
CHAPTER 17 BIOENGINEERED CHANNEL

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17.1 INTRODUCTION

One of the tools available for protecting stream banks and channels in an environmentally sensitive area from the negative consequences of bank erosion and sloughing is the application of bioengineering techniques. Bioengineering is the combination of biological, mechanical, and ecological concepts to control channel degradations and bank erosion through the use of vegetation or a combination of vegetation and construction materials.

17.2 RIPARIAN MANAGEMENT

Riparian vegetation plays an important role in the maintenance of stable watercourse morphology as well as in the preservation of ecological values such as terrestrial and avian wildlife habitat. For these reasons the preservation riparian zones along watercourses needs to be a part of stormwater management planning

17.2.1 Approach

The principal approaches to managing riparian and floodplain vegetation are retention and replanting with appropriate native species that are indigenous to the area. In practical terms a riparian zone at either side of the channel should be reserved for retention of existing vegetation or replanting when it is disturbed. The width of this zone is influenced by a number of factors including channel width, the nature of existing development, the importance of local flora and fauna bio-diversity and the need to maintain wildlife corridors. The nature and size of riparian reserves should be determined early during the planning process.

17.2.2 Objectives

a) *Vegetation Retention*

The most important principle is to maintain existing indigenous riparian vegetation where possible.

b) *Vegetation Replacement*

Restoration of riparian zones can generally be undertaken by planting indigenous vegetation. If indigenous vegetation is scarce or limited in numbers, appropriate species can be imported from nearby catchments with similar climatic and soil conditions. In some circumstances, changed conditions such as increased wind exposure, temperature fluctuations (due to removal of adjacent vegetation) and loss of topsoil may preclude the use of indigenous vegetation. In these cases the use of non-invasive and easy to maintain species from other Malaysian catchments may be necessary at least in the initial stages. A diversity of species is recommended to replicate the pre-development condition of the riparian zone and to encourage terrestrial and aquatic bio-diversity.

17.3 RIPARIAN ZONES

The riparian zone (Figure 17.1) is the area of land (including floodplains) adjacent to a watercourse. Riparian vegetation can include emergent aquatic and semi-aquatic plants, terrestrial over storey (canopy) and terrestrial under storey (cover). The riparian zones contribute to the ecological value and geomorphologic stability of a watercourse through a number of processes. These values and processes are discussed in the following sections.

17.3.1 Bank Stability and Channel Integrity

Vegetation can exert a significant control over fluvial processes through two main mechanisms: resistance to flow (through the vegetation increasing roughness) and bank strength (through the binding of soil by root systems). Bank vegetation disturbances can include unrestricted access by people and animals. Human disturbance in riparian zone includes removal of vegetation or logging, agricultural development or cultivation, and urban development. These activities can lead to bank destabilisation, soil compaction and higher overbank flow velocities.

Examples of bank stability project for stream channel using bioengineering techniques are shown in Table 17.1.

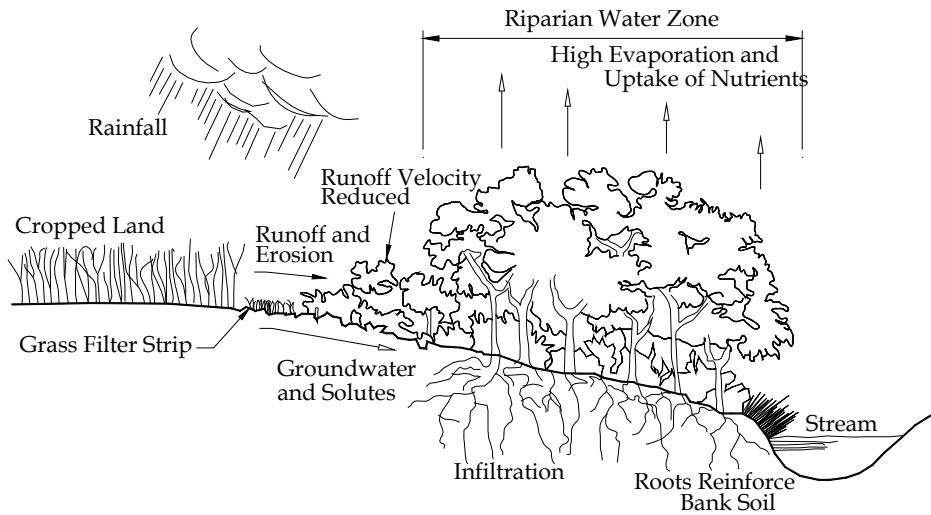








Figure 17.1: Example of Riparian Buffer Zone (DID, 2009)

Table 17.1: Bioengineering Technique Projects

Bioengineering Techniques	Bank Stability Projects	
	During Installation	After Installation
TRM Reinforced Grass		
Sand Filled Mattress Reinforced Grass		
Gabion Mattress Reinforced Grass		

17.3.2 Habitat Values

Broadly, riparian reserves can be described as having a number of habitat functions:

- habitat island. This is a zone that has an adequate width of retention of natural vegetation to be able to permanently sustain communities of natural terrestrial fauna;
- wildlife corridor. This is a zone that has an adequate width of retention of natural vegetation to facilitate the movement of natural fauna from one “habitat island” to the next;
- food source. Riparian vegetation contributes to the ecology of freshwater communities by providing food in the form of fallen organic material and fallen insects and invertebrates (Figure 17.2); and
- aquatic habitat. Trees and branches that fall into the stream and exposed tree roots provide shelter from high velocity flow, predators and sunlight.

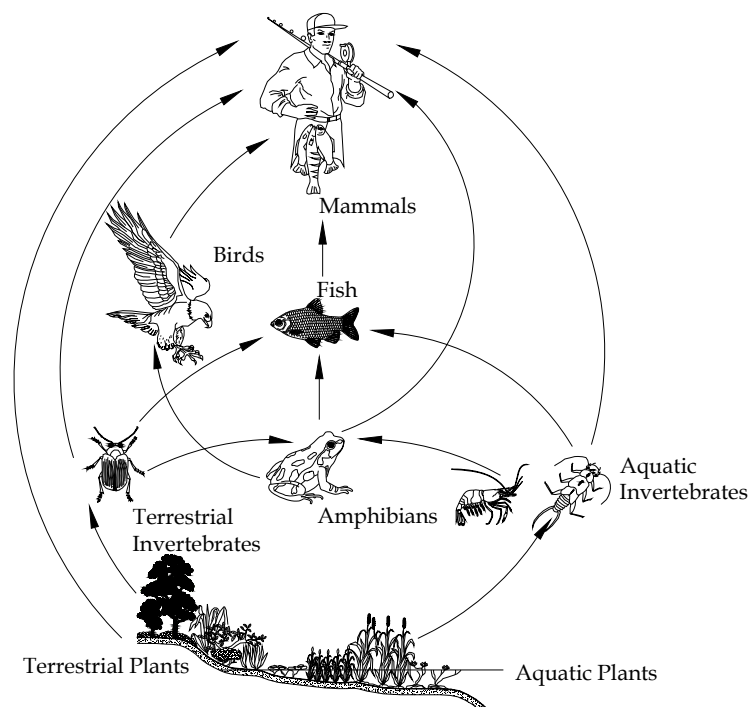


Figure 17.2: Riparian Food Chain

17.3.3 Importance of Diverse Natural Vegetation

The basis for maintaining a natural food chain is natural vegetation. Maintaining natural vegetation is also important in maintaining appropriate levels of shading for the watercourse. This directly affects water temperature, the rate of photosynthesis and shelter from predators such as birds.

17.3.4 Buffer Filters

The riparian zone provides a buffer strip between land use and watercourses. This buffer can provide a filter zone for sediments, nutrients and to some degree pollutants. Buffer zone width as well as the type and magnitude of pollutant loads will determine the long-term effectiveness of the buffer. The filter buffer works by slowing surface sheet runoff, intercepting sediment particles and trapping them around stems and roots. Nutrients in sediments can be taken up into the riparian vegetation, whilst non-organic pollutants may be bound into the soil system. The effectiveness of riparian filter buffers can also depend on site-specific factors such as soil type, permeability, vegetation type and density, and terrain slope. Without such function, sediments and pollutant loads can have long term degrading effects on the overall well being of the watercourse.

17.3.5 Buffer Width

The required width of riparian vegetation buffers zones is dependent on all of the factors outlined above and is a major determinant in the effectiveness of the buffer. The primary function of the buffer depends on its width. Minimum widths suggested for different functions are shown in Table 17.2.

Table 17.2: Recommended Widths for Riparian Buffer Zones (Fischer and Fischenich, 2000; Price, Lovett and Lovett, 2005)

Management Objectives	Recommended Width	Remarks
Protect Water Quality	5 – 30 m	Low slope (0-10%) – Dense grassy or herbaceous buffers intercept runoff, trap sediments, remove pollutants and promote ground water recharge. Moderate slope (10-20%) – most filtering occur within the first 10 m. Greater widths are required for: steeper slopes; where the buffer comprise mainly trees and shrubs; where soils have low permeability; or where non-point source pollutions are significant.
Reduce Bank Erosion	10 – 20 m	Riparian vegetation enhances bank stability by moderating soil moisture and providing tensile strength through the root system. Greater width may be necessary where there is active bank erosion.
Provide Food Input/Aquatic Habitat and Maintain Light/Temperature Level	5 – 10 m	Fallen leaves, twigs and branches are important sources of nutrients and aquatic habitats. Native riparian vegetation provides shade which is crucial for maintaining natural levels of light intensity and temperature for healthy in-stream ecosystem.
Provide Terrestrial Habitat	30 – 500 m	Buffers comprising diverse stands of shrubs and trees provide food and shelter for a wide range of riparian and aquatic wildlife.
Enable Agriculture Production	10 – 30 m	Riparian land is often a highly productive part of the landscape. It can be managed directly for commercial products such as timber or honey, or indirectly so that it improves production by providing habitat for pollinators or acting as windbreak for commercial crops and domestic stock. When acting as windbreak, the length should be at least 20 times the width.
Downstream Flood Attenuation	20 – 150 m	Riparian buffers promote floodplain storage through backwater effects. They increase water flow time by interception, resulting in reduced flood peaks.

The others criteria to be considered are:

- the slope of the site and the erodibility of the soils are the factors having the largest influence in determining buffer widths for the purpose of sediment control;
- site specific investigations will need to take into account factors such as channel and floodplain geometry, vegetation, flora and fauna requirements, adjacent land uses and soil erodibility; and
- indigenous species will inhibit weed growth, although weed management may be required until the indigenous vegetation is established and windbreak plantings may also be necessary to assist with riparian vegetation establishment in exposed areas.

17.3.6 Flow Management

Management of flow velocities and flow depths, in addition to the frequency and extent of inundation will enhance the viability of riparian vegetation. Generally, natural vegetation has adapted to the natural cycles of runoff and the frequency of inundation. The alterations to the hydrological regime leads to the displacement of riparian vegetation from its natural level on the stream bank and may lead to erosion and reduced bank stability.

17.4 STREAM PROCESSES

a) Introduction

Stream management problems may arise from either underlying processes of change in the river system or localised perturbations. Stream instability can be the result of natural processes or human activities. It is therefore important to identify the dominant stream processes present if stream management strategies are to be implemented, which are appropriate and unlikely to cause adverse responses elsewhere in the system.

Stream instability can be initiated by natural and human induced causes such as:

- long term alteration to the hydrologic and/or sediment regime;
- a catastrophic flood or sequence of major floods;
- crossing of a geomorphic threshold; and
- direct or indirect human interference.

b) Bank Erosion Processes

Bank erosion can be the effect of morphological processes such as:

- meander processes;
- channel avulsion; and
- bed degradation, or
- combination of the above, or
- the product of localised processes unrelated to the more general morphological changes in the river system.

The mechanism of bank failure will generally involve more than one failure modes. It normally involves mass failure such as collapse caused by undermining and slumping (sloughing), rotational or slip circle failure, and initial detachment of individual particles involving attrition or fretting. Other modes of failure include erosion by overland flow entering or leaving the main channel creating a headward erosion gully and tunnel erosion (piping failure).

c) Causes of Bank Erosion

Typical factors, which may contribute to bank erosion, include:

- altered water-sediment ratio in the watercourse;
- altered flow patterns including tidal currents and heights;
- general or local stream bed degradation (i.e., lowering) resulting from altered flows;
- changes in stream flow velocities;
- loss of bank vegetation;
- wave action; and

- soil pore water pressure.

Some typical failure modes are illustrated in Figures 17.3 and 17.4.

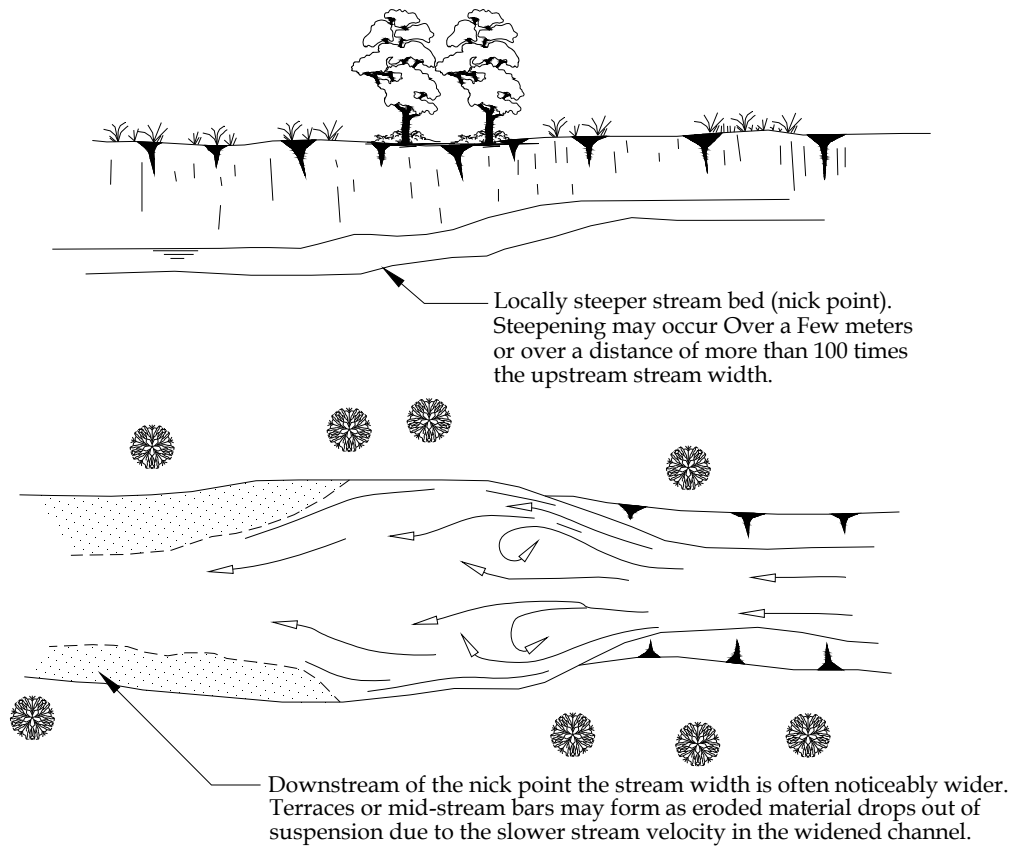


Figure 17.3: Typical Characteristics of Bed Scour

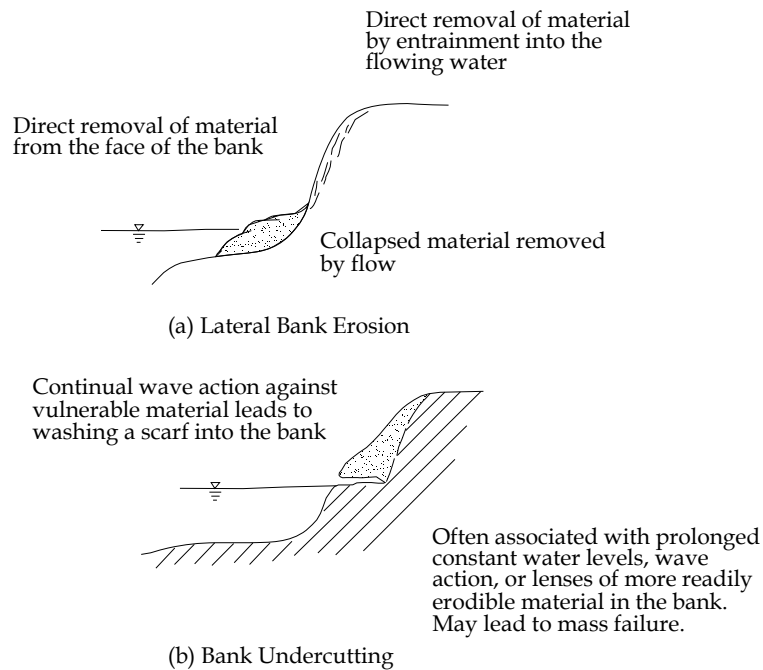


Figure 17.4: Bank Failures by Attrition and Fretting

17.5 WATERCOURSE MANAGEMENT TYPES

Erosion mechanisms include bed scour, bank attrition and bank collapse caused by undermining, piping, slumping, or rotational failure.

17.5.1 Bed Scour (Degradation)

a) Description

A deepening of the stream bed that propagates in an upstream direction. The deepening moves upstream by an advancing erosion head that may take the form of a small waterfall or locally steeper section of stream bed (head cut or nick point) (Figure 17.3). In some cases the location of the erosion head is not easy to identify.

b) Indicators/Symptoms

- a visible waterfall;
- steep section of stream bed at head of scour hole;
- bell shaped scour hole immediately downstream of erosion head;
- exposure of foundations on structures such as bridge piers and culverts;
- steep raw banks caused by lowering of the bed and the consequential collapse of the adjacent banks;
- relatively sudden decrease in bank height in upstream direction;
- choking of downstream reaches by sediment deposits;
- steep banks; and
- downstream flooding through loss of flood storage resulting from concentration of streamflow within the incised stream channel.

c) Possible Causes

- Clearing and/or urbanisation of the catchment resulting in an increase in flow entering the stream at the original head cut location, or
- Direct human modification to the stream such as:
 - channelisation works causing a sudden increase in mean flow velocity which has a knock on upstream effect;
 - in-stream gravel and sand mining operations;
 - de-snagging; and
 - unstable drop inlets upstream of culverts.

17.5.2 Bank Attrition

a) Description

Bank attrition is the direct removal of material from the face and toe of the bank by entrainment into the stream flow (Figure 17.4). It may be caused by channel flow and/or runoff from the surrounding area flowing down the face of the bank.

b) Indicators/Symptoms

- steepening of the stream banks;
- absence of bank vegetation;

- lateral gullies and/or columnisation (this is a special case, refer to Section 17.5.7);
- widening of the stream;
- meander migration; and
- downstream sedimentation.

c) *Possible Causes*

High velocity flow in contact with the bank which maybe the result of one or more of the following:

- increase in the rate and volume of flow entering the stream caused by land clearing and/or urbanisation of the catchment;
- obstructions in the stream channel such as fallen trees, dumped material or bridge piers; and
- a lack of vegetation on the bank due to shading, trampling from animals or humans, wave action, or direct removal by human activities.

17.5.3 Bank Undermining (Fretting)

a) *Description*

Fretting is the direct removal of material from an exposed underlying vulnerable soil layer by the continual movement of water (flow or waves) against the layer (Figure 17.4). An erosion scarf is formed which can lead to mass failure of the overhanging bank material.

b) *Indicators/Symptoms*

- overhanging bank; and
- a sharp steeping of the bank with a near vertical face close to the waterline.

c) *Possible Causes*

- increase in water level that makes continual or frequent contact with an exposed and highly erodible soil layer; and
- increased wave action due to boating, or change in the prevailing wind direction due to the removal or addition of nearby obstructions including trees or buildings.

17.5.4 Piping

a) *Description*

Erosion tunnels or pipes are formed where surface flows seep into the ground behind the bank and daylight at the bank face. The seepage flows dissolve and/or dislodge soil particles from the soil matrix and transport them to the face of the bank where they are removed by stream flow. On occasions, piping can be initialised by animal burrows or by decaying roots of dead trees, which leaves subsurface cavities.

b) *Indicators/Symptoms*

- sink holes on the floodplain and especially when close to the stream bank;
- trenches or narrow line(s) of collapsed material extending laterally across the floodplain;
- concentrated seepage flows appearing on the bank; and
- burrows or tunnels on the bank.

c) *Possible Causes*

- poorly drained floodplain areas;

- animal burrows;
- decaying roots of dead trees close to the top of bank; and
- adversely orientated dispersive soil layer.

17.5.5 Bank Slumping

a) Description

Bank slumping (Figure 17.5) is the mass failure of the bank material due to either:

- deepening of the stream bed at the toe of the bank resulting in the bank becoming unstable and slumping into the stream under its own weight (or under some surcharge weight on the top of the bank); and
- high pore water pressure in the bank material not being balanced by adjacent hydrostatic pressures in the stream. The high pore water pressure weakens the structure of the bank material causing it to slump into the stream.

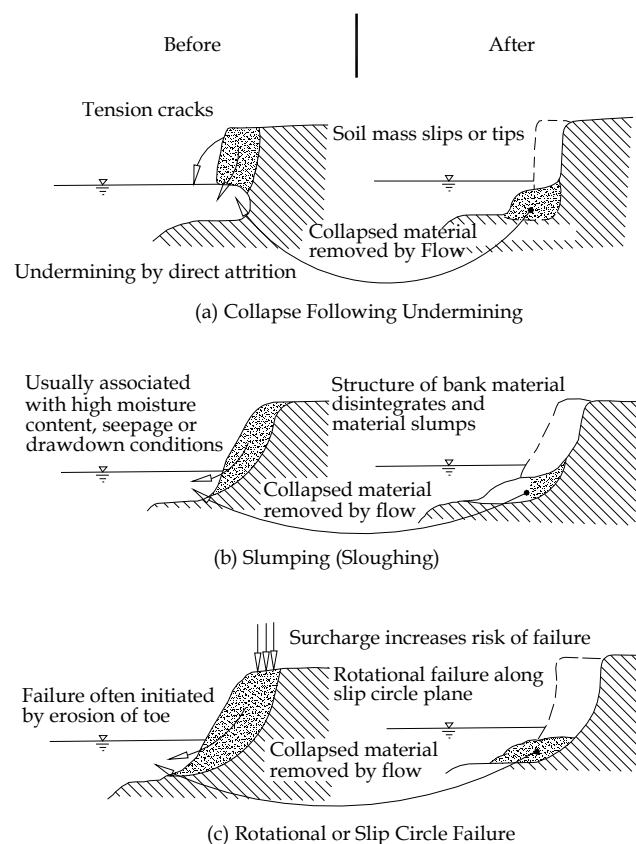


Figure 17.5: Mass Bank Failure Modes

b) Indicators/Symptoms

- lateral movement or widening of the stream banks;
- tension cracks in overbank material running parallel to top of the bank;
- large dumps of vegetated bank slumped below the obvious original location of the vegetation;
- significant groundwater seepage from the face of the stream bank;
- near vertical, unvegetated banks; and
- the presence of mature vegetation types not normally associated with regular and prolonged inundation at the toe of the bank.

c) *Possible Causes*

- high velocity streamflow (often on the outside of stream bends) resulting in bed scour at the toe of the bank. This can be made worse by land clearing and/or urbanisation of the catchment;
- rapid drawdown of stream water level following a prolonged period of high flows, which have saturated the bank material. This is not common in urban streams and is more prevalent in regulated rural streams and irrigation channels;
- surcharge loading on the top of the bank; and
- lack of binding bank vegetation.

17.5.6 Bank Rotational Failure

a) *Description*

Bank rotational failure (also known as slip circle failure) is the failure of an embankment along a curved surface, which approximates to the plane of least resistance within the soil mass (Figure 17.5).

b) *Indicators/Symptoms*

- block slippage of the bank exposing a curved failure surface on the bank. The slumped material may or may not be present depending on whether stream flows have removed the material from the base of the bank;
- lateral movement or widening of the stream banks;
- absence of bank vegetation; and
- the presence of mature vegetation types not normally associated with regular and prolonged inundation at the toe of the bank.

c) *Possible Causes*

- deepening of the stream bed at the toe of the bank resulting in the bank becoming unstable;
- surcharge weight on the top of the bank (vehicles, buildings);
- high pore water pressure in the bank material not being balanced by adjacent hydrostatic pressures in the stream; and
- removal of binding vegetation.

17.5.7 Lateral Bank Erosion

a) *Description*

Lateral bank erosion is most prevalent at locations where runoff from adjacent land is concentrated within culverts, roadways and drainage lines and depressions prior to entering the main stream. The erosion takes the form of an upstream progressing erosion head that propagates laterally from the main stream channel. Where the runoff reaches the top of bank as sheet flow the bank may display a columnar or vertical fold formation (Figure 17.4).

b) *Indicators/Symptoms*

- ephemeral gullies or rills entering the river bank above the normal water level;
- columns or vertical erosion folds in the bank; and
- tension cracks in the bank and crumbling of the upper soil horizons.

c) Possible Causes

- culverts, roadways, drainage swales etc. discharging concentrated stormwater runoffs into the stream channel without proper outlet protection measures;
- redirection of the stream channel due to urbanisation of the catchment and/or clearing of fringing bank vegetation (particularly where this occurs on the inside of a meander);
- erosion prone material at the top of the bank such as dispersive clays, soft silts, and unconsolidated sands and gravels; and
- lack of vegetation (especially ground cover) on the bank.

17.6 WATERCOURSE MANAGEMENT TECHNIQUES

The techniques listed in Table 17.3 are not an exhaustive list but represent the most commonly applied techniques suitable for urban streams and rivers. However not all techniques described would be suitable in an urban environment due to site specific constraints. Public safety, aesthetics, and cost will often determine the adoption of a technique.

Figures 17.6 and 17.7 provide examples of slightly improved natural channels. Stabilisation measures in Figure 17.6(a) include check structures, riprap, minor grading, and short sections of retaining walls. In general, little or no channel capacity improvements are included. In Figure 17.6(b), channel capacity has been increased to lower or confine the design storm flow by excavating outside of the environmentally sensitive area and constructing retaining walls. Figure 17.7 shows possible drainage improvements for composite channels. Stabilisation measures in Figure 17.7(a) include check structures, riprap, grading, and retaining walls. Improvements to the main channel increase capacity for minor flood flows and may confine or reduce the depth of the design flood. In Figure 17.7(b), the main channel area has been left undisturbed (i.e. that area containing the base flow plus the immediate vegetation area) and the overbank conveyance capabilities improved by excavating the floodplain area. This 'improved' natural channel has increased capacity to safely convey the major system design flow. Provision should be provided for maintenance access to the channel. In stabilising the main channel and overbank, vegetation should be retained as much as possible to meet the objectives of enhancing stability and capacity. Multiple uses of the overbank flooding area should be encouraged, especially if the main channel capacity is substantial, i.e. overbank flooding is infrequent.

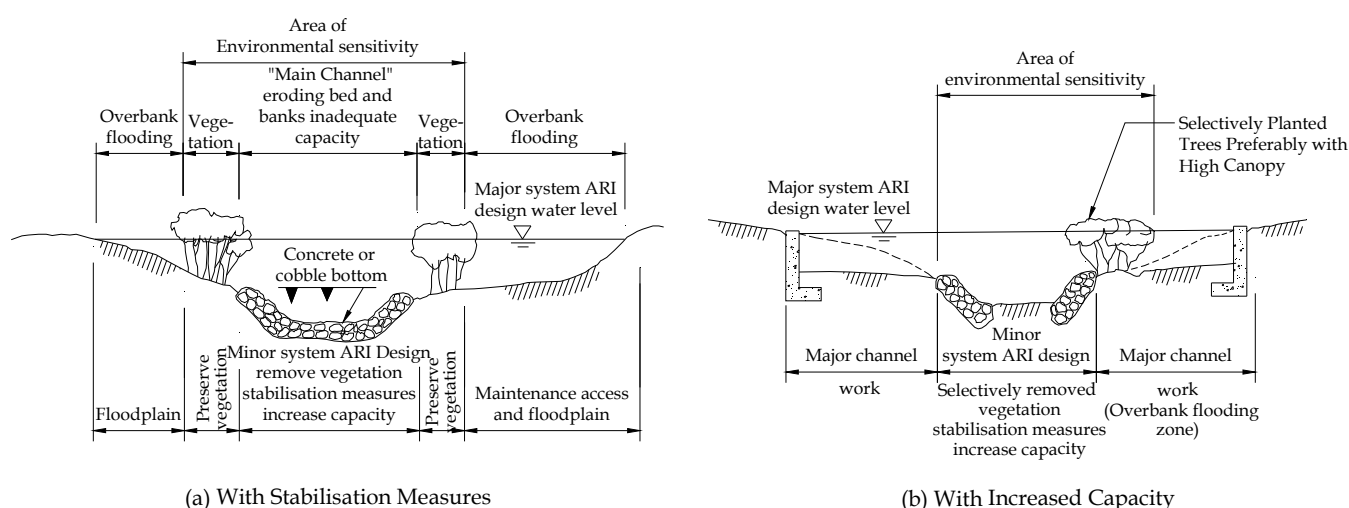


Figure 17.6: Typical Channel (ASCE, 1992)

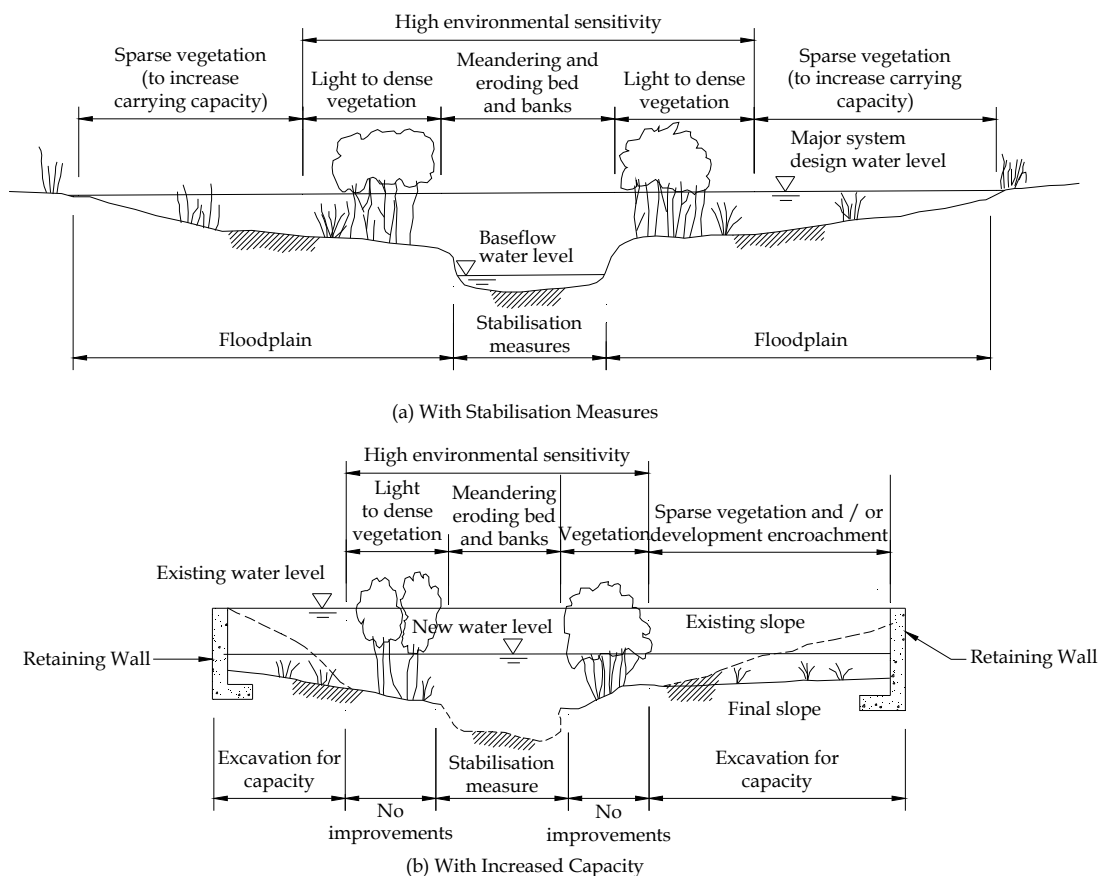


Figure 17.7: Composite Channel (ASCE, 1992)

17.7 CHANNEL DESIGN CONSIDERATION

The design of 'natural channels' involves the creation of channels with the attributes of natural watercourses pertinent to the location within the watershed and should be based on a sound understanding of fluvial geomorphic principles. Guidelines on natural channel design methodology are provided by OMNR (1994). The suggested design steps are:

- Define Design Objectives - Identify the objectives to be met for the design. Multiple objectives regarding conveying flood flows, aquatic habitat, recreation, aesthetics and maintenance may exist and frequently will appear to be in conflict.
- Define Existing Conditions - The existing flow regime, sediment load, channel, valley and catchment conditions can be obtained or estimated.
- Define the Expected Conditions - The expected flow, sediment loading and channel slope conditions can be estimated or calculated.
- Identify Inconsistencies - Any inconsistencies between the existing and expected conditions should be identified and resolved.
- Design Parameters - The design parameters for the channel for unconstrained design conditions should be developed to satisfy the objectives.
- Identify Constraints - Constraints to the channel design are to be identified. Some of the more common constraints include funding, property boundaries, roads, services, flooding, and stakeholders or management disputes.
- Identify Compromises - Compromises may be required to determine the optimum design conditions by considering all the site constraints.
- Develop Design - The design of the channel system should emphasise on creating a channel in dynamic equilibrium with appropriate habitat features.
- Evaluate Design - The resulting design should be compared to the optimum design and the extent of any discrepancies (there are usually some) are to be identified and assessed as to their importance in achieving the overall design objectives.

Table 17.3: Watercourse Management Techniques Suitable for Urban Streams and Rivers

Techniques	Application	Limitation
Bank armouring <ul style="list-style-type: none"> Rock rip-rap 	Direct protection against erosion	Requires a supply of hard sound rock.
Bank armouring <ul style="list-style-type: none"> Articulated concrete block mattress 	Provides protection and stability to eroding banks. Suitable for a range of bank conditions including fretting and direct attrition.	a) Toe apron requires anchoring. b) Where the stream is prone to bed scour an extensive toe apron is required.
Bank armouring <ul style="list-style-type: none"> Rock filled wire baskets and mattresses 	Provides protection and stability to eroding banks.	Usually fail by wire breakage due to high sediment loads carried by stream or by vandalism or by undermining.
Bank armouring <ul style="list-style-type: none"> Brushing 	Provides bank protection for a limited time to enable “permanent” vegetation to become established on the bank. The technique is effective against fretting and attrition erosion. It may also contribute to lowering the risk of mass failure by reducing the risk of material being removed from the toe of the bank.	Only provides short term protection.
Bank stabilisation <ul style="list-style-type: none"> Battering 	Reduce public safety hazard caused by steep banks, reduce erosion hazard caused by fast flowing overland flow, increase bank stability against rotational failure or mass failure, and create conducive environment for vegetation establishment.	Land take behind the bank line may be required if flat slopes are to be applied.
Bank stabilisation <ul style="list-style-type: none"> Reinforced vegetation 	Act as a separating layer between river flows and an eroding bank. Often combined with bank battering.	Limited effectiveness below normal river level.
Bank stabilisation <ul style="list-style-type: none"> Retaining and training walls 	Normally used as an alignment training technique but also provides protection and stability to eroding banks. Suitable for bank conditions involving: a) fretting; and b) direct attrition.	a) Where the stream is prone to bed scour the wall may be destabilised by undermining. b) Pile driving equipment may be required.
Bank stabilisation <ul style="list-style-type: none"> Bio-reinforced embankments 	Provides bank protection against undermining, piping, rotational, and slumping failure modes.	Requires a supply of suitable vegetative material. Toe scour may occur especially where the reinforced bank is terminated above the low water line.
Bank stabilisation <ul style="list-style-type: none"> Reinforced earth proprietary products 	Used to re-establish an eroded river bank or to reinforce an existing bank.	Requires a facing to limit the risk of continued scour.
Grade control structures <ul style="list-style-type: none"> Check weirs 	Used to reduce the effective hydraulic grade and control stream bed degradation (deepening) by promoting controlled sedimentation upstream of the weir. When the upstream ponding area is full of sediment the check weir behaves in the same manner as a Rock Chute.	Maybe subject to damage under certain depths of inundation. Disturbance of the bank is necessary to anchor the weir and prevent outflanking.
Land and water management <ul style="list-style-type: none"> Fish refuges 	Used to create variation in fish habitat that provides a variation in water temperature and velocity as well as protection from predators.	Stream must be sufficiently wide if jetties or boardwalks are contemplated. A good fishing location may be inadvertently created if there is a high level of people access along the stream.

17.7.1 Developing a Channel Design

Every watercourse is uniquely defined by the catchment hydrology, geology and soils, climate, vegetation, landuse, stream use, and its geological age (stream maturity). In designing an alluvial channel consideration should be given to the following criteria.

a) *Planform*

This refers to the shape or stream configuration when viewed on a plan. It covers characteristics such as stream sinuosity (a measure of meander shape, size and frequency), meander length and amplitude, channel pattern (straight, multi-channel, braided), and presence of ox-bow lakes, meander cutoffs, etc. An examination of a stream's planform can give an indication of whether the meanders are migrating, increasing or decreasing, or whether different reaches of the stream are aggrading (areas of deposition) or degrading (eroding).

b) *Bedform*

Bedforms can provide important clues to the stream processes that are taking place. The presence of recently formed or growing mid-stream bar(s) will generally indicate an area of deposition, which may have ramifications on the stability of the banks opposite the bars. The presence of pools and riffles will usually conform to a natural frequency of occurrence along a reach. In sand bed streams they are hardly noticeable, often only being defined by regular alternating deposits of coarser and finer bed deposits.

c) *Flow resistance*

This design characteristic influences the velocity profile both vertically and horizontally across a section. It is affected by bedform, bed and bank material, vegetation and natural or artificial obstructions in the channel or on the floodplain. The removal of bank vegetation will usually lower the surface resistance to flow thus increasing the near bank flow velocity. If the velocity increases above the scour threshold value for the bank material erosion will occur.

d) *Stream slope*

This is a measure of the longitudinal slope of the stream thalweg (line traced by the lowest point on successive cross sections). An examination of the stream slope can assist in identifying any sudden changes in slope, which may indicate the presence of stream instability due to bridge, dam or other in-stream structure. The causes of slope change can be natural or artificial (i.e. bridges, dams, or other in-stream structure or activity such as gravel or sand extraction). Changes in slope may be sudden (i.e. a waterfall or riffle) or gradual and only noticeable over a considerable distance.

e) *Stream width and depth*

When stream width is usually considered together with depth and the ratio of the two dimensions can provide further clues as to the dominant stream processes in the reach. In an alluvial stream a high width to depth ratio will often indicate that the stream is in a deposition stage where the load carrying capacity of the stream is greater than the sediment input at the top of the reach. Urban watercourses are often relatively deep and narrow which is a reflection on the increased water supply following urbanisation of the catchment.

f) *Vegetation*

When specifying the vegetation for a channel design an assessment of the height and extent of flooding for a range of flood frequencies and durations should be made. The plants should be selected according to the expected flooding regime, light conditions and soil types present. Unless the stream bank is particularly stable, care should be exercised when planting large trees close to the top of the bank where they may be subject to undermining from stream flow or high winds which may cause them to fall into the stream and expose the bank. Natural vegetation is often unable to cope with the expected hydraulic loading and consideration can be given to reinforcing the vegetation with either temporary or permanent matting or other proprietary products.

17.7.2 Stable Channel Design

The stability of a channel or the suitability of various channel linings can be determined by first calculating both the mean velocity and tractive stress. Allowable tractive stresses for various types of soil, linings, ground covers, and stabilization measures including soil bioengineering treatments, are listed in Table 17.4. Additionally, product literatures from manufacturers can provide information on allowable tractive stresses or velocities for various types of erosion control products. Table 17.5 shows the factors influencing erosion. A general procedure for the application of information presented by Fischenich (2001) is outlined in the following paragraphs.

Step 1 - Estimate Mean Hydraulic Conditions

Flow of water in a channel is governed by the discharge, hydraulic gradient, channel geometry, and roughness coefficient. This functional relationship is most frequently evaluated using normal depth or backwater computations that take into account principles of linear momentum conservation. The latter is preferable because it accounts for variations in momentum slope, which is directly related to shear stress.

Step 2 - Estimate Local/Instantaneous Flow Conditions

The computed values for velocity and shear stress may be adjusted to account for local variability and instantaneous values higher than mean. A number of procedures are available to serve this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. For straight channels, the local maximum shear stress can be calculated from the following simple equation:

$$\tau_{max} = 1.5\tau \quad (17.1)$$

For sinuous channels, the maximum shear stress should be determined as a function of the planform characteristics using Equation 17.2:

$$\tau_{max} = 2.65\tau \left(\frac{R_c}{W}\right)^{-0.5} \quad (17.2)$$

where,

$$\begin{aligned} R_c &= \text{Radius of curvature (m); and} \\ W &= \text{Top width of the channel (m).} \end{aligned}$$

Equations 17.1 and 17.2 adjust for the spatial distribution of shear stress; however, temporal maximum in turbulent flows can be 10 to 20 percent higher, so an adjustment to account for instantaneous maximum should be added as well. A factor of 1.15 is usually applied.

Step 3 - Determine Existing Stability

Existing stability should be assessed by comparing estimates of local and instantaneous shear and velocity to values presented in Table 17.4. Both the underlying soil and the soil or vegetation condition should be assessed. If the existing conditions are deemed stable and are in consonance with other project objectives, then no further action is required. Otherwise, proceed to step 4.

Step 4 - Select Channel Lining Material

If existing conditions are unstable, or if a different material is needed along the channel perimeter to meet project objectives, a lining material or stabilization measure should be selected from Table 17.4, using the threshold values as a guideline in the selection. Only material with a threshold exceeding the predicted value should be selected. The other project objectives can also be used at this point to help select from among the available alternatives. Fischenich and Allen (2000) characterize attributes of various protection measures to help in the selection.

Table 17.4: Permissible Shear and Velocity for Selected Lining Materials (Fischenich, 2001)

Boundary Category	Boundary Type	Permissible Shear Stress (N/m ²)	Permissible Velocity (m/s)	Citation (s)
Soils	Fine colloidal sand	0.96 - 1.44	0.46	A
	Sandy loam (noncolloidal)	1.44 - 1.92	0.53	A
	Alluvial silt (noncolloidal)	2.15 - 2.39	0.61	A
	Silty loam (noncolloidal)	2.15 - 2.39	0.53 - 0.69	A
	Firm loam	3.59	0.76	A
	Fine gravels	3.59	0.76	A
	Stiff clay	12.45	0.91 - 1.37	A, F
	Alluvial silt (colloidal)	12.45	1.14	A
	Graded loam to cobbles	18.19	1.14	A
	Graded silts to cobbles	20.59	1.22	A
	Shales and hardpan	32.08	1.83	A
Gravel/Coble	25 mm	15.80	0.76 - 1.52	A
	50 mm	32.08	0.91 - 1.83	A
	150 mm	95.76	1.22 - 2.29	A
	300 mm	191.52	1.68 - 3.66	A
Vegetation	Class A turf	177.16	1.83 - 2.44	E, N
	Class B turf	100.55	1.22 - 2.13	E, N
	Class C turf	47.88	1.07	E, N
	Long native grasses	57.46 - 81.40	1.22 - 1.83	G, H, L, N
	Short native and bunch grass	33.52 - 45.49	0.91 - 1.22	G, H, L, N
	Reed plantings	4.79 - 28.73	N/A	E, N
Temporary Degradable RECPs	Hardwood tree plantings	19.63 - 119.70	N/A	E, N
	Jute net	21.55	0.30 - 0.76	E, H, M
	Straw with net	71.82 - 79.00	0.30 - 0.91	E, H, M
	Coconut fiber with net	107.73	0.91 - 1.22	E, M
Non-Degradable RECPs	Fiberglass roving	95.76	0.76 - 2.13	E, H, M
	Unvegetated	143.64	1.52 - 2.13	E, G, M
	Partially established	191.52 - 287.28	2.29 - 4.57	E, G, M
Riprap	Fully vegetated	383.04	2.44 - 6.40	F, L, M
	d ₅₀ = 150 mm	119.70	1.52 - 3.05	H
	d ₅₀ = 225 mm	181.94	2.13 - 3.35	H
	d ₅₀ = 300 mm	244.19	1.52 - 3.96	H
	d ₅₀ = 450 mm	363.89	1.68 - 4.88	H
Soil Bioengineering	d ₅₀ = 600 mm	483.59	4.27 - 5.49	E
	Wattles	9.58 - 47.88	0.91	C, I, J, M
	Reed fascine	28.73 - 59.85	1.52	E
	Coir roll	143.64 - 239.40	2.44	E, M, N
	Vegetated coir mat	191.52 - 383.04	2.90	E, M, N
	Live brush mattress (initial)	19.15 - 196.31	1.22	B, E, I
	Live brush mattress (grown)	186.73 - 392.62	3.66	B, C, E, I, N
	Brush layering (initial/grown)	19.15 - 299.25	3.66	E, I, N
Hard Surfacing	Live fascine	59.85 - 148.43	1.83 - 2.44	C, E, I, J
	Live willow stakes	100.55 - 148.43	0.91 - 3.05	E, N, O
Hard Surfacing	Gabions	478.80	4.27 - 5.79	D
	Concrete	598.50	> 5.49	H

¹ Ranges of values generally reflect multiple sources of data or different testing conditions.

A. Chang, H.H. (1988).	I. Schiechl, H.M. and R. Stem. (1996).
B. Florineth. (1982).	J. Schoklitsch, A. (1937).
C. Gerstgraser, C. (1998).	K. Sprague, C.J. (1999).
D. Goff, K. (1999).	L. Temple, D.M. (1980).
E. Gray, D.H., and Sotir, R.B. (1996).	M. TXDOT (1999).
F. Julien, P.Y. (1995).	N. Data from Author (2001).
G. Kouwen, N., Li, R.M., and Simons, D.B., (1980).	O. USACE (1997).
H. Norman, J.N. (1975).	

Table 17.5: Factors Influencing Erosion (Fischenich, 2001)

Factor	Relevant characteristics
Flow properties	Magnitude, frequency and variability of stream discharge; Magnitude and distribution of velocity and shear stress; Degree of turbulence
Sediment composition	Sediment size, gradation, cohesion and stratification
Climate	Rainfall amount, intensity and duration; Frequency and duration of freezing
Subsurface conditions	Seepage forces; Piping; Soil moisture levels
Channel geometry	Width and depth of channel; Height and angle of bank; Bend curvature
Biology	Vegetation type, density and root character; Burrows
Anthropogenic factors	Urbanization, flood control, boating, irrigation

Step 5 - Recompute Flow Values

Resistance values in the hydraulic computations should be adjusted to reflect the selected channel lining, and hydraulic condition should be recalculated for the channel. At this point, reach or section averaged hydraulic conditions should be adjusted to account for local and instantaneous extremes. Table 17.6 presents velocity limits for various channel boundaries conditions. This table is useful in screening alternatives, or as an alternative to the shear stress analysis presented in the preceding sections.

Step 6 - Confirm Lining Stability

The stability of the proposed lining should be assessed by comparing the threshold values in Table 17.4 to the newly computed hydraulic conditions. These values can be adjusted to account for flow duration using Figures 17.8 and 17.9 as a guide. If computed values exceed thresholds, Step 4 should be repeated. If the threshold is not exceeded, a factor of safety (FS) for the project should be determined from the following equations:

$$FS = \frac{\tau_{max}}{\tau_{computed}} \quad \text{or} \quad FS = \frac{V_{max}}{V_{computed}} \quad (17.3)$$

Table 17.6: Stability of Channel Linings for Given Velocity Ranges (Fischenich, 2001)

Lining	0 - 0.61 m/s	0.61 - 1.22 m/s	1.22 - 1.83 m/s	1.83 - 2.44 m/s	> 2.44 m/s
Sandy Soils					
Firm Loam					
Mixed Gravel and Cobbles					
Average Turf					
Degradable RECPs					
Stabilizing Bioengineering					
Good Turf					
Permanent RECPs					
Armoring Bioengineering					
CCMs & Gabions					
Riprap					
Concrete					
Key :					
	Appropriate				
	Use Caution				
	Not Appropriate				

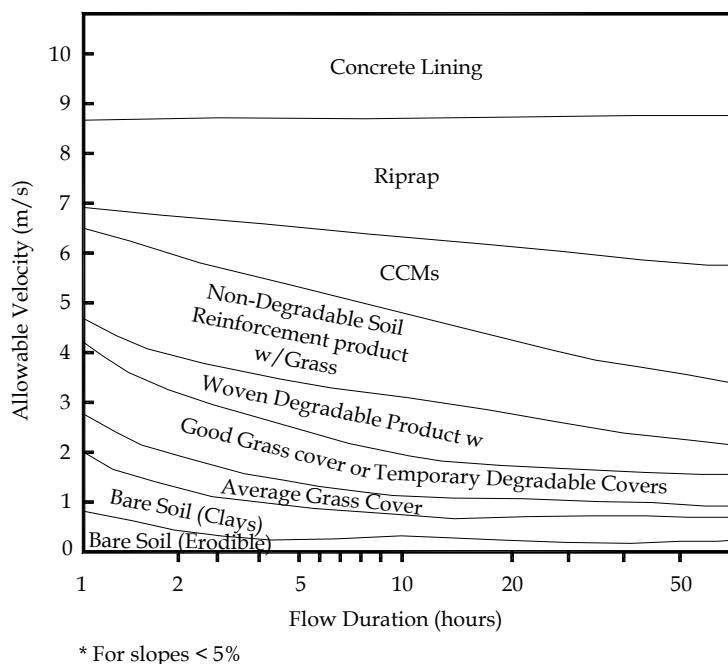


Figure 17.8: Erosion Limits as a Function of Flow Duration (Fischenich and Allen, 2000)

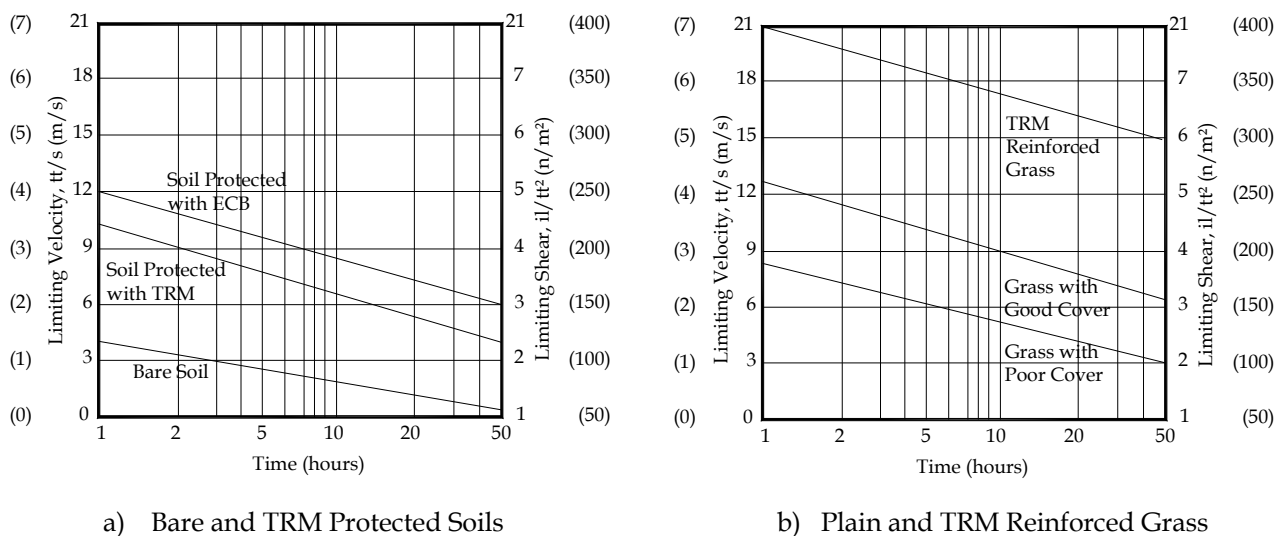


Figure 17.9: Limiting Value for Velocity and Shear (Sprague, 1999)

17.7.3 Limitations

Techniques described in previous section are generally applicable to stream restoration projects that include revegetation of the riparian zone or bioengineering treatment. Detailed design criteria can be found in DID Manual, Volume 2-River Management (DID, 2009).

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