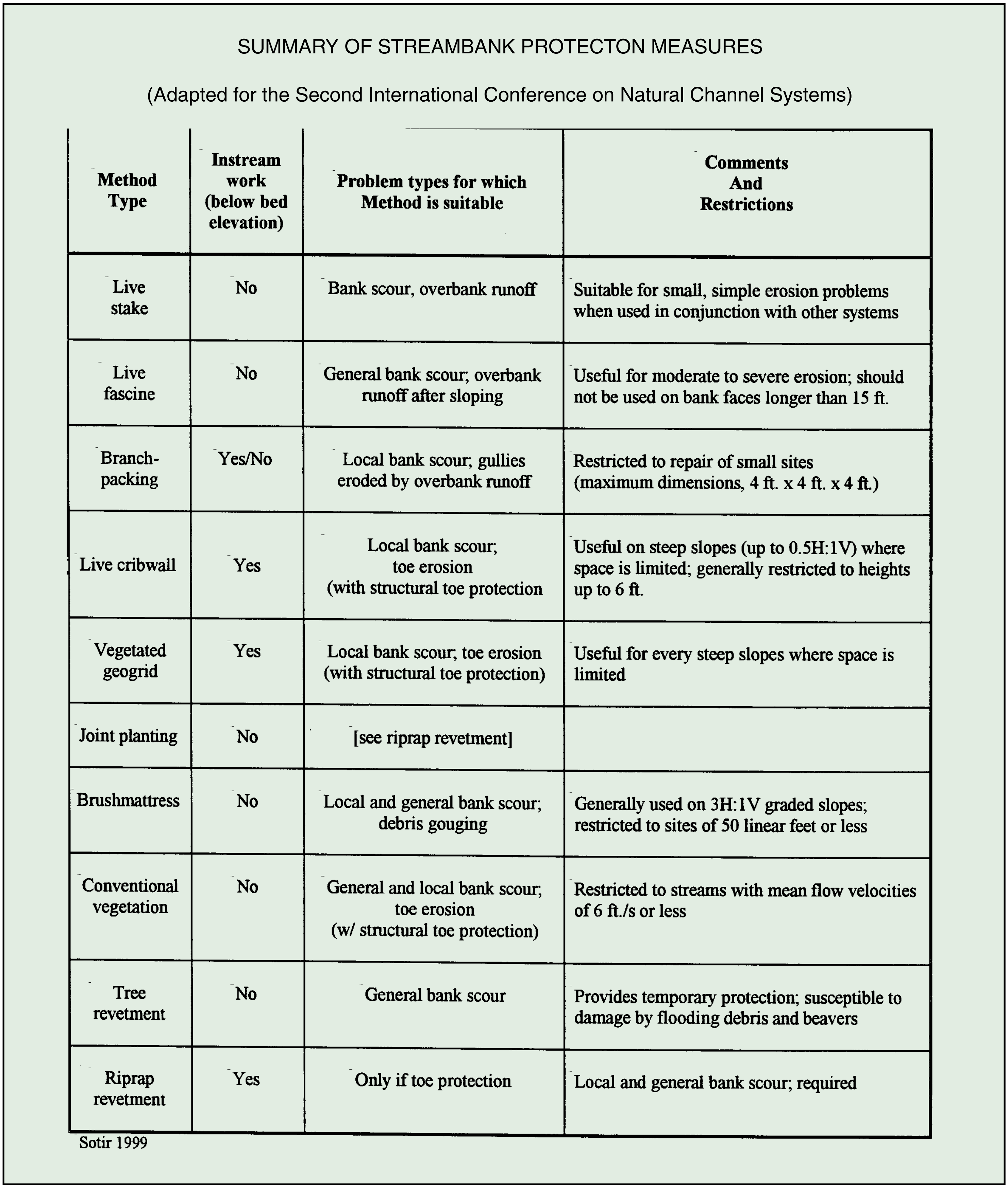
Table A4.1 - Appropriate Streambank Protection Measures

APPROPRIATE UPLAND SLOPE PROTECTION MEASURES (Adapted for the Second International Conference on Natural Channel Systems)	
Erosion Process	**Upland Slope Protection Ranked by Environmental Benefits and Effectiveness**
Surficial erosion Shallow (rilling)	1. Live fascine with long straw 2. Live stake with long straw & fabric 3. Conventional plantings with long straw
Gullying	1. Live fascine with long straw
Toe erosion and over-steepened slope	1. Rock two with vegetation 2. Conventional riprap 3. Low breast wall
Local slump Or blow out	1. Branchpacking 2. Conventional riprap
Shallow mass (transitional movement)	1. Brushlayering 2. Live fascine 3. Conventional plantings with live staking
Shallow mass movement & resistance to low - moderate earth forces	1. Live cribwall 2. Brushlayering 3. Joint planting 4. Conventional riprap 5. Low breast wall

Table A4.2: Appropriate Upland Slope Protection Measure



SUMMARY OF STREAMBANK PROTECTON MEASURES

(Adapted for the Second International Conference on Natural Channel Systems)

Method Type	Instream work (below bed elevation)	Problem types for which Method is suitable	Comments And Restrictions
Live stake	No	Bank scour, overbank runoff	Suitable for small, simple erosion problems when used in conjunction with other systems
Live fascine	No	General bank scour; overbank runoff after sloping	Useful for moderate to severe erosion; should not be used on bank faces longer than 15 ft.
Branch-packing	Yes/No	Local bank scour; gullies eroded by overbank runoff	Restricted to repair of small sites (maximum dimensions, 4 ft. x 4 ft. x 4 ft.)
Live cribwall	Yes	Local bank scour; toe erosion (with structural toe protection	Useful on steep slopes (up to 0.5H:1V) where space is limited; generally restricted to heights up to 6 ft.
Vegetated geogrid	Yes	Local bank scour; toe erosion (with structural toe protection)	Useful for every steep slopes where space is limited
Joint planting	No	[see riprap revetment]	
Brushmattress	No	Local and general bank scour; debris gouging	Generally used on 3H:1V graded slopes; restricted to sites of 50 linear feet or less
Conventional vegetation	No	General and local bank scour; toe erosion (w/ structural toe protection)	Restricted to streams with mean flow velocities of 6 ft./s or less
Tree revetment	No	General bank scour	Provides temporary protection; susceptible to damage by flooding debris and beavers
Riprap revetment	Yes	Only if toe protection	Local and general bank scour; required

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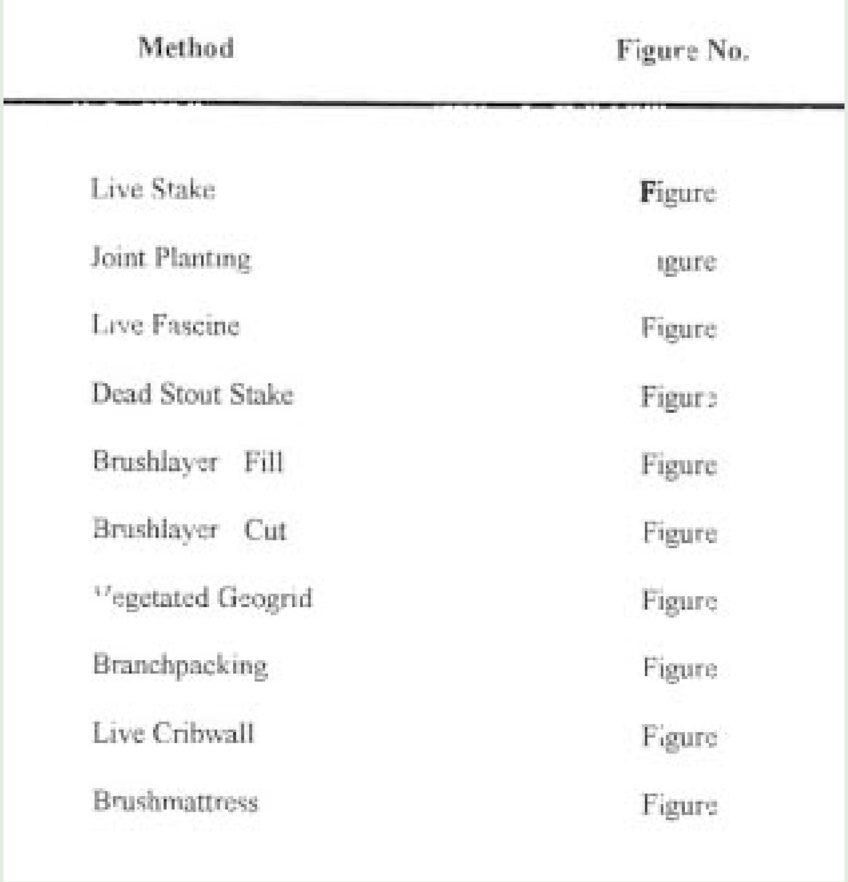
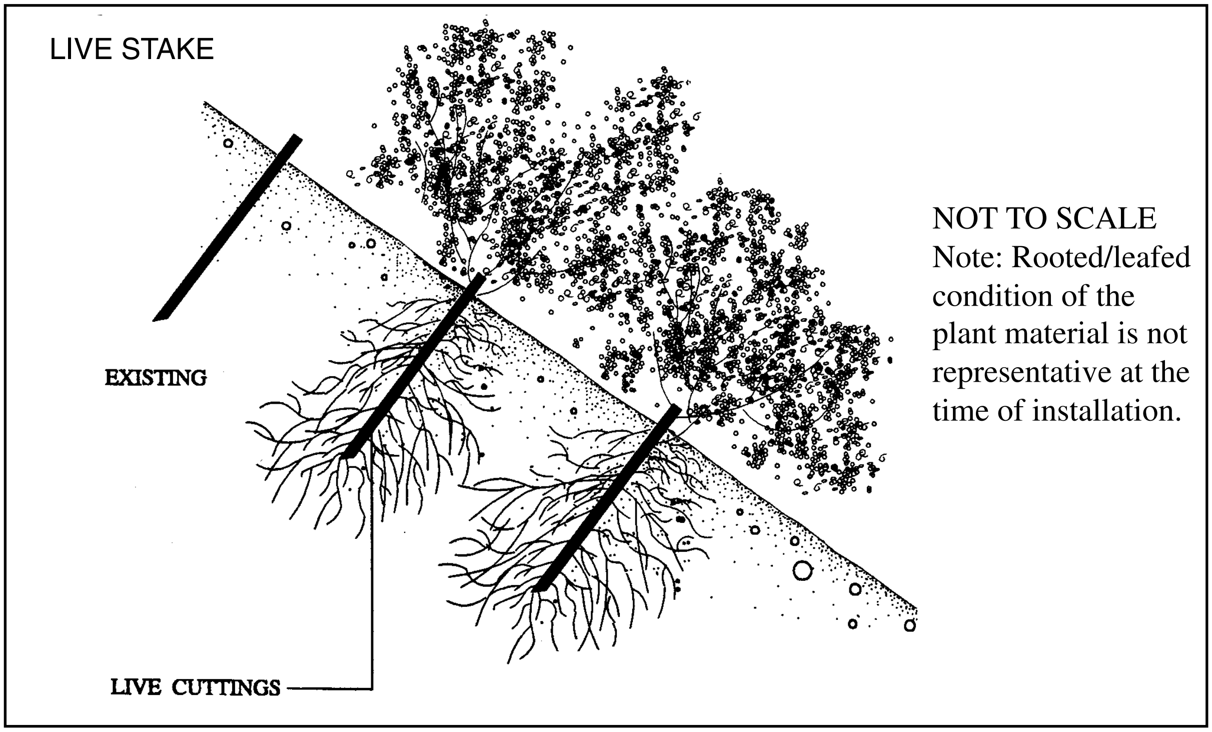
Table A4.3 Summary of Streambank Protection Measures

FIGURES OF UPLAND SLOPE STREAMBANK AND SHORELINE METHODS



Method	Figure No.
Live Stake	Figure
Joint Planting	igure
Live Fascine	Figure
Dead Stout Stake	Figure
Brushlayer Fill	Figure
Brushlayer Cut	Figure
Vegetated Geogrid	Figure
Branchpacking	Figure
Live Cribwall	Figure
Brushmattress	Figure

Figure 4-1 Upland Slope, Streambank & Shoreline Methods



NOT TO SCALE
Note: Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 4-3 - Live Stake Drawing

DISCUSSIONS

This information is intended to offer a better understanding of the merits of soil bioengineering technology and to acquaint the reader with the "tools" and terms used for design and construction. It is not adequate for design or installation purposes. The information represents selected experiences and judgement of Robbin B. Sotir & Associates, Inc.

Live Stake

Description

Live stakes are living, woody plant cuttings capable of rooting with relative ease. The cuttings are large enough and long enough to be tamped into the ground. They are intended to root and grow into mature shrubs that, over time, will serve to reinforce and stabilize the soils and produce vegetative growth. (See Figure 1 and Photographs 1 and 2.)

Effectiveness

This is an effective stabilization method for simple minor erosion problems. Once the roots and vegetation have become established, they are able to function in soil reinforcement and stabilization.

The live staking technique is effective when the construction time is limited and an inexpensive and simple method will handle the repair.

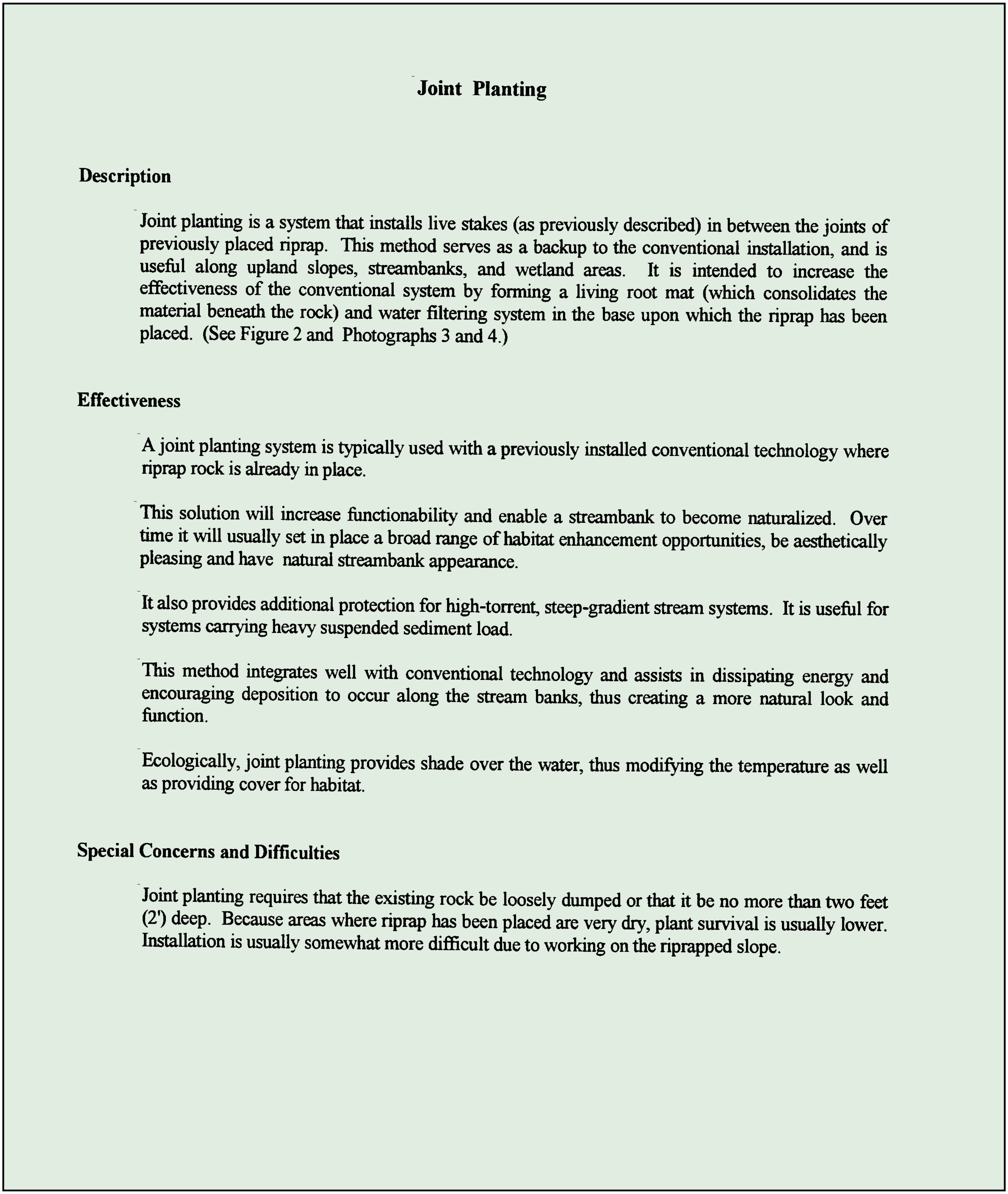
Live staking is an effective system for securing natural geotextiles such as jute mesh, coir, or other blanket surface treatments. This is a good combination for areas which would benefit from both treatments.

After they have become well established, live stakes are effective in camouflaging an open area. They usually enhance the development of healthy habitat areas over time. These installations also reinforce the soil mantle and provide surface protection via the top leaf growth and leaf litter.

Special Concerns and Difficulties

When first installed the live staking systems offer no immediate surface or soil mantle stabilization to an area.

Figure 4-2 Live Steak



Joint Planting

Description

Joint planting is a system that installs live stakes (as previously described) in between the joints of previously placed riprap. This method serves as a backup to the conventional installation, and is useful along upland slopes, streambanks, and wetland areas. It is intended to increase the effectiveness of the conventional system by forming a living root mat (which consolidates the material beneath the rock) and water filtering system in the base upon which the riprap has been placed. (See Figure 2 and Photographs 3 and 4.)

Effectiveness

A joint planting system is typically used with a previously installed conventional technology where riprap rock is already in place.

This solution will increase functionability and enable a streambank to become naturalized. Over time it will usually set in place a broad range of habitat enhancement opportunities, be aesthetically pleasing and have natural streambank appearance.

It also provides additional protection for high-torrent, steep-gradient stream systems. It is useful for systems carrying heavy suspended sediment load.

This method integrates well with conventional technology and assists in dissipating energy and encouraging deposition to occur along the stream banks, thus creating a more natural look and function.

Ecologically, joint planting provides shade over the water, thus modifying the temperature as well as providing cover for habitat.

Special Concerns and Difficulties

Joint planting requires that the existing rock be loosely dumped or that it be no more than two feet (2') deep. Because areas where riprap has been placed are very dry, plant survival is usually lower. Installation is usually somewhat more difficult due to working on the riprapped slope.

Figure 4-4 Joint Planting

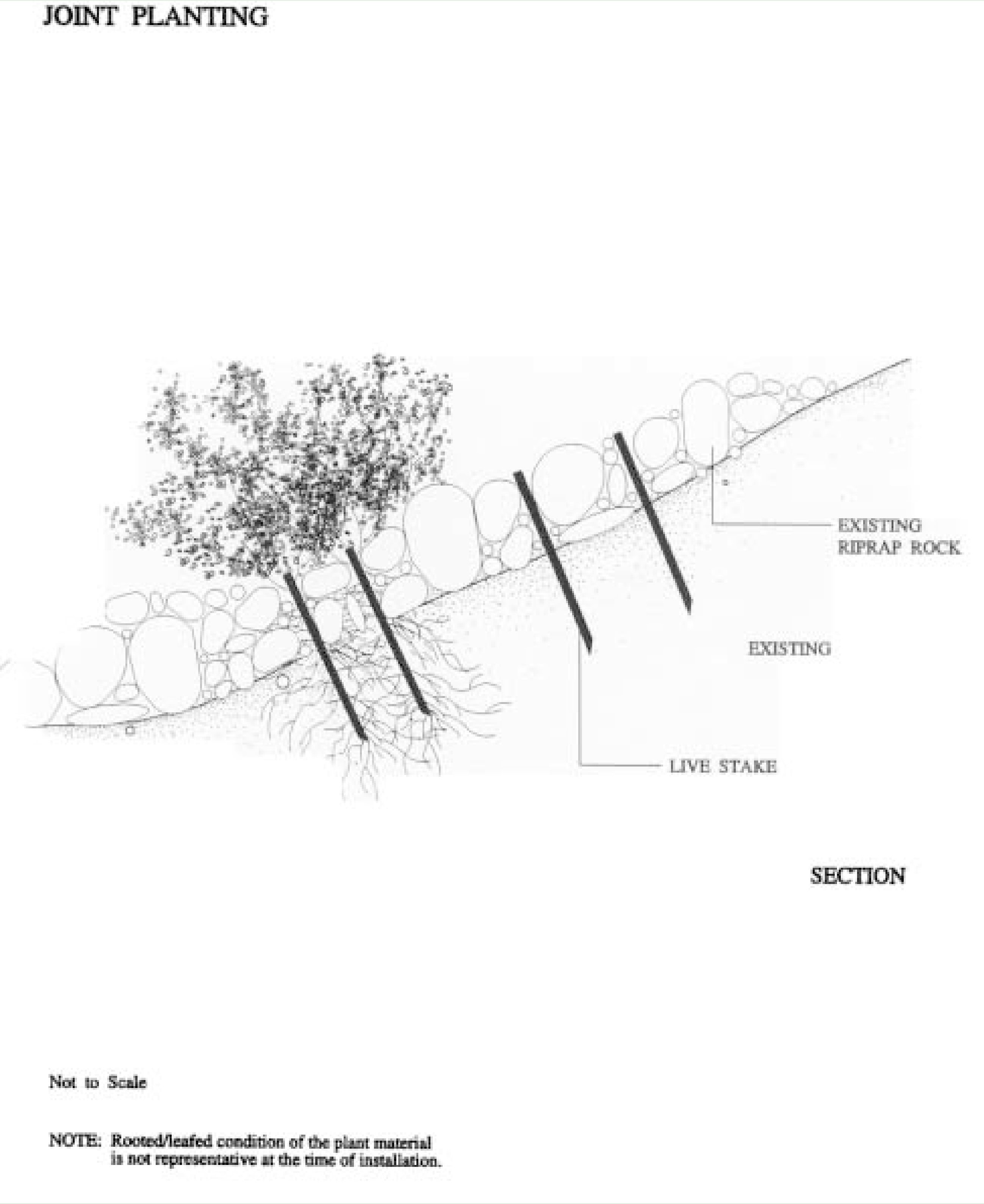
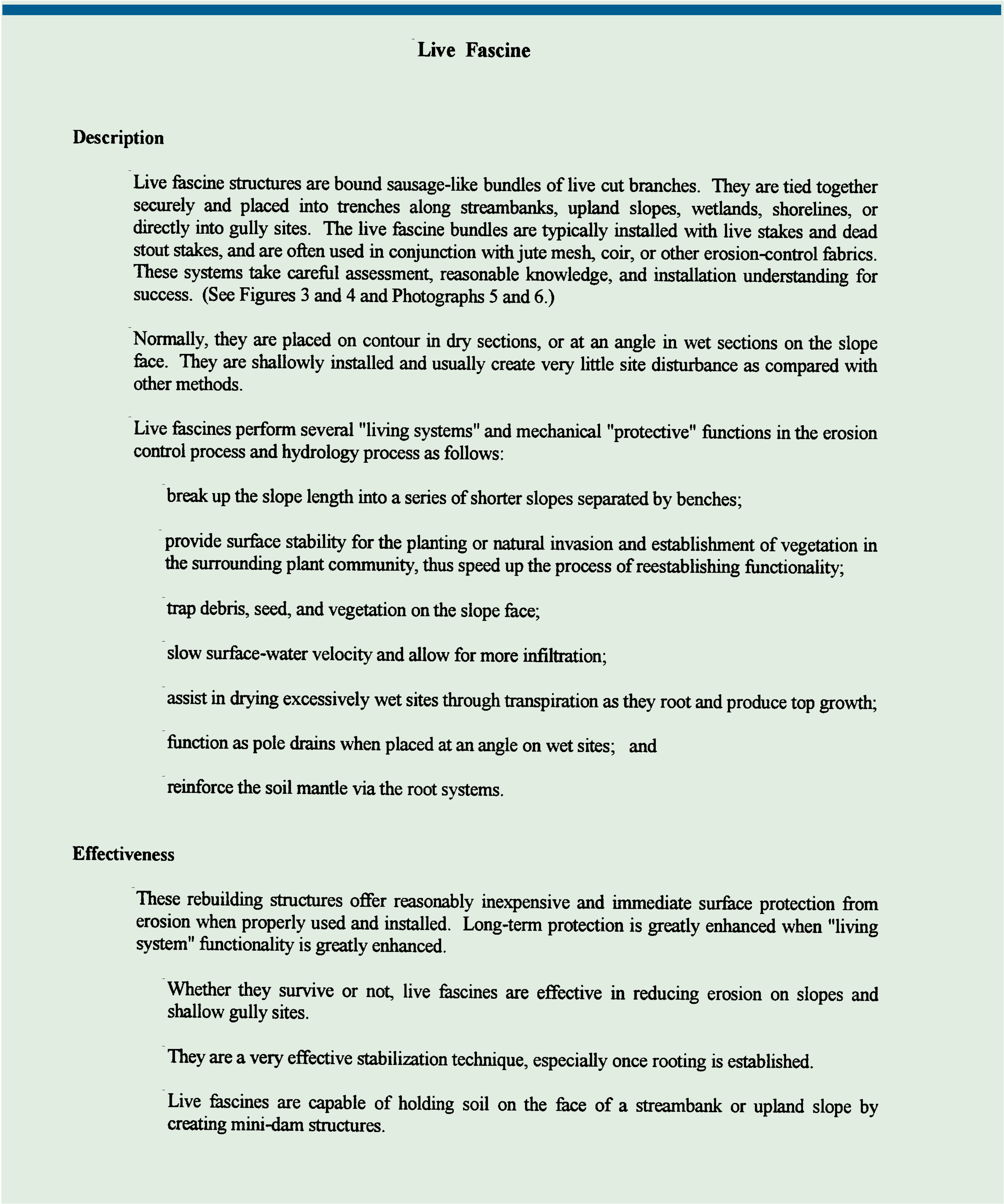


Figure 4-5 Joint Planting



Live Fascine

Description

Live fascine structures are bound sausage-like bundles of live cut branches. They are tied together securely and placed into trenches along streambanks, upland slopes, wetlands, shorelines, or directly into gully sites. The live fascine bundles are typically installed with live stakes and dead stout stakes, and are often used in conjunction with jute mesh, coir, or other erosion-control fabrics. These systems take careful assessment, reasonable knowledge, and installation understanding for success. (See Figures 3 and 4 and Photographs 5 and 6.)

Normally, they are placed on contour in dry sections, or at an angle in wet sections on the slope face. They are shallowly installed and usually create very little site disturbance as compared with other methods.

Live fascines perform several "living systems" and mechanical "protective" functions in the erosion control process and hydrology process as follows:

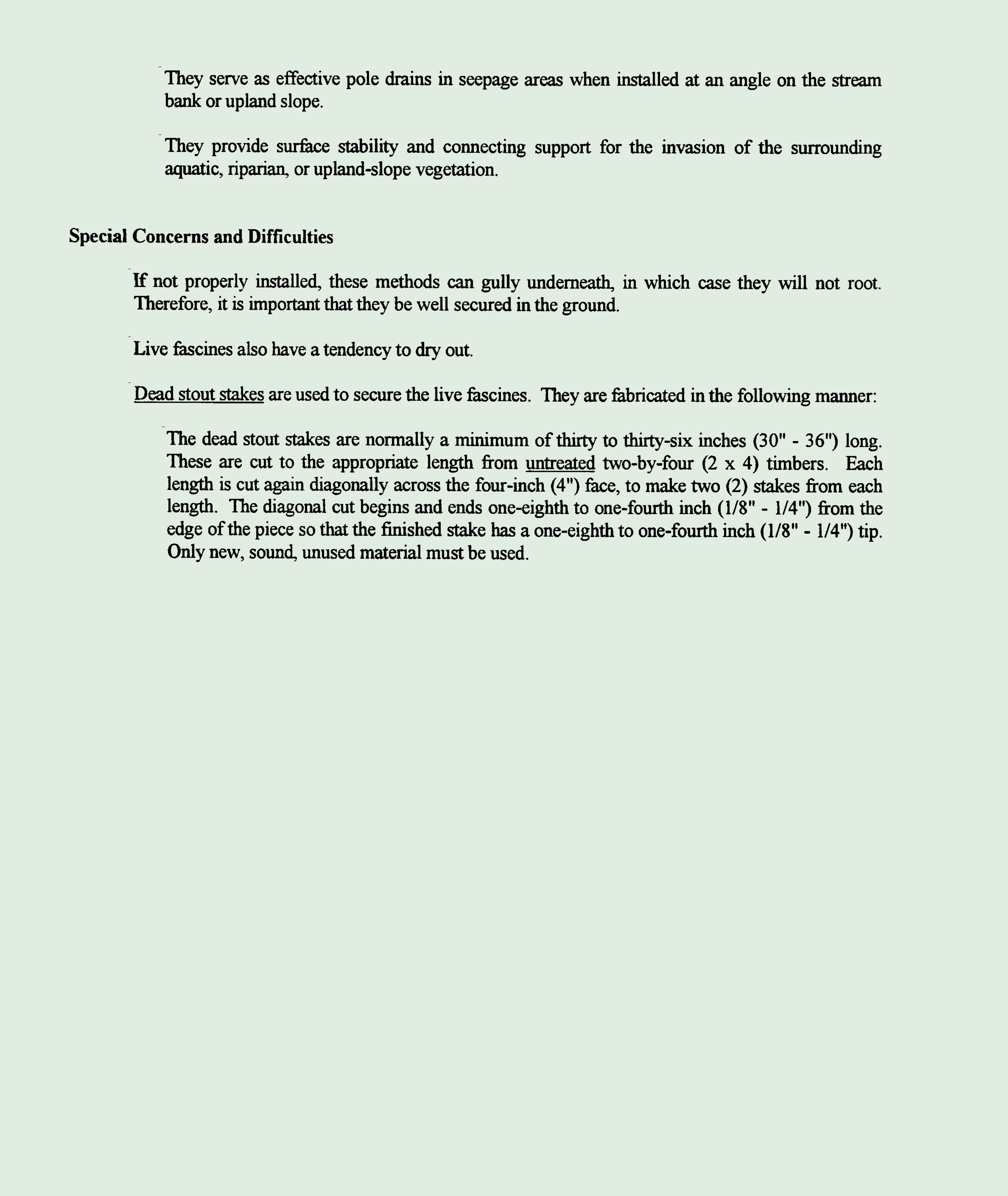
- break up the slope length into a series of shorter slopes separated by benches;
- provide surface stability for the planting or natural invasion and establishment of vegetation in the surrounding plant community, thus speed up the process of reestablishing functionality;
- trap debris, seed, and vegetation on the slope face;
- slow surface-water velocity and allow for more infiltration;
- assist in drying excessively wet sites through transpiration as they root and produce top growth;
- function as pole drains when placed at an angle on wet sites; and
- reinforce the soil mantle via the root systems.

Effectiveness

These rebuilding structures offer reasonably inexpensive and immediate surface protection from erosion when properly used and installed. Long-term protection is greatly enhanced when "living system" functionality is greatly enhanced.

- Whether they survive or not, live fascines are effective in reducing erosion on slopes and shallow gully sites.
- They are a very effective stabilization technique, especially once rooting is established.
- Live fascines are capable of holding soil on the face of a streambank or upland slope by creating mini-dam structures.

Figure 4-6 - Live Fascine



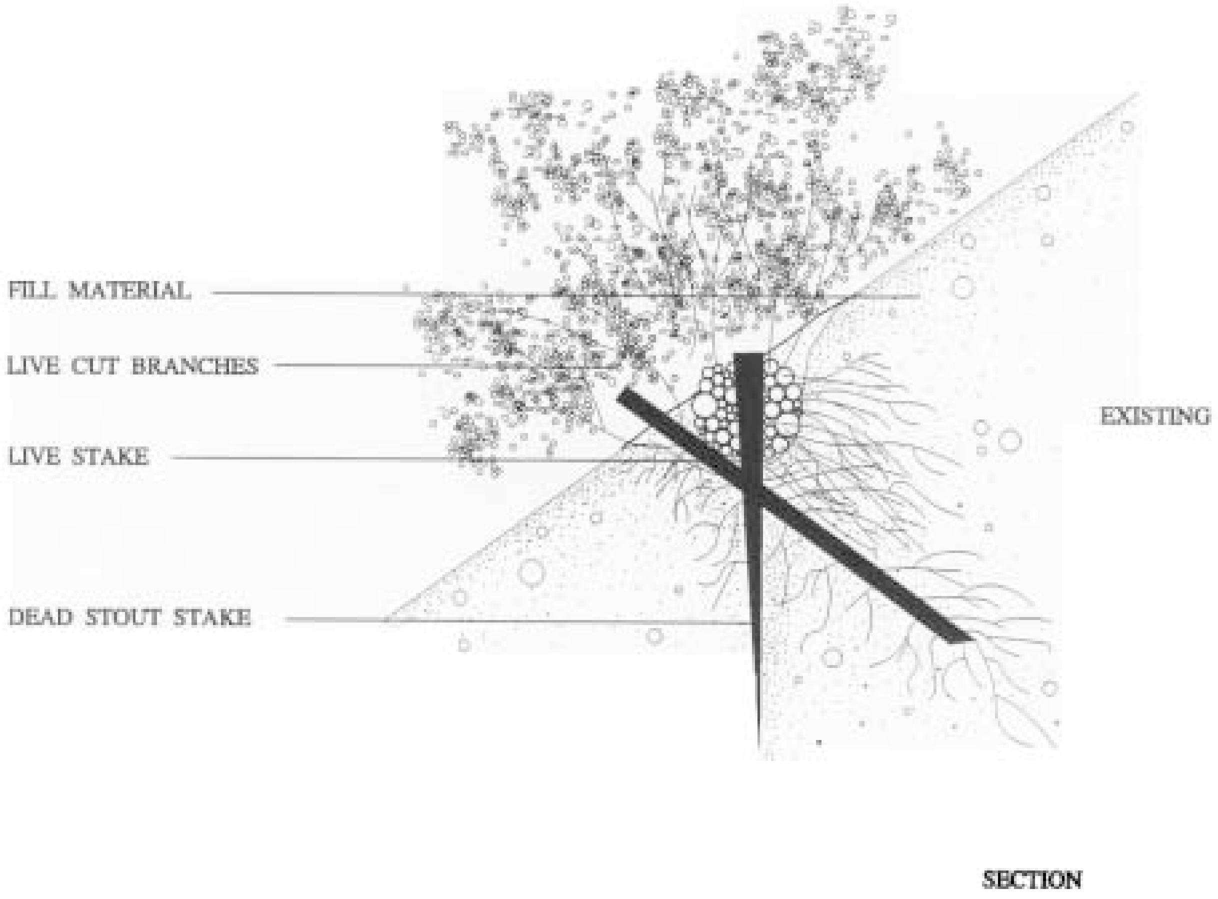
- They serve as effective pole drains in seepage areas when installed at an angle on the stream bank or upland slope.
- They provide surface stability and connecting support for the invasion of the surrounding aquatic, riparian, or upland-slope vegetation.

Special Concerns and Difficulties

- If not properly installed, these methods can gully underneath, in which case they will not root. Therefore, it is important that they be well secured in the ground.
- Live fascines also have a tendency to dry out.
- Dead stout stakes are used to secure the live fascines. They are fabricated in the following manner:
  - The dead stout stakes are normally a minimum of thirty to thirty-six inches (30" - 36") long. These are cut to the appropriate length from untreated two-by-four (2 x 4) timbers. Each length is cut again diagonally across the four-inch (4") face, to make two (2) stakes from each length. The diagonal cut begins and ends one-eighth to one-fourth inch (1/8" - 1/4") from the edge of the piece so that the finished stake has a one-eighth to one-fourth inch (1/8" - 1/4") tip. Only new, sound, unused material must be used.

Figure 4-7 Live Fascine

LIVE FASCINE



Not to Scale

NOTE: Rooted/leafed condition of the plant material
is not representative at the time of installation.

Figure 4-8 Live Fascine Drawing

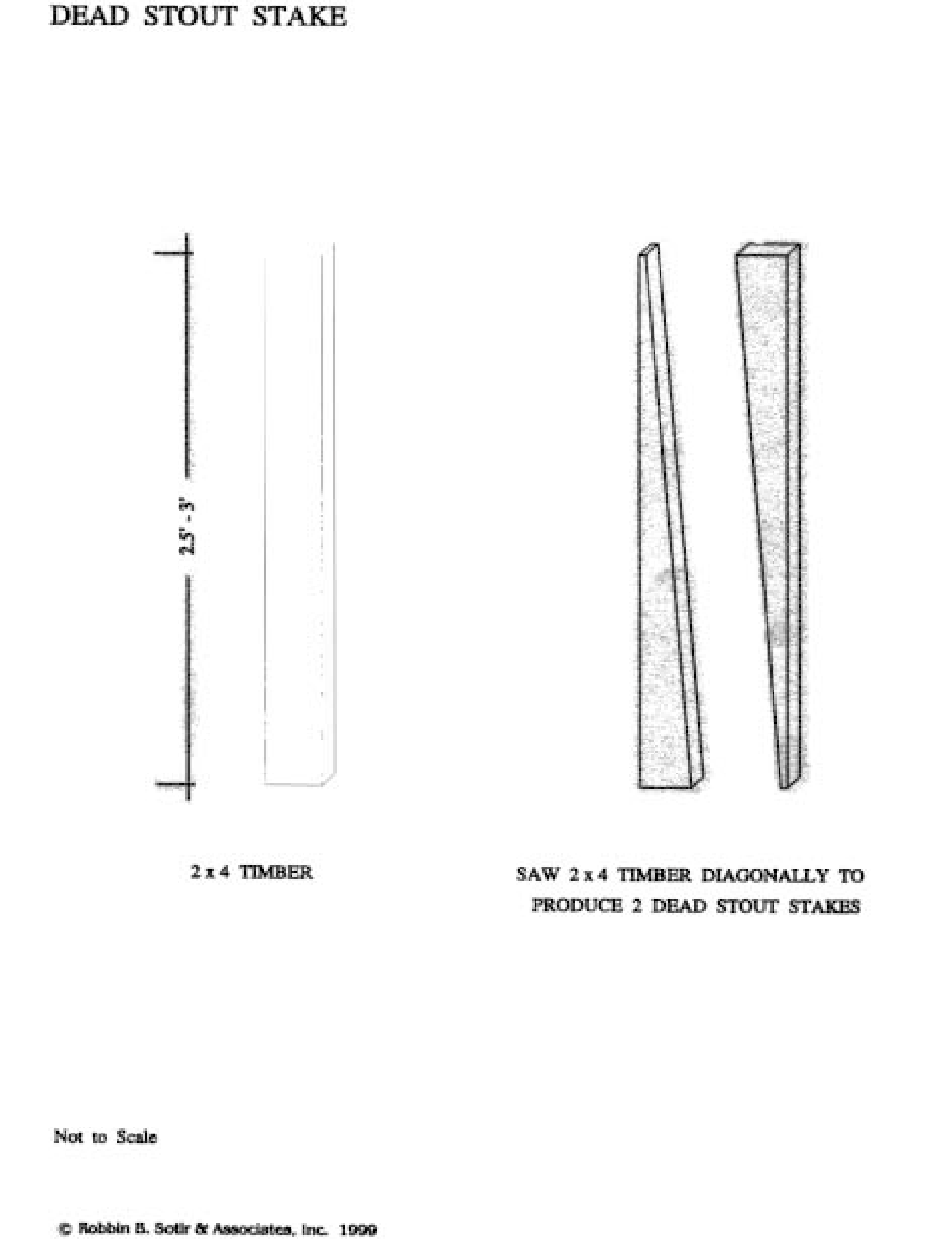
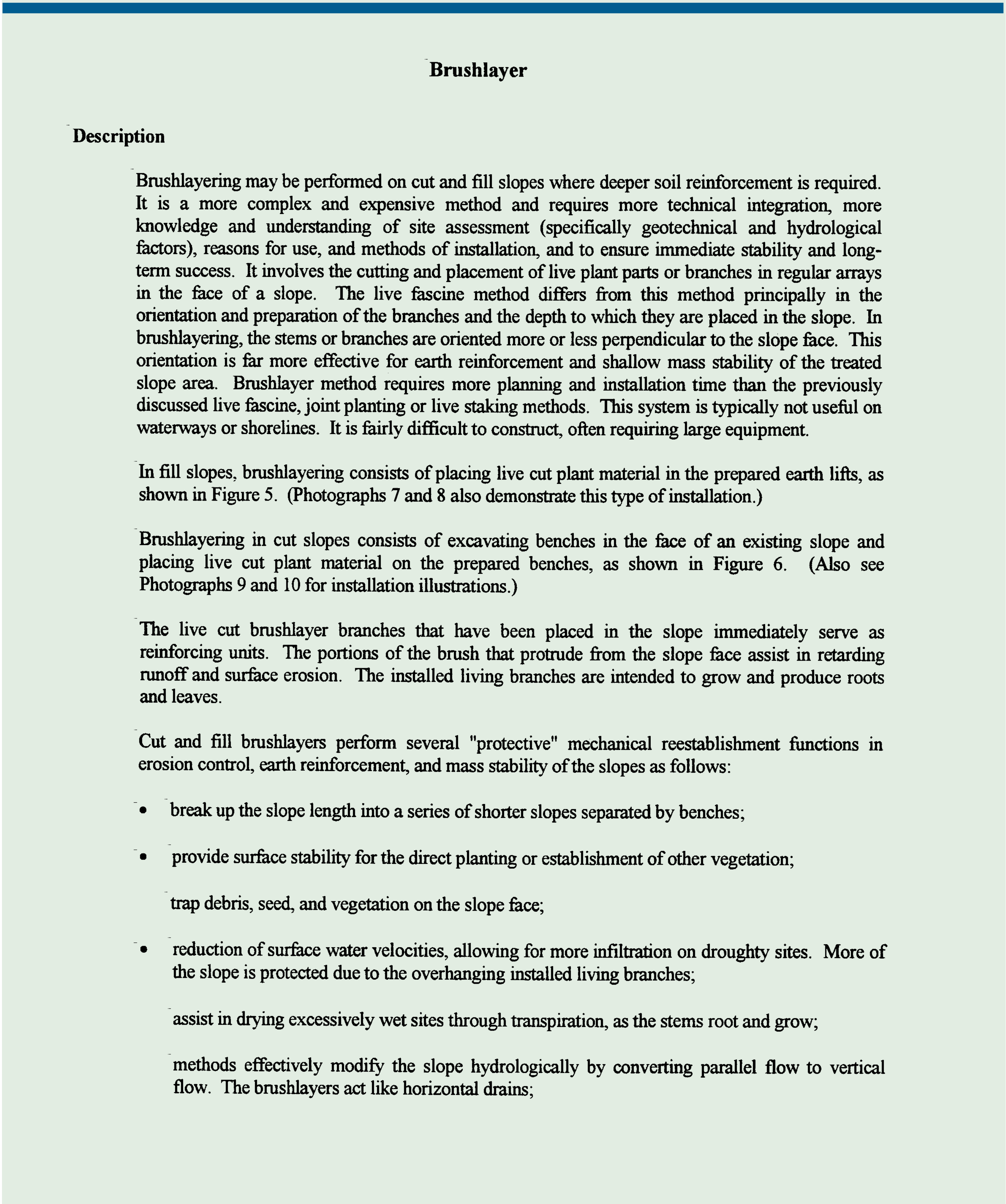


Figure 4-9 Dead Stout Stake



Brushlayer

Description

Brushlayering may be performed on cut and fill slopes where deeper soil reinforcement is required. It is a more complex and expensive method and requires more technical integration, more knowledge and understanding of site assessment (specifically geotechnical and hydrological factors), reasons for use, and methods of installation, and to ensure immediate stability and long-term success. It involves the cutting and placement of live plant parts or branches in regular arrays in the face of a slope. The live fascine method differs from this method principally in the orientation and preparation of the branches and the depth to which they are placed in the slope. In brushlayering, the stems or branches are oriented more or less perpendicular to the slope face. This orientation is far more effective for earth reinforcement and shallow mass stability of the treated slope area. Brushlayer method requires more planning and installation time than the previously discussed live fascine, joint planting or live staking methods. This system is typically not useful on waterways or shorelines. It is fairly difficult to construct, often requiring large equipment.

In fill slopes, brushlayering consists of placing live cut plant material in the prepared earth lifts, as shown in Figure 5. (Photographs 7 and 8 also demonstrate this type of installation.)

Brushlayering in cut slopes consists of excavating benches in the face of an existing slope and placing live cut plant material on the prepared benches, as shown in Figure 6. (Also see Photographs 9 and 10 for installation illustrations.)

The live cut brushlayer branches that have been placed in the slope immediately serve as reinforcing units. The portions of the brush that protrude from the slope face assist in retarding runoff and surface erosion. The installed living branches are intended to grow and produce roots and leaves.

Cut and fill brushlayers perform several "protective" mechanical reestablishment functions in erosion control, earth reinforcement, and mass stability of the slopes as follows:

- break up the slope length into a series of shorter slopes separated by benches;

- provide surface stability for the direct planting or establishment of other vegetation;

trap debris, seed, and vegetation on the slope face;

- reduction of surface water velocities, allowing for more infiltration on droughty sites. More of the slope is protected due to the overhanging installed living branches;

assist in drying excessively wet sites through transpiration, as the stems root and grow;

methods effectively modify the slope hydrologically by converting parallel flow to vertical flow. The brushlayers act like horizontal drains;

Figure 4-10 Brush Layer

- assist in serving to promote seed germination, i.e., natural invasion, of the surrounding plant community;

- offers immediate soil reinforcement and shallow mass stability in the slope via the branch stems;

- reinforces the soil mantle via the development of the root systems (or fibrous inclusions). Such secondary development is critical to the long-term success of the method. It reduces the possibility of soil displacement.

Effectiveness

Brushlayer installations produce immediately reinforced slope.

Brushlayers serve to create rapid revegetation on upland slope sites, directly from the installed methods and through natural invasion.

Habitat restoration is enhanced for wildlife corridors, food sources, nesting, and protection.

Special Concerns and Difficulties

These methods cannot tolerate water running through the installed brushlayers, as gullies occur quickly. It is important that no over-the-slope drainage occurs.

Figure 4-11 Brush Layer

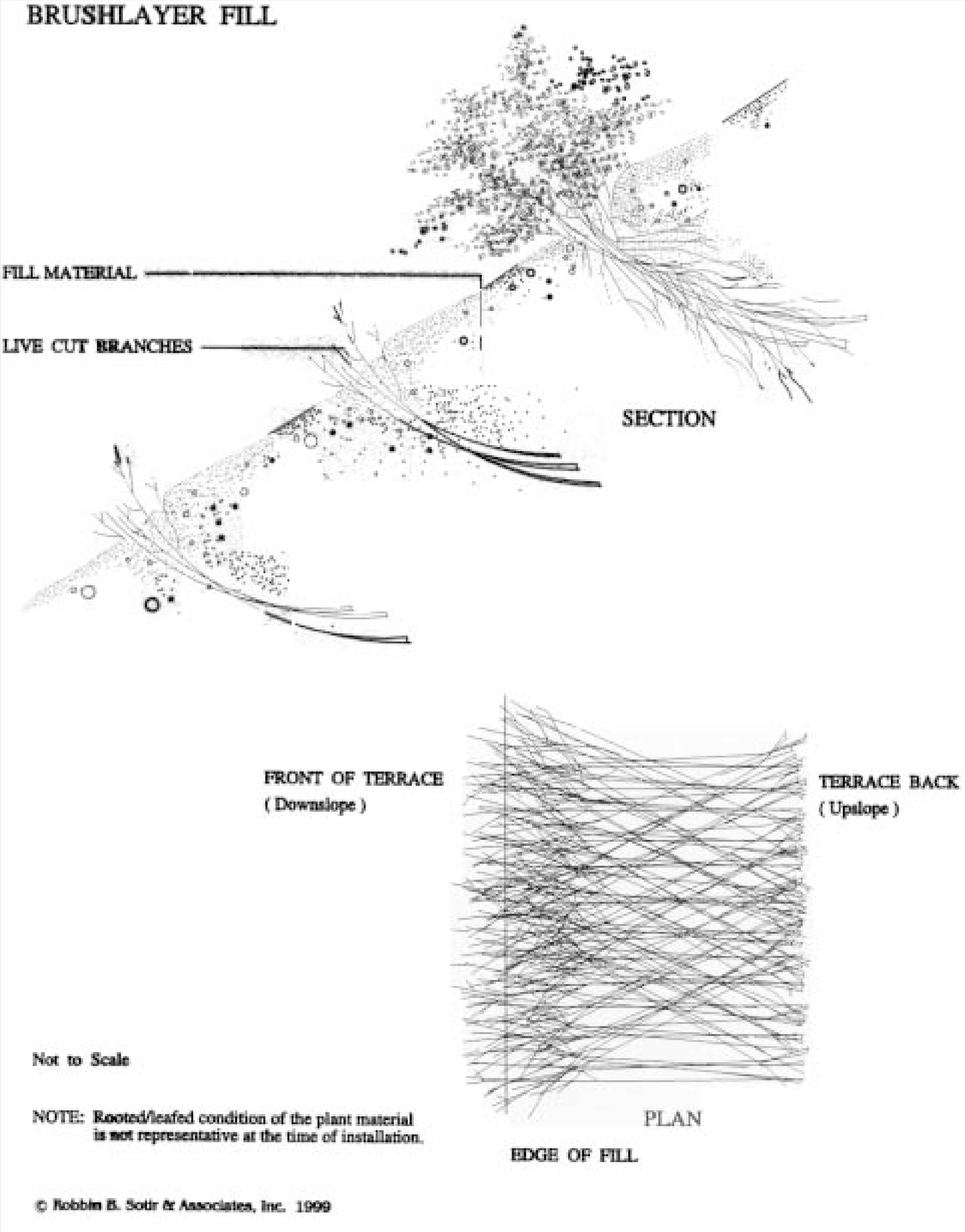
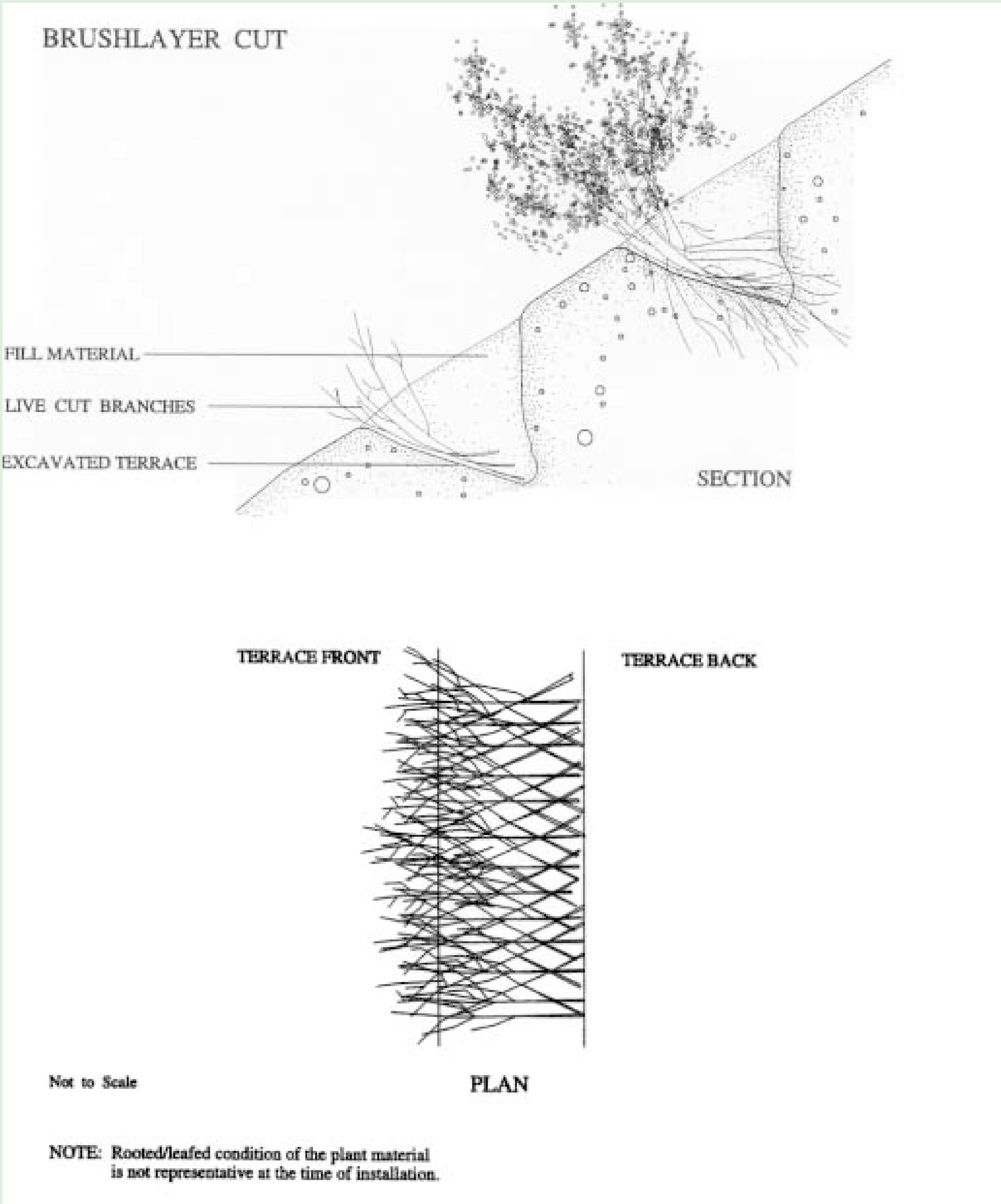


Figure 4-12 Brush Layer Fill Drawing



NOTE: Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 4-13 - Brush Layer Cut

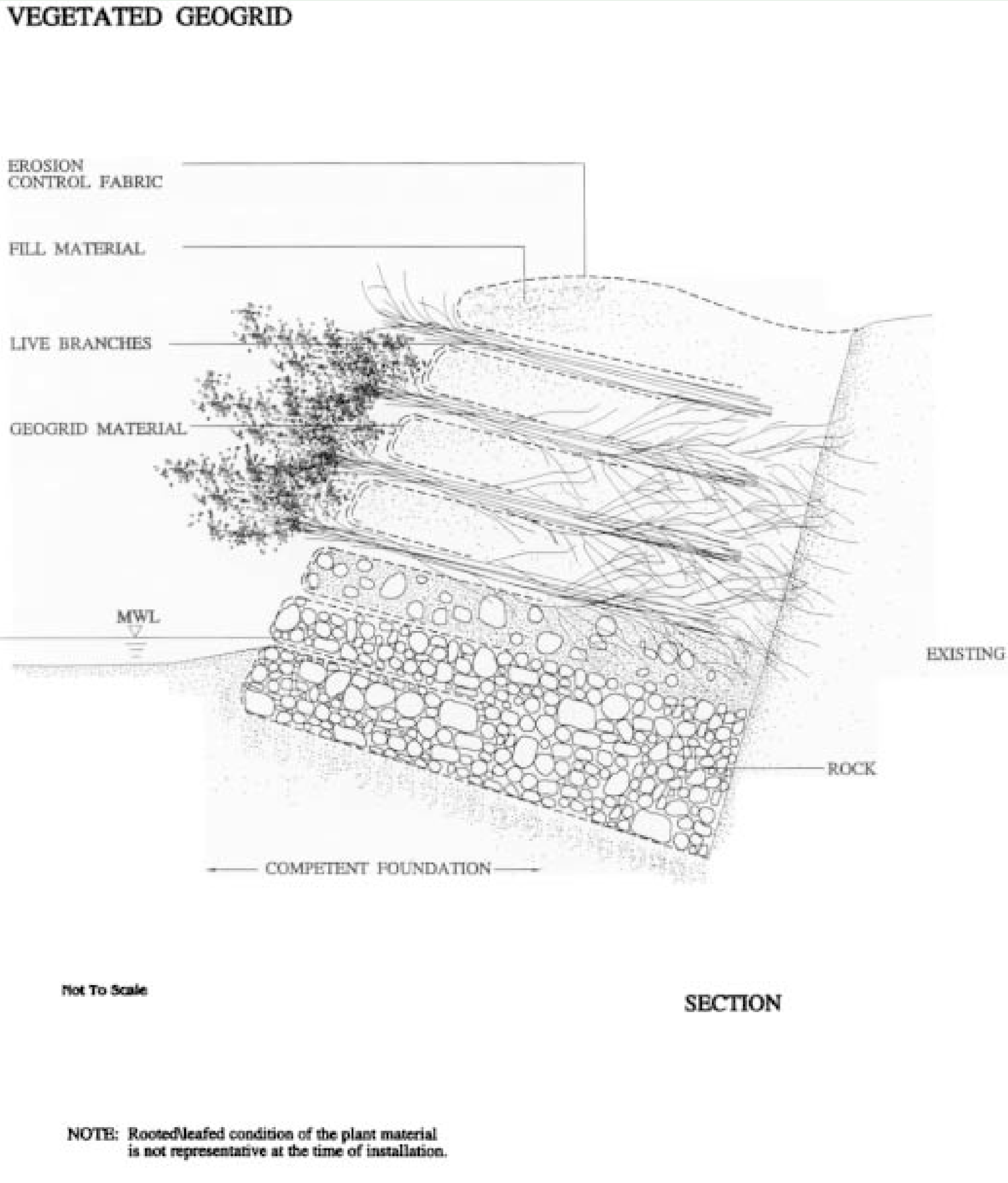


Figure 4-14 - Vegetated Geogrid

further reinforce the soil mantle via the development of the root systems (or fibrous inclusions). Such secondary development is critical to the long-term success and functionality of the system. It reduces the possibility of soil displacement.

Effectiveness

Vegetated geogrid installations produce an immediate reinforced slope.

Vegetated geogrids serve to create rapid revegetation on upland slope sites, directly from the installed systems and through natural invasion.

Habitat restoration is enhanced for wildlife corridors, food sources, nesting and protection.

Useful for overhanging cover for aquatic habitat.

Offers water quality improvement.

Special Concerns and Difficulties

These methods are excellent for stabilizing very steep slopes, but always must be accomplished by using an interdisciplinary team.

Figure 4-15 - Vegetated Geogrid, Cont'd

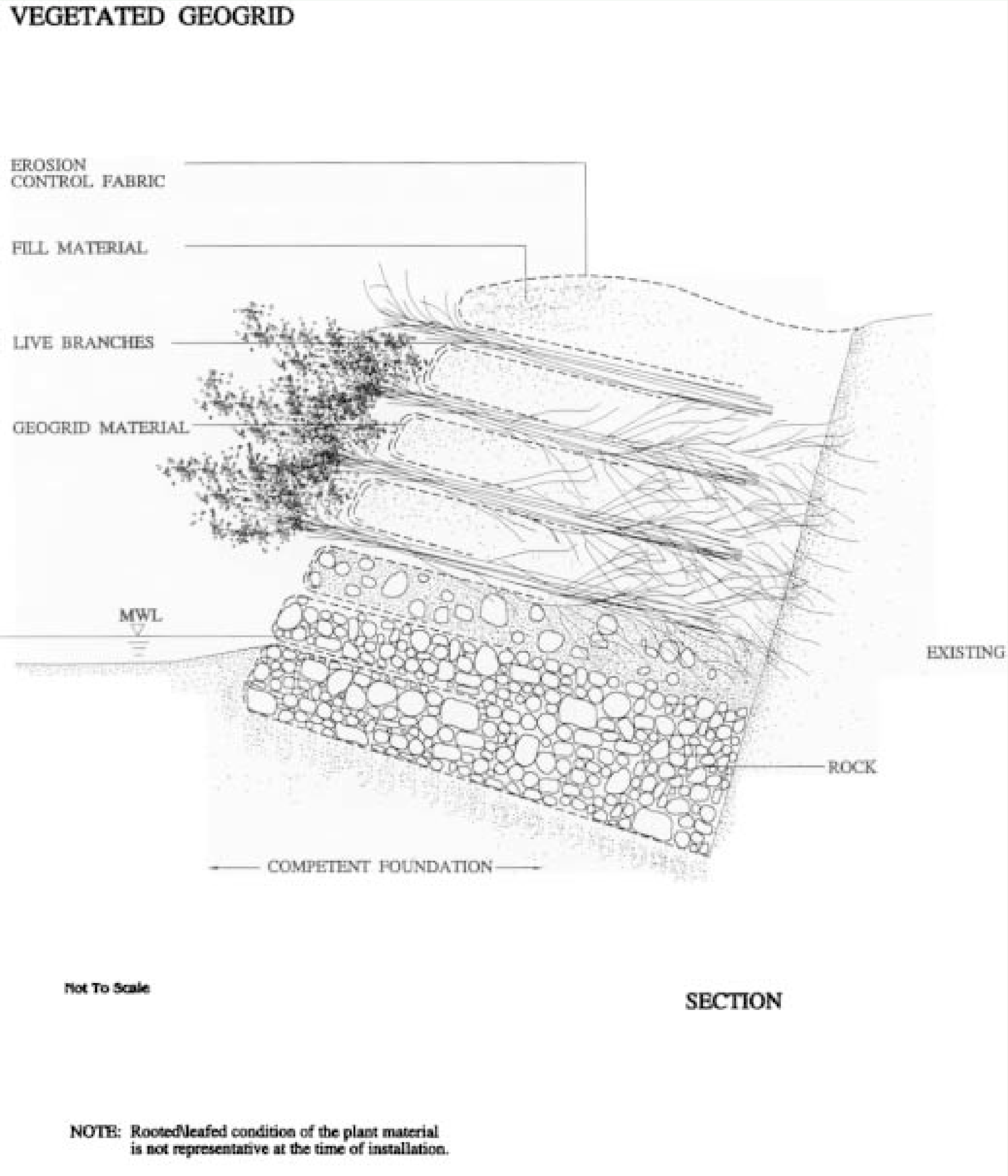
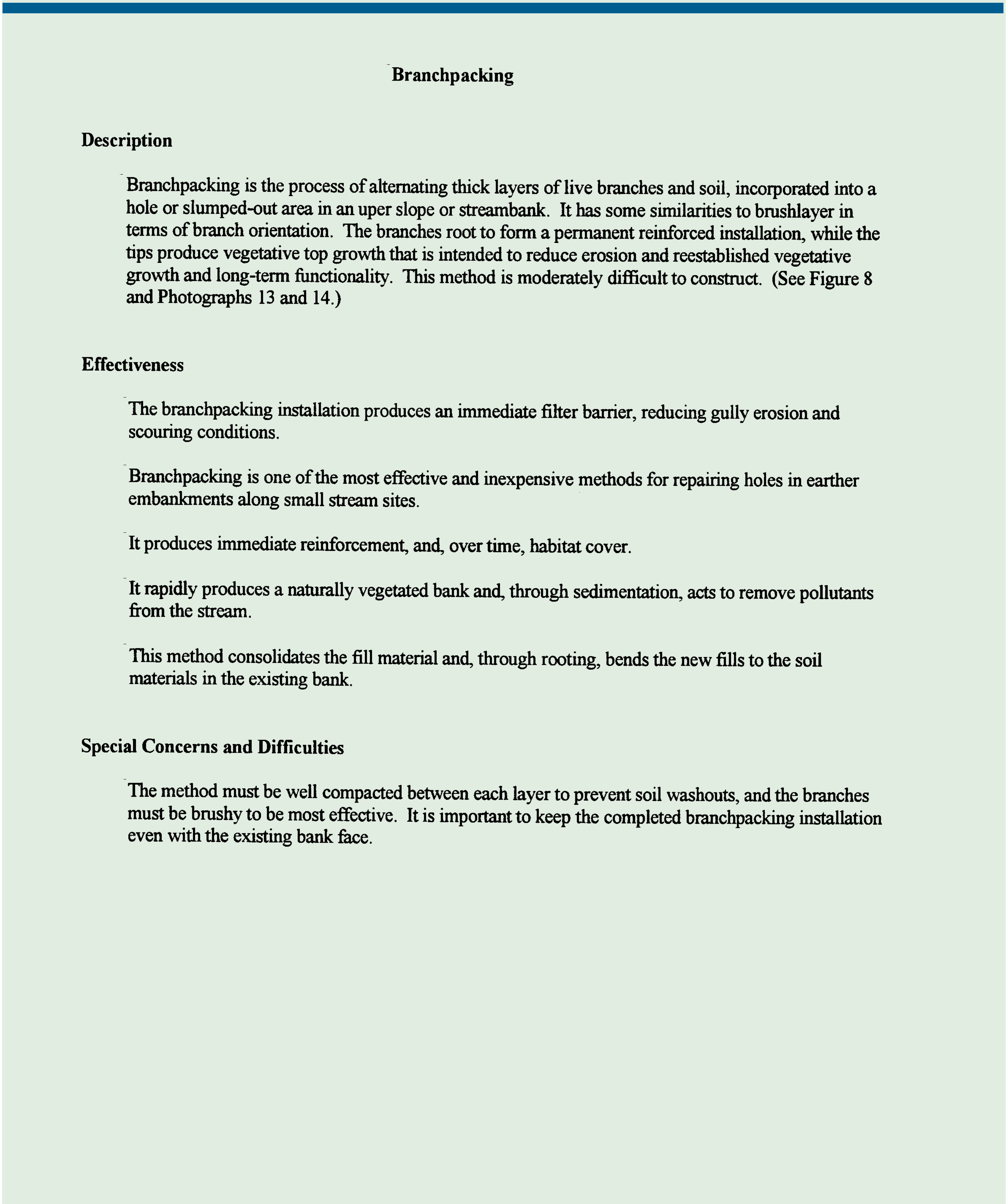


Figure 4-16 Vegetated Geogrid Drawing



Branchpacking

Description

Branchpacking is the process of alternating thick layers of live branches and soil, incorporated into a hole or slumped-out area in an uper slope or streambank. It has some similarities to brushlayer in terms of branch orientation. The branches root to form a permanent reinforced installation, while the tips produce vegetative top growth that is intended to reduce erosion and reestablished vegetative growth and long-term functionality. This method is moderately difficult to construct. (See Figure 8 and Photographs 13 and 14.)

Effectiveness

The branchpacking installation produces an immediate filter barrier, reducing gully erosion and scouring conditions.

Branchpacking is one of the most effective and inexpensive methods for repairing holes in earther embankments along small stream sites.

It produces immediate reinforcement, and, over time, habitat cover.

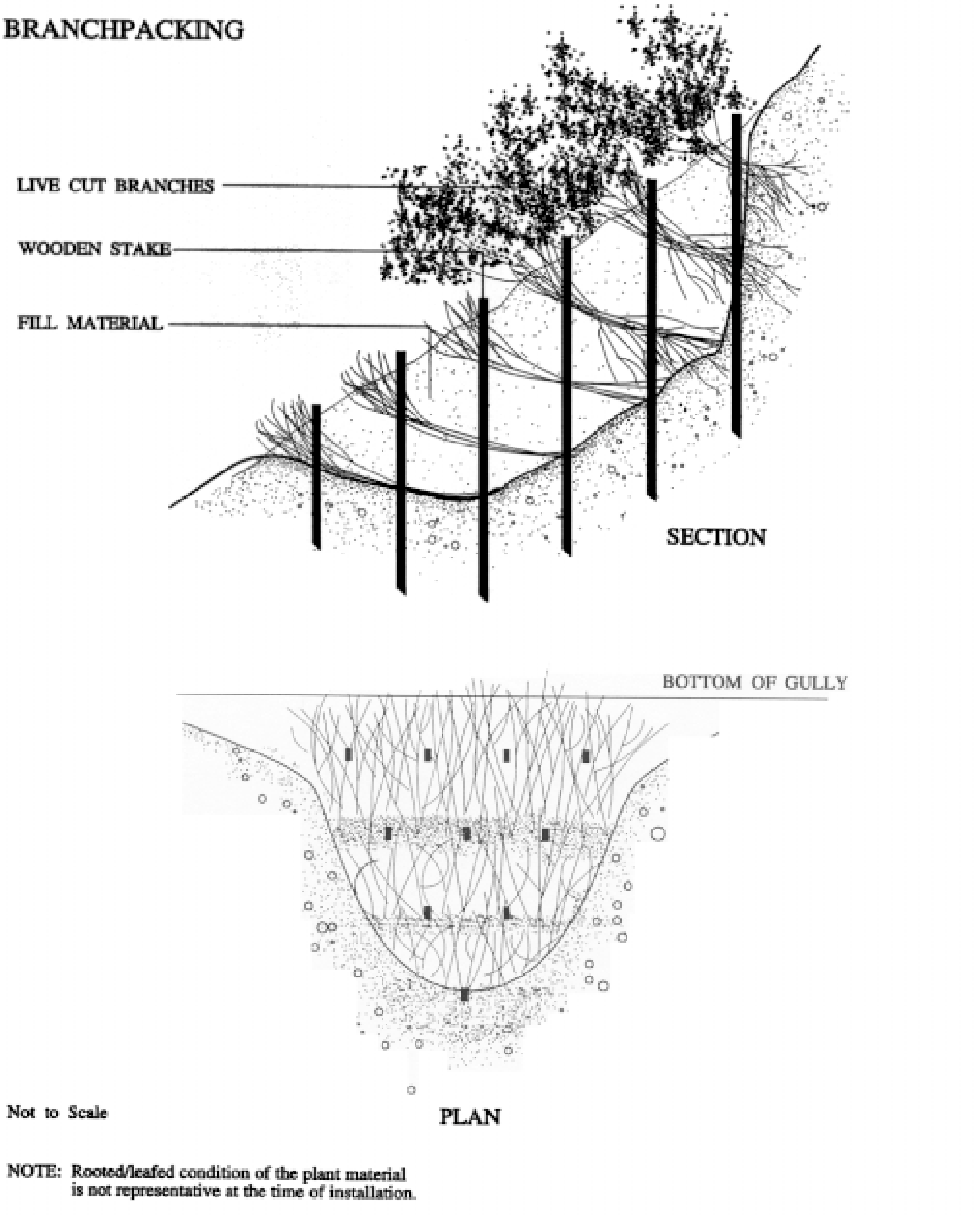
It rapidly produces a naturally vegetated bank and, through sedimentation, acts to remove pollutants from the stream.

This method consolidates the fill material and, through rooting, bends the new fills to the soil materials in the existing bank.

Special Concerns and Difficulties

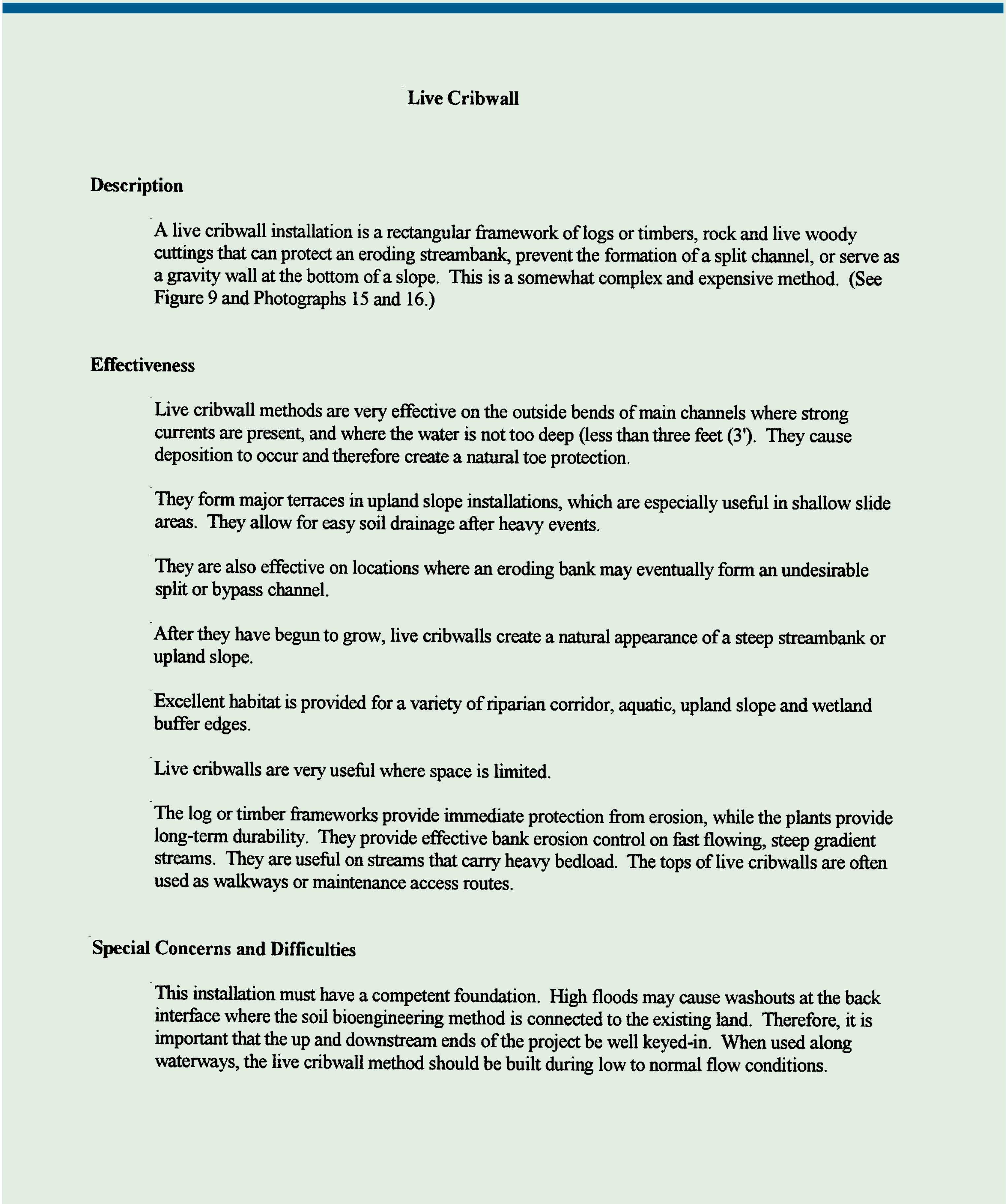
The method must be well compacted between each layer to prevent soil washouts, and the branches must be brushy to be most effective. It is important to keep the completed branchpacking installation even with the existing bank face.

Figure 4-17 Branchpacking



NOTE: Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 4-18 - Branchpacking Drawing



Live Cribwall

Description

A live cribwall installation is a rectangular framework of logs or timbers, rock and live woody cuttings that can protect an eroding streambank, prevent the formation of a split channel, or serve as a gravity wall at the bottom of a slope. This is a somewhat complex and expensive method. (See Figure 9 and Photographs 15 and 16.)

Effectiveness

Live cribwall methods are very effective on the outside bends of main channels where strong currents are present, and where the water is not too deep (less than three feet (3'). They cause deposition to occur and therefore create a natural toe protection.

They form major terraces in upland slope installations, which are especially useful in shallow slide areas. They allow for easy soil drainage after heavy events.

They are also effective on locations where an eroding bank may eventually form an undesirable split or bypass channel.

After they have begun to grow, live cribwalls create a natural appearance of a steep streambank or upland slope.

Excellent habitat is provided for a variety of riparian corridor, aquatic, upland slope and wetland buffer edges.

Live cribwalls are very useful where space is limited.

The log or timber frameworks provide immediate protection from erosion, while the plants provide long-term durability. They provide effective bank erosion control on fast flowing, steep gradient streams. They are useful on streams that carry heavy bedload. The tops of live cribwalls are often used as walkways or maintenance access routes.

Special Concerns and Difficulties

This installation must have a competent foundation. High floods may cause washouts at the back interface where the soil bioengineering method is connected to the existing land. Therefore, it is important that the up and downstream ends of the project be well keyed-in. When used along waterways, the live cribwall method should be built during low to normal flow conditions.

Figure 4-19 - Live Cribwall

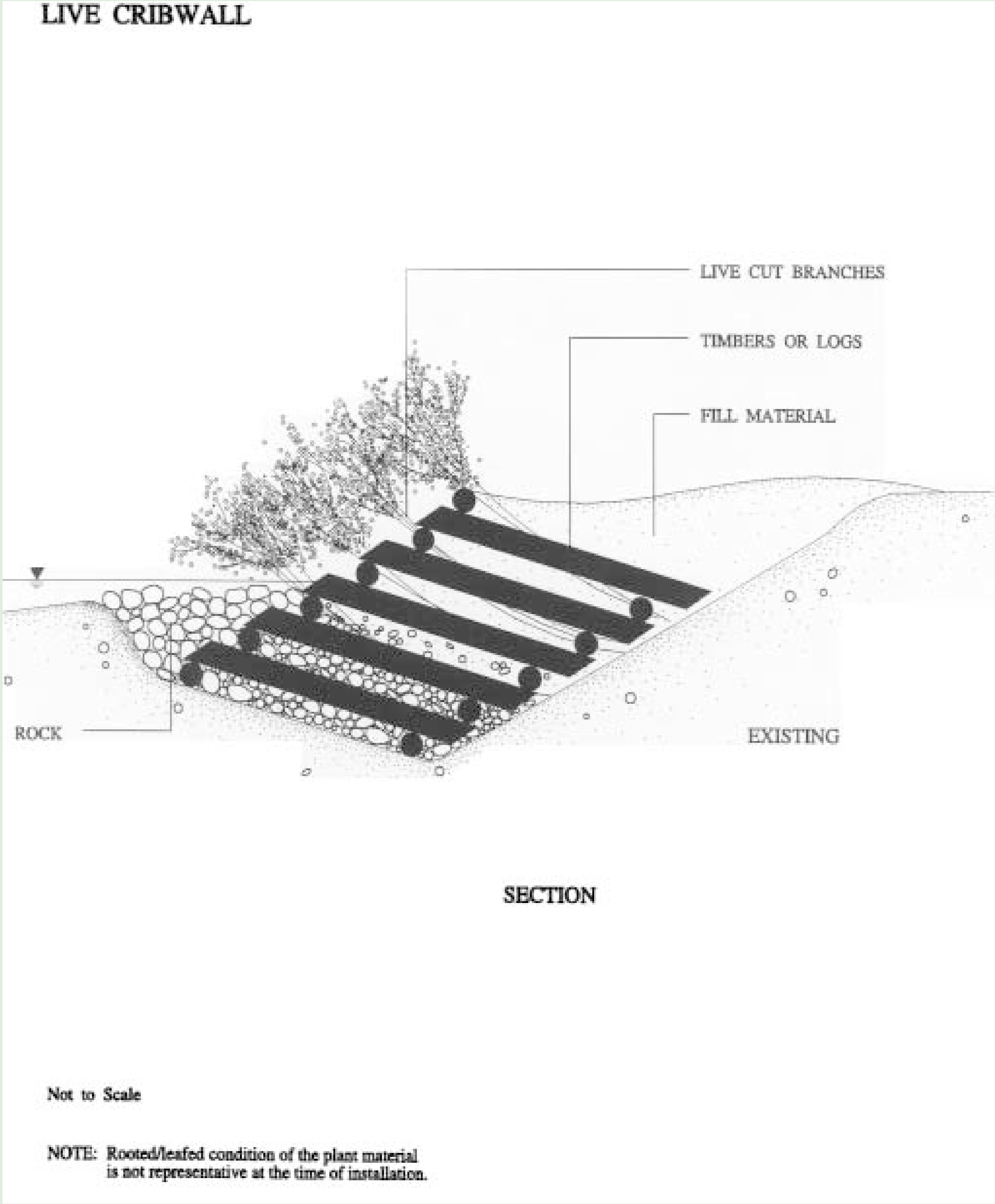
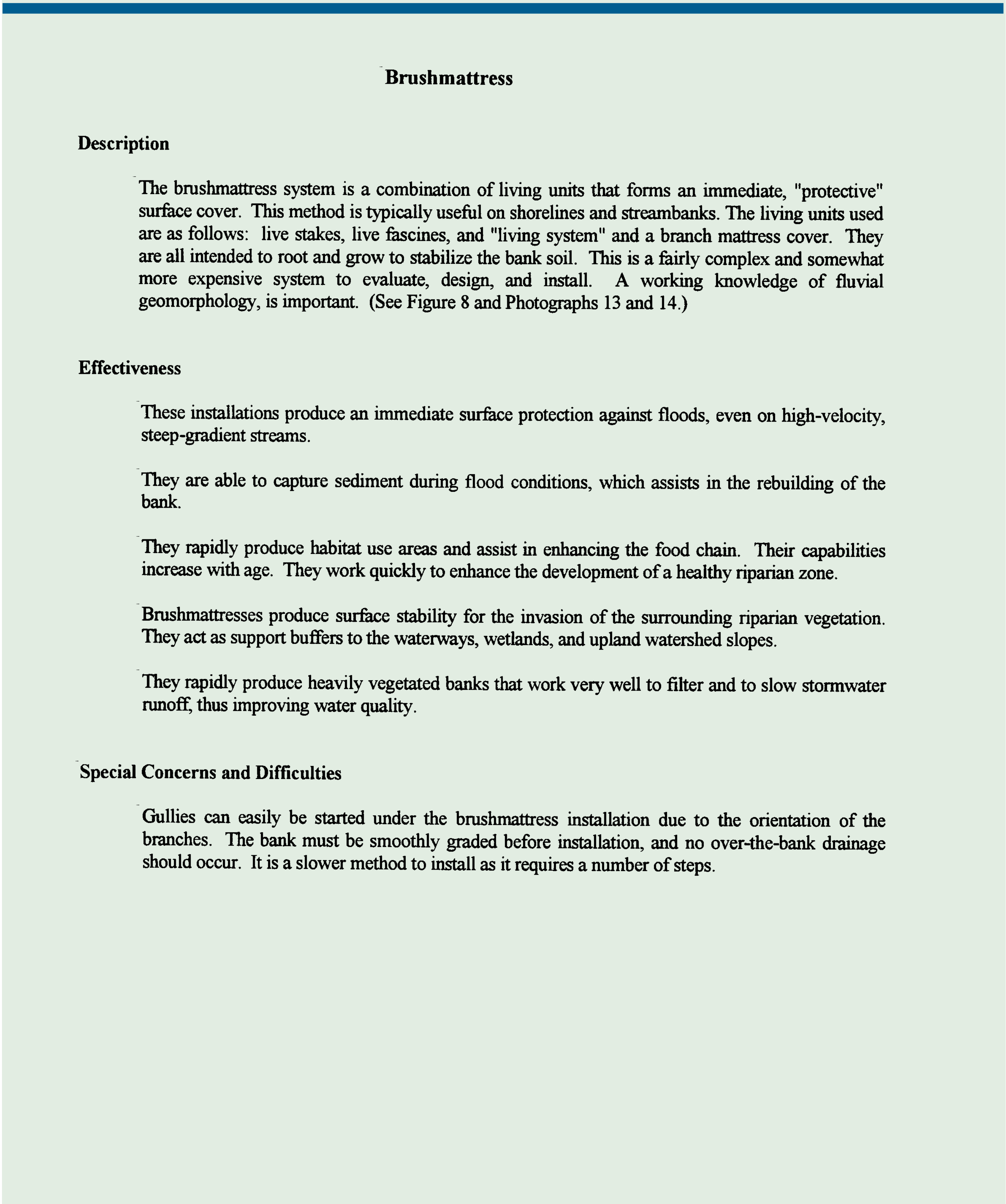


Figure 4-20 - Live Cribwall Drawing



Brushmattress

Description

The brushmattress system is a combination of living units that forms an immediate, "protective" surface cover. This method is typically useful on shorelines and streambanks. The living units used are as follows: live stakes, live fascines, and "living system" and a branch mattress cover. They are all intended to root and grow to stabilize the bank soil. This is a fairly complex and somewhat more expensive system to evaluate, design, and install. A working knowledge of fluvial geomorphology, is important. (See Figure 8 and Photographs 13 and 14.)

Effectiveness

These installations produce an immediate surface protection against floods, even on high-velocity, steep-gradient streams.

They are able to capture sediment during flood conditions, which assists in the rebuilding of the bank.

They rapidly produce habitat use areas and assist in enhancing the food chain. Their capabilities increase with age. They work quickly to enhance the development of a healthy riparian zone.

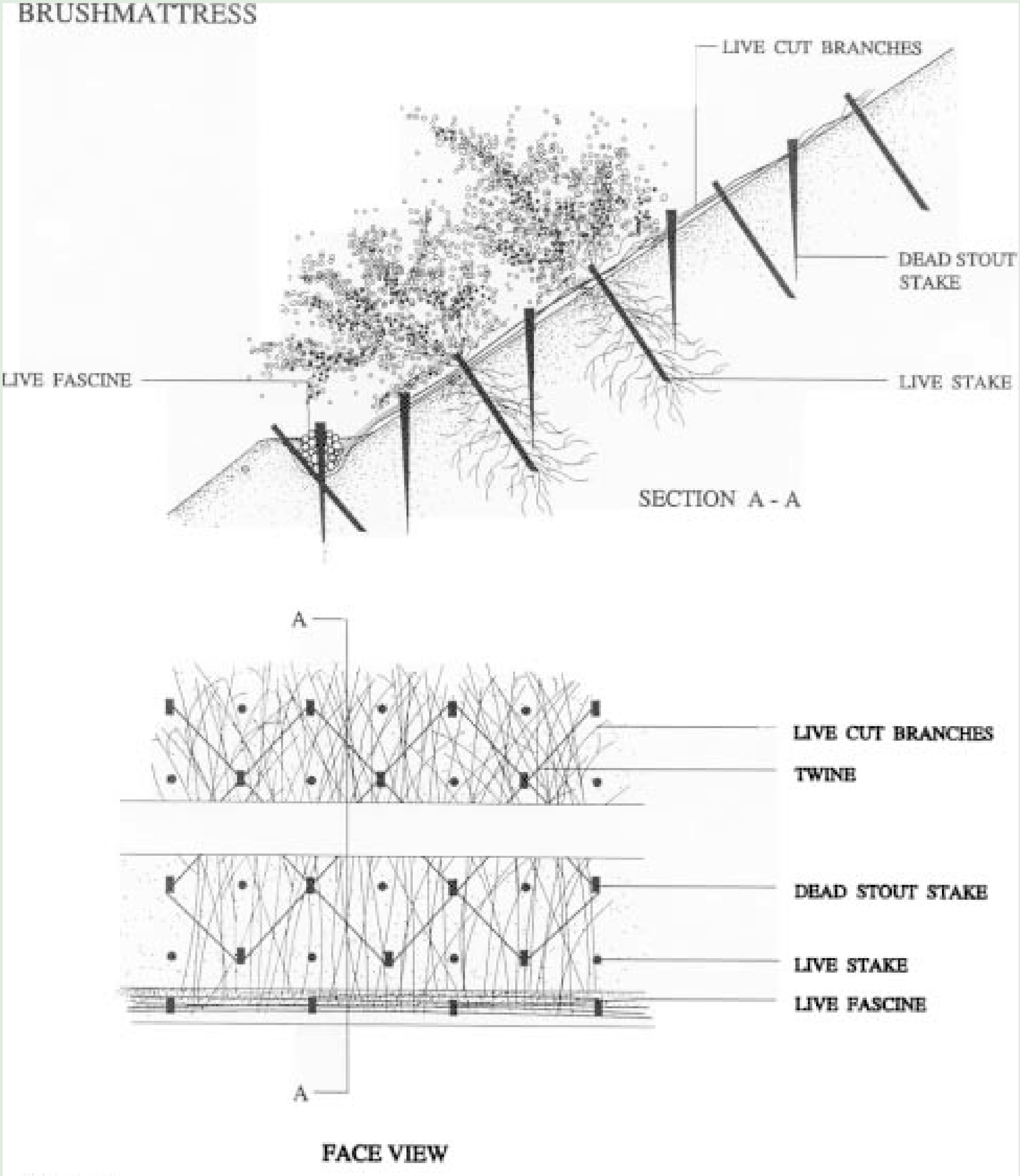
Brushmattresses produce surface stability for the invasion of the surrounding riparian vegetation. They act as support buffers to the waterways, wetlands, and upland watershed slopes.

They rapidly produce heavily vegetated banks that work very well to filter and to slow stormwater runoff, thus improving water quality.

Special Concerns and Difficulties

Gullies can easily be started under the brushmattress installation due to the orientation of the branches. The bank must be smoothly graded before installation, and no over-the-bank drainage should occur. It is a slower method to install as it requires a number of steps.

Figure 4-21 - Brushmattress



Not to Scale

NOTE: Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 4-22 - Brushmattress Drawing

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