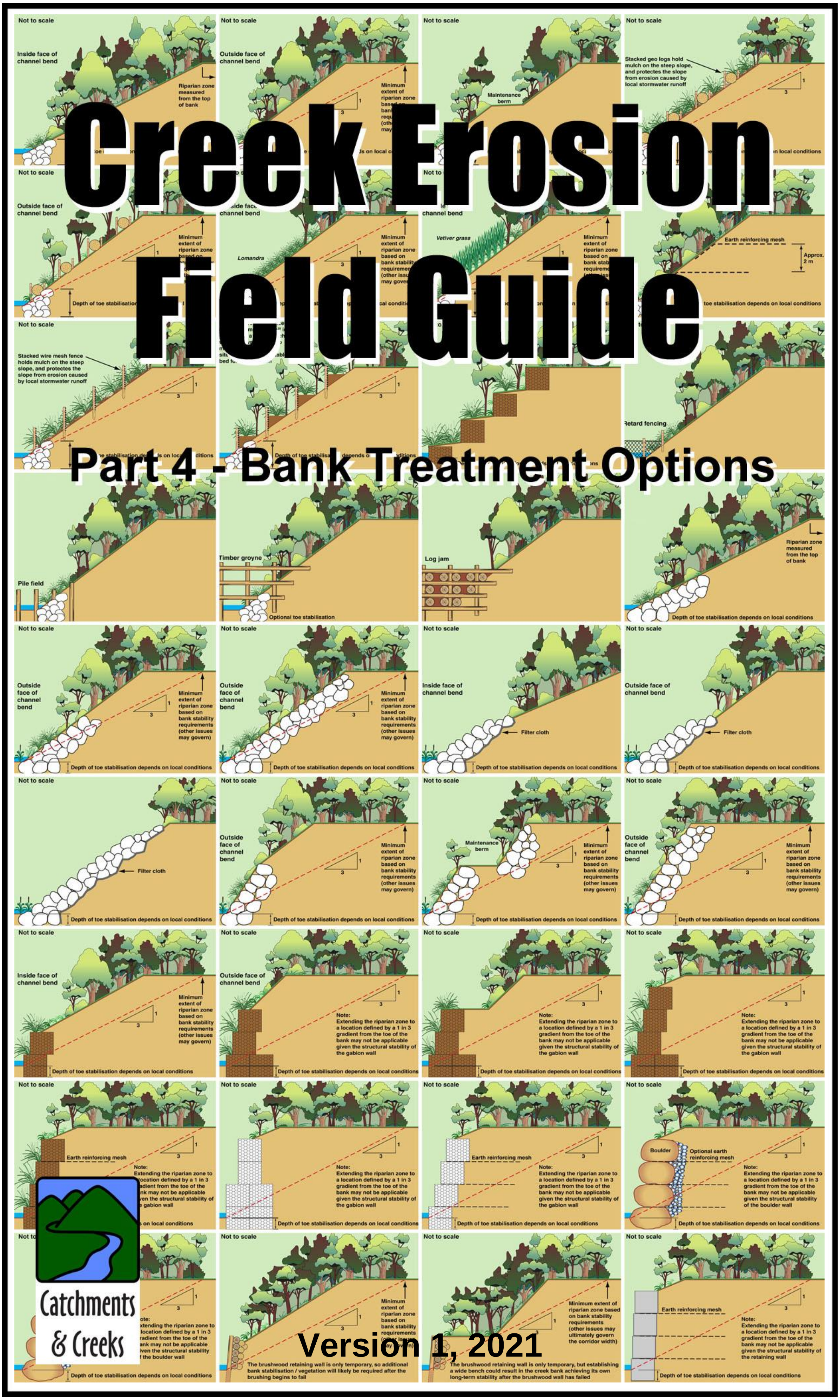
Creek Erosion Field Guide

Part 4 - Bank Treatment Options



Catchments & Creeks

Version 1, 2021

Creek Erosion Field Guide

Part 4 – Bank Treatment Options

April 2021

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Disclaimer

Significant effort has been taken to ensure that this document is representative of current best practice waterway management; however, the author cannot and does not claim that the document is without error, or that the recommendations presented within this document will not be subject to future amendment.

To be effective, erosion repairs must be appropriately investigated, planned, and designed in a manner appropriate for the site conditions. Each site is different, and the solutions to creek erosion are also likely to vary from site to site. Erosion control is a complex subject that requires significant training and experience to fully understand.

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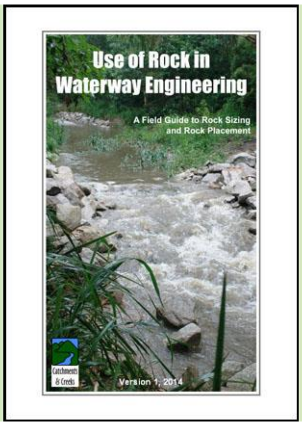


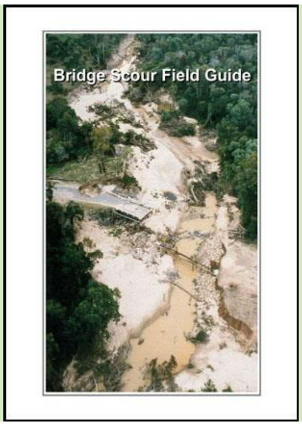
Use of Rock in Waterway Engineering

Use of Rock in Waterway Engineering

Catchments and Creeks Pty Ltd, Bargara, Queensland

Free PDF available from the C&C website.

First published in 2014, with regular updates being produced since then.



Bridge Scour Field Guide

Bridge Scour Field Guide

Catchments and Creeks Pty Ltd, Bargara, Queensland

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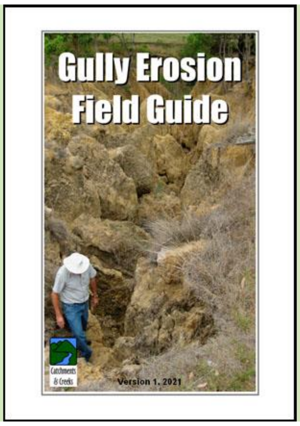
First published in 2020, this document provides a summary of the AustRoads and Queensland Main Roads guidelines.



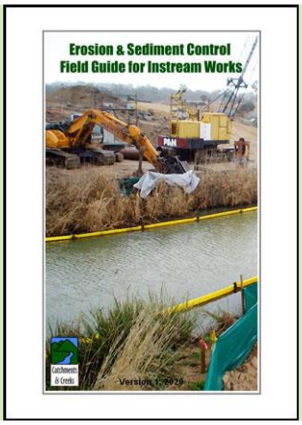
Gully Erosion Field Guide

Gully Erosion Field Guide

Catchments and Creeks Pty Ltd, Bargara, Queensland

At the time of first publishment of the Creek Erosion Field Guide, this gully erosion field guide had not been completed.

This field guide is due for release in late 2021.



ESC Field Guide for Instream Works

Erosion and Sediment Control Field Guide for Instream Works

Catchments and Creeks Pty Ltd, Bargara, Queensland

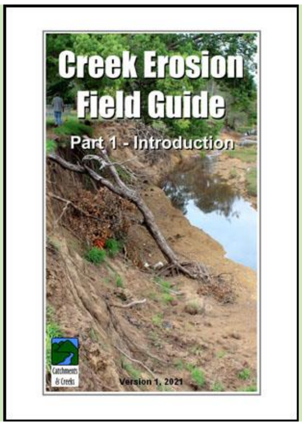
Free PDF available from the C&C website.

First published early 2020, then updated late 2020.

This field guide addresses the erosion and sediment control issues that need to be managed during the construction phase of creek erosion control measures.

Contents

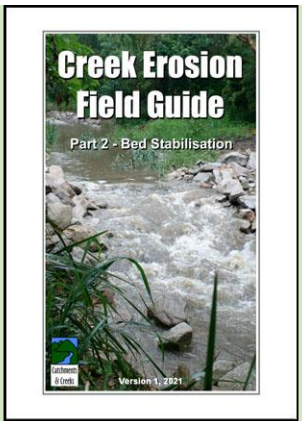
Layout of this four-part field guide



Creek Erosion Field Guide – Part 1

Part 1 – Types of waterways and causes of waterway erosion

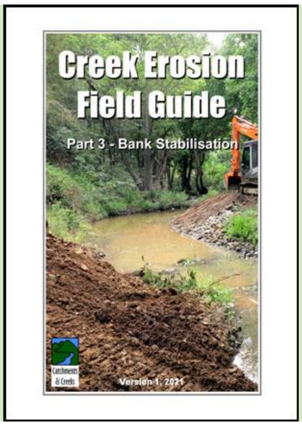
- Designing the appropriate treatment measures for creek erosion depends on knowing:
  - the type of watercourse
  - the type of erosion, and
  - the likely causes of the erosion.
- Part 1 discusses each of these issues, as well as presenting an introduction to creek engineering and fluid mechanics.



Creek Erosion Field Guide – Part 2

Part 2 – Bed stabilisation

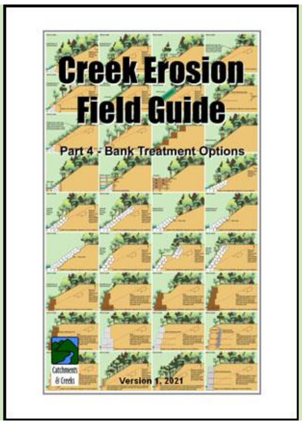
- Prior to presenting detailed information on bed stabilisation techniques, discussion is presented on the following topics:
  - fish-friendly waterways
  - common properties of rock
  - hydraulics of bed structures.
- Information on the treatment of bed erosion is then grouped into two chapters:
  - fish-friendly options
  - non fish-friendly options.



Creek Erosion Field Guide – Part 3

Part 3 – Bank stabilisation

- The treatment of bank erosion has been grouped into:
  - soft engineering options
  - hard engineering options
  - management of dispersive soils
  - management of lateral bank erosion
  - flow diversion techniques.
- Part 3 ends with a discussion on how vegetation can be incorporated into the various bank stabilisation measures.



Creek Erosion Field Guide – Part 4

Part 4 – Bank stabilisation

- Part 4 starts with an overview of the various recommendations presented in Part 3 on the stabilisation of creek banks.
- The main focus of Part 4 is the presentation of a pictorial guide to the selection of bank stabilisation options—starting with the lower gradient options, and moving onto the steeper bank options.
- A glossary of technical terms is presented at the end of the document.

Purpose of field guide

This field guide has been prepared for the purpose of:

- providing guidance to landowners, community groups and waterway managers on the treatment of bed and bank erosion within minor waterways (i.e. creeks)
- providing engineers and scientists that are new to the waterway industry with educational material on the investigation and design of treatment measures for creek erosion
- presenting information that focuses on the management of erosion issues within creeks rather than within rivers, while also providing general discussion on the differences between the behaviour of creeks and rivers.

What makes this document a ‘field guide’ is the fact that the document is visually based (i.e. it utilises 1080 photos and 400 diagrams), and that it does not provide comprehensive design information. The focus of this document is on education, rather than design details. Other publications, such as those presented at the beginning of this document, already provide useful information on the design of erosion control measures.

The photos presented within this document are intended to represent the current topic being discussed. These photos have been selected for the purpose of depicting either a preferred or discouraged outcome (as the case may be). In some cases the photos may not represent current best practice, but are simply the best photos available to the author at the time of publication, and yes, in some cases the photos show plants that are classified as weeds.

The caption and/or associated discussion should **not** imply that the actual site shown within the photograph is representative of either good or bad waterway practice. The financial and political circumstances, site conditions, and history are not known in each case, and may be very different from the issues currently being discussed. This means that there may be a completely valid reason why the designer chose the particular treatment option shown within the photo.

About the author

Grant Witheridge is a civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has 40 years experience in the fields of hydraulics, creek engineering and erosion & sediment control, during which time he has worked for a variety of federal, state and local governments, as well as private organisations.

Grant commenced his career at the UNSW Water Research Laboratory (1981) constructing and operating physical flood models of river floodplains. He later worked for Brisbane City Council on creek engineering and stormwater management issues. He currently works through his own company Catchments & Creeks Pty Ltd.

Grant is the principal author of more than 40 engineering publications covering the topics of creek engineering, fish passage, stormwater management, and erosion and sediment control.

Introduction

It is my experience that many of the professionals that deal with creek erosion issues on a regular basis have a tendency to focus on the use of just one or two treatment options throughout their career. Once people become familiar with one particular technique, often the first technique they use on a creek erosion job, they then tend to focus on the use of that particular technique for most of their career.

Ideally, the choice of bank stabilisation technique should be based on a wide range of factors, and the treatment should be based on what is best of the site, rather than what technique the designer is most familiar with (or the product the designer/distributor happens to sell).

Part 4 of this field guide has been produced to help introduce creek engineers to a wider range of treatment options, and to allow these professionals to better discuss with the landowner/client the full range of treatment options.

When dealing with creek erosion, there are different issues that should rise to the top of your concern compared to those issues you may need to focus on when dealing with river or gully erosion. The following tables examine these issues and differences.

Table 1 – Relative importance of key issues

Issues	Gully erosion	Creek erosion	River erosion
Water (hydrology) [1]	Though always important, its relative importance for a gully is often (but not always) less than for a creek or river.	Flow conditions (i.e. velocity & turbulence) are more complex than in rivers. A greater change in flow conditions can be expected from changing catchment conditions as compared to rivers.	Water flow in rivers usually dominates over vegetation, soil and rock placement. Changes in the catchment are unlikely to significantly alter the impact of major floods.
Vegetation [2]	In the short-term, vegetation usually plays a minor role in gully repair. The importance of vegetation increases with time, and it is usually critical for long-term stability.	Vegetation plays a critical role in creeks. Creek stability is usually directly related to the type of vegetation cover. Vegetation usually plays a lesser role in arid and semi-arid creeks.	Vegetation is important for bank stability between flood events. Significant vegetation damage is expected during floods. Vegetation plays an important aesthetic and ecological role.
Soil stability [3]	The management of unstable (dispersive) soils is critical for both short and long-term stability.	Soil conditions influence the choice and design of most bank treatment options.	Soil conditions play an important role in bank stability and the risk of post-flood bank slumping.
Rock [4]	Rock is just one of several different types of gully stabilisation measures. The stability of rock work depends on the stability of the underlying soil.	Rock stabilisation can integrate well with most revegetation options. The use of non-vegetated rock should be discouraged.	Vegetated rock can help to stabilise river banks between flood events. Rock cannot be placed directly on an unstable (dispersive or slaking) soil.
Sediment movement [5]	Some bed stabilisation options can capture and retain migrating bed sediment.	The make-up of the creek bed (e.g. clay, sand, gravel) plays an important role in the choice of bed stabilisation options.	The movement of bed sediments can strongly influence the depth and width of river channels.
Fish passage [6]	Rarely important in the treatment of gully erosion.	Can have a strong influence on the choice of both bed and bank stabilisation options.	Influences the choice of bank vegetation. Can play a critical role in the design of bed stabilisation.
Catchment [7]	The stabilisation of gully erosion is critically linked to the management of the drainage catchment, including the use of flow diversion systems, and stock management.	Creek hydrology can be significantly altered by changes in catchment conditions, including deforestation, urbanisation, and fire management.	The catchment area of most river systems is generally so large that no one activity can significantly change the flood hydrology, with the exception of major dams and lake/ wetland systems.

Notes linked to Table 1:

[1] Water issues combine catchment hydrology with channel hydraulics. For creeks and rivers, the critical discharge is typically the bankfull discharge. For gullies, the critical discharge is up to the discretion of the landowner or designer—the term 'bankfull discharge' is typically meaningless. Channel hydraulics focuses on the average channel velocity, and the variation in flow velocity near structures and around channel bends.

[2] Vegetation issues relate to the choice of plant species, their location, density and health, and to the type of root system (e.g. surface roots, tap roots, fibrous roots). The ratio of natives-to-weeds, and the distribution of ground covers, mid-storey and upper storey plants can also impact soil, bank and channel stability. In arid and semi-arid regions, vegetation cover becomes less important because of its low density.

[3] Soil stability focuses on the relative stability of the soil when either 'wet' or 'extremely dry'. Dispersive and slaking soils are unstable when wet. Cracking clays can cause bank instabilities if allowed to dry excessively, particularly if poorly vegetated.

[4] Rock issues focus on the use of loose rock, whether imported or obtained from the channel. If solid bed or bank rock exists, then this usually dominates over most issues. The short-term stability of loose rock usually depends on the diameter of the rock. The long-term stability of rock-lined surfaces usually depends on how well vegetation is integrated into the rock work.

[5] Bed sediment refers to the type and movement of natural bed sediments, not unnatural sediments washed from poorly-managed land. The make-up of the bed sediment is usually categorised as: clay, sand or gravel. The term 'gravel' can include small gravels, cobbles, and boulders. The 'type' and 'volume' of this migrating bed material can have a strong influence over the choice of bed stabilisation measures.

[6] Fish passage becomes an important issue because it can influence the choice and design of bed stabilisation measures in creeks and rivers. Fish passage considerations can also influence the design of bank and overbank vegetation. Fish passage is rarely an issue in the management of gully erosion; however, exceptions do exist.

[7] Catchment management issues include; deforestation, fire management, farm dams, stock management, use and design of fencing, use and design of flow diversion systems (i.e. directing water into or away from a gully), and the management of riparian zones.

Table 2 – Top five issues (general observation only)

Gully erosion	Creek erosion	River erosion
1. Soil conditions (soil science)	1. Vegetation management (except in arid regions)	1. Flow hydraulics, including catchment hydrology
2. Catchment management (topography & hydrology)	2. Catchment hydrology, including flow hydraulics	2. Movement of bed sediment
3. Catchment management (animal management)	3. Soil conditions	3. Soil conditions
4. Vegetation management	4. Use of rock	4. Vegetation management
5. Use of rock	5. Fish passage	5. Use of rock

Table 3 – Likely best source of professional advice (general observation only)

Gully erosion	Creek erosion	River erosion
1. Soil scientist	1. Creek engineer	1. River morphologist
2. Soil conservation officer	2. Waterway or bush rehabilitation officer	2. Flood or waterway engineer
3. Land management officer	3. River morphologist	3. Waterway or bush rehabilitation officer
4. Hydraulic engineer	4. Soil scientist	4. Fisheries officer
5. Waterway or bush rehabilitation officer	5. Fisheries officer	5. Soil scientist

Planning your response to creek erosion (from Part 2, Chapter 8)

Project meeting

Standing tall against bank erosion (Qld)

16 steps to planning and design

Step 1 – Action or no action

- Investigate if the creek erosion actually needs to be repaired.

Step 2 – Ownership

- Which entity owns the land on which the erosion is occurring.

Step 3 – Interested parties

- How many organisations are likely to want to have a say in what you plan to do.

Step 4 – Data collection

- Don't waste money collecting data that you won't need.

Step 5 – Type and cause of erosion

- What form of erosion exists, and what was the likely cause of the erosion.

Step 6 – Channel stability

- Is the channel so unstable that any repairs will likely fail in the short-term.

Step 7 – Setting priorities

- What are you trying to achieve, and who are you trying to make happy.

Step 8 – Assess material options

- Are there any preferred materials, or materials of limited availability.

Step 9 – Assess equipment options

- Assess equipment availability and access to the site.

Step 10 – Develop treatment options

- Is there more than one option for the treatment of the erosion.

Step 11 – Impacts on fauna and flora

- Think about the needs of the creek.

Step 12 – Choose the best treatment option

- Look for the best overall outcome.

Step 13 – Detailed design of the preferred treatment option

- Prepare a detailed design of the preferred option for costing and construction.

Step 14 – Cost estimation

- Prepare a detailed cost estimation of the preferred treatment option.

Step 15 – Recontact interested parties

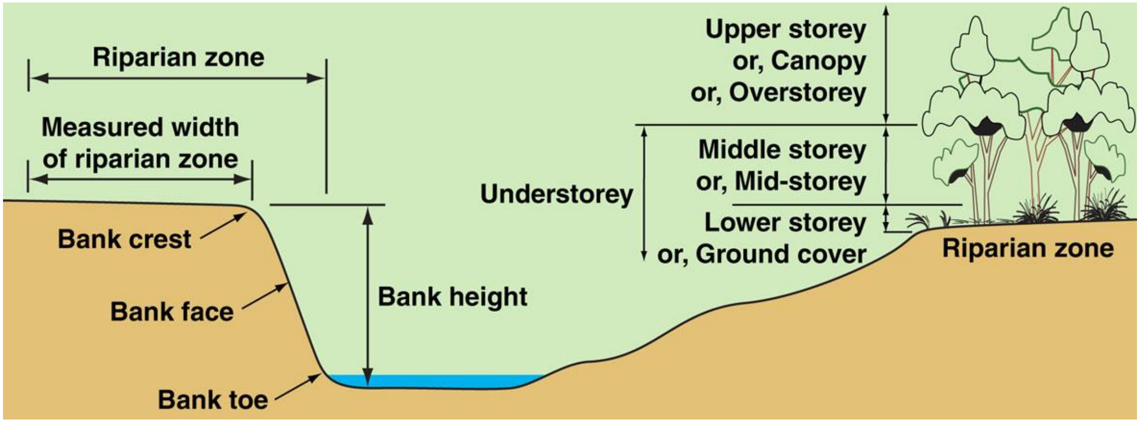
- Don't be a party of one; let people know what you are planning to do.

Step 16 – Obtain approvals and permits

- Get all necessary approvals for your proposed works.

20. Overview of Bank Stabilisation Recommendations

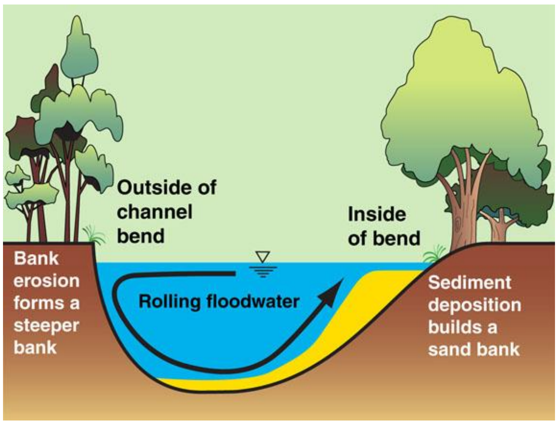
Introduction



Terminology

Post-repair creek inspection (Qld)

Bank slump (Qld)



Typical bank conditions at bends

Introduction

- Critical design issues include:
  - stabilisation of the toe of the bank
  - bank gradients (note; the slope of the lower bank may be different from the upper bank)
  - whether or not to incorporate benching into the bank repair
  - the extent of revegetation, including the width of the riparian zone
  - selection of plant species and plant location.

Matching bank repairs to existing conditions

- The treatment of any bank erosion should pay appropriate attention to the bank conditions immediately upstream and downstream of the bank failure.
- Critical issues include bank height and bank slope (gradient).
- In many cases, the existing bank slope will be steeper than the ideal bank slope suggested for a particular bank repair option.

Differences between the inside and outside of channel bends

- Scour forces are usually much higher on the outside of a channel bend, which increases the need for scour protection.
- Also, floodwaters often ‘roll’ as they pass around a sharp bend, which can cause the formation of an asymmetric cross-section.
- Typically the slope of the outside bank is much steeper than the inside bank on the same bend, and this condition should remain after the bank has been repaired.

Stabilisation of the toe (refer to Part 3, Section 14.8)

Toe erosion (Qld)

The need for toe protection

- Creek banks are often divided into three zones: upper bank, lower bank and toe.
- Scour controls placed along the toe of the bank can be different from those used across the rest of the bank.
- Toe erosion is common along creeks because it can result from just minor increases in stream flow.
- Even though the initial erosion is often minor, it can slowly undermine the rest of the bank.

Geo log toe protection (Qld)

Use of geo logs

- Geo logs have a diameter of around 300 mm and can be manufactured from:
  - jute (made from tropical Asian plants), which have a useable life of a few months, or
  - coir (made from coconut fibre), which is more durable, making it better suited for in-bank use.
- Geo logs need to be well-integrated into the bank and toe vegetation.

Rock toe protection (Qld)

Use of rock

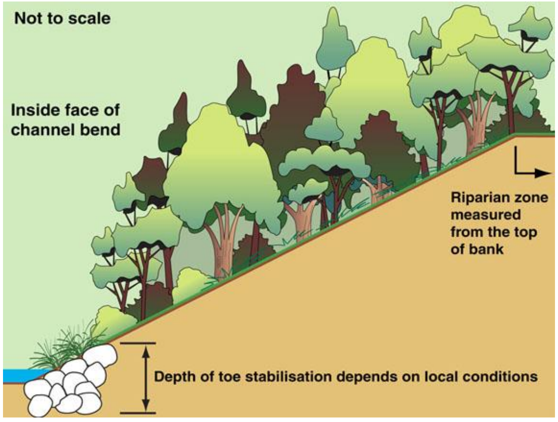
- On creek banks that are fully vegetated, rock is often placed along the toe of the bank, especially on the outside of bends.
- Design issues:
  - typically 300 to 450 mm diameter rock
  - placed to a height of 0.5 to 1.0 m above normal water level
  - the depth below normal bed level depends on bed stability issues
  - ideally fully vegetated to provide shading of the water.

Brushwood toe protection (Qld)

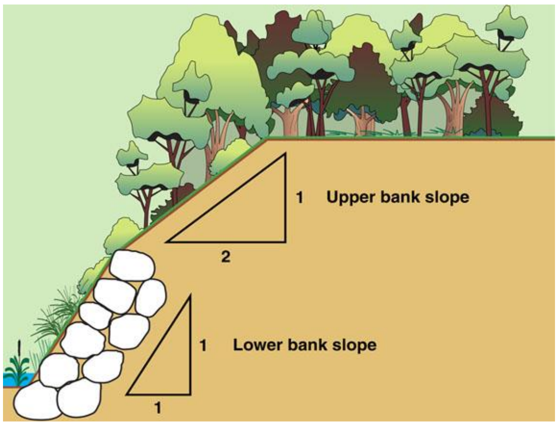
Use of brushwood

- Brushwood is a temporary toe protection system that is likely to survive a sufficient amount of time to allow the establishment of newly planted bank vegetation.
- The loose or tied brushwood is normally retained behind timber posts, which can be enhanced to act like a minor pile field.
- Brushwood banking is typically placed along the outside of channel bends to a height of around 1 metre.

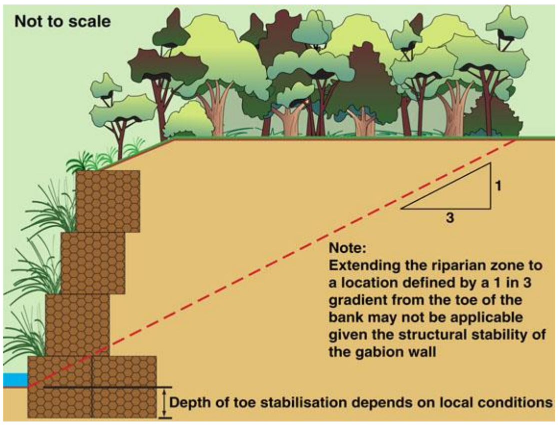
Bank gradients



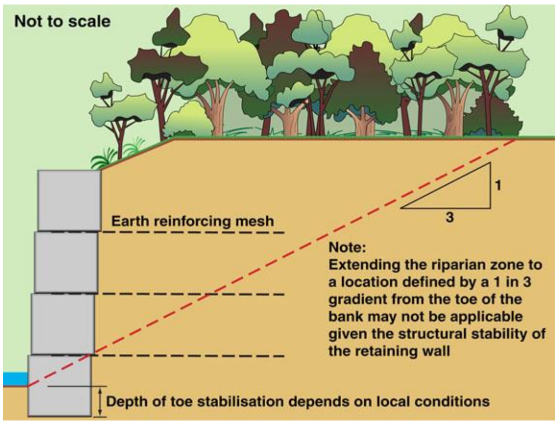
Fully vegetated creek bank



Vegetated dumped rock



Vegetated gabion wall



Modular retaining wall

Vegetated banks

- Recommended maximum gradients:
  - 1 in 2 (V:H) on the outside of channel bends; however, such slopes can be difficult for workers to vegetate, especially on bank higher than 3 metres
  - 1 in 3 on the inside of channel bends.
- If safety issues are expected due to the height or steepness of the bank, then consider adding a 1.5 m wide safety berm, or 4.5 m wide maintenance berm.

Rock stabilisation

- Recommended maximum gradients:
  - 1 in 0.5 for stacked boulders
  - 1 in 1 for vegetated, individually placed rock; however, such slopes can be difficult, if not unsafe, for workers to plant
  - 1 in 2 for dumped rock on the outside of channel bends
  - 1 in 3 for dumped rock on the inside of channel bends.

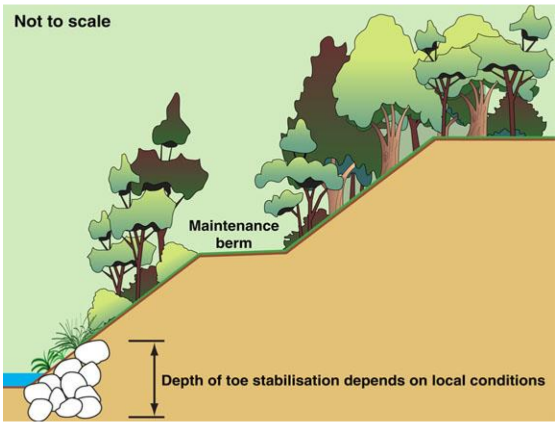
Gabion walls

- Gabion retaining walls can be built vertically, but this is generally not recommended on creek banks.
- The unstable nature of the creek bed and banks means that some slight movement (rotation) of the gabion wall is possible over time; therefore, gabion walls are normally constructed with a slight tilt away from the channel.
- A bank gradient of around 1 in 0.5 is recommended for vegetated gabion walls.

Hard engineering retaining walls

- In-situ concrete walls can be built vertically.
- Modular retaining walls can also be built vertically; however, the unstable nature of the creek bed and banks means that some slight movement (rotation) of the wall is possible over time; therefore, modular walls are normally constructed with a slight tilt away from the channel.
- A 'stepped' wall can provide better public access, which may or may not be desirable depending on site conditions.

Use of benching (refer to Part 3, Section 14.2)



Permanent maintenance berm

Benefits of benching

- Benching a creek bank can provide several benefits, including:
  - increased bank stability (especially if there is the risk of bank slumping)
  - improved access during bank repairs and weeding
  - improved safety for revegetation personnel
  - permanent access for maintenance equipment.

Pedestrian pathway (Qld)

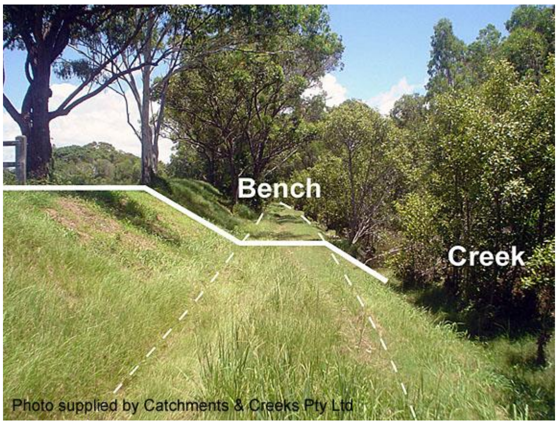
Pedestrian safety berms

- Recommended minimum width of 1.5 m.
- Pedestrian tracks that run parallel with the creek should incorporate some type of zigzag alignment that prevents floodwater from picking up excessive flow velocity along these tracks (i.e. don't let the track become a high-velocity floodway).
- These tracks should also be designed to shed local stormwater runoff from the track at regular intervals in order to prevent soil scour.

Equipment access (Qld)

Equipment access benching

- These are usually temporary berms used during the construction phase for the purpose of allowing equipment access.
- If retained as a permanent feature, these benches can eventually be vegetated, or retained as maintenance berms.
- The minimum width is usually based on the width of the tracked vehicle that is required to use the access bench, which is likely to be between 3.0 and 3.6 metres (refer to examples in Section 22).



Maintenance berm (Qld)

Maintenance berms

- Recommended minimum width of 4.5 m.
- Maintenance berms allow equipment access along the creek in situations where the top of bank:
  - contains critical riparian vegetation, such as mature habitat trees, or
  - the top of bank is privately owned land.
- Maintenance berms can also be used during the removal of flood debris from creeks.

Bank and riparian vegetation (refer to Part 3, Chapter 19)

Riparian vegetation (Qld)

The importance of riparian vegetation

- Riparian vegetation is the vegetation that occurs from normal water level to the edge of the floodplain, and which has a direct association with the watercourse.
- This association can include:
  - erosion control
  - providing hydraulic roughness that reduces flow velocities
  - providing fauna habitat, shelter & food
  - providing flow conditions suitable for fish passage during flood events.

Flood damage to riparian vegetation (Qld)

Living with an 'acceptable level of flood damage' to riparian vegetation

- In engineering terms, any form of 'damage' is normally considered an indication of a design failure.
- However, creek engineering cannot judge its outcomes using such terms.
- The occurrence of vegetation damage during a flood event is not in itself an indication of a design failure; instead, the real measure is based on the long-term success (survival) of the vegetation.

Vegetated rock stabilisation (Qld)

Integrating vegetation into bank stabilisation measures

- Integrating vegetation into bank stabilisation measures provides the following benefits:
  - increased stability of the rock (if used)
  - improved ecological benefits
  - improved aesthetics
  - increased shading of the water
  - increased interaction between aquatic and terrestrial fauna.

Vegetated gabion wall (Qld)

Integrating vegetation into hard engineering options

- Hard engineering repair measures should be limited to the minimum area necessary, and wherever practical, should be fully vegetated.
- Actively planting these surfaces with native vegetation helps to reduce weed invasion, and therefore maintenance costs, as well as all the benefits listed above.

Bank and riparian vegetation (refer to Part 3, Chapter 19)

Site revegetation (Qld)

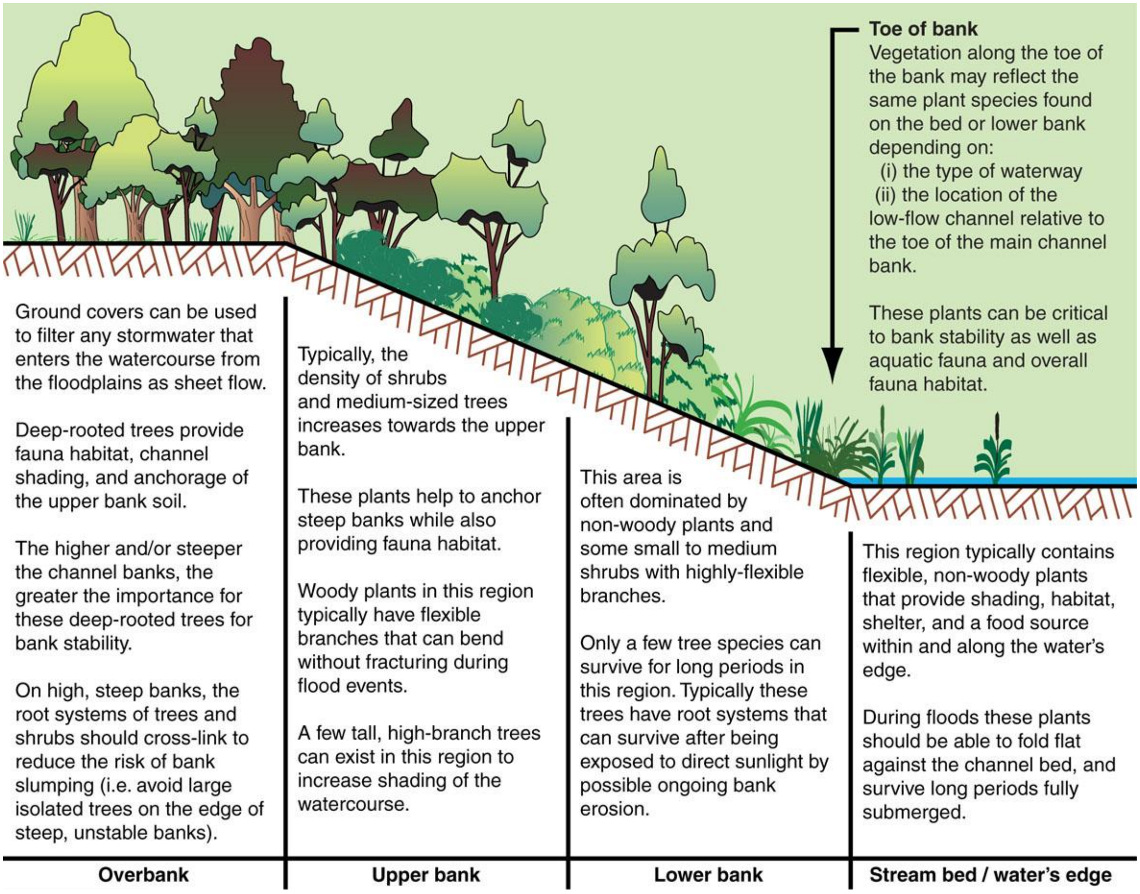
Planting density (general guide)

- An appropriate balance between ground cover, mid-storey and canopy plants is:
  - 50% ground cover species
  - 30% middle storey species
  - 20% upper storey (canopy) species.
- Planting density (spacing) in non-flood control areas could be:
  - 0.5 to 1 m for ground covers
  - 2 to 4 m for mid-storey plants
  - 4 to 5 m for upper storey plants.

Water's edge (Qld)

Planting along the water's edge

- The shading of the water's edge provides the following benefits:
  - control of water temperature (especially in tropical regions)
  - sheltering aquatic life from predators
  - controlling the boundary layer and local stream velocity adjacent to the bank
  - providing a food source for aquatic fauna
  - improving fish passage conditions during flood events.



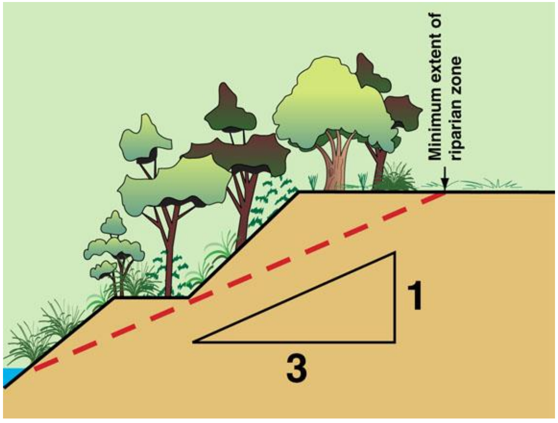
Desirable characteristics of riparian vegetation

Minimum desirable width of riparian zones (refer to Part 3, Section 14.6)

Riparian zone and grassed floodway (Qld)

Minimum width of riparian zone

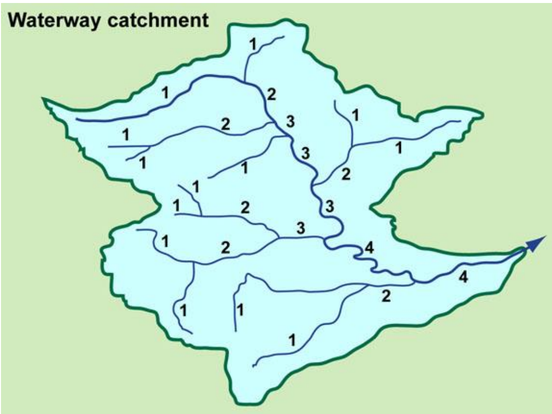
- The suggested minimum width is 5 m.
- However, specifying a minimum width can become problematic if it results in only this minimum width ever being provided.
- In order to filter pollutants from stormwater inflows (sheet flow runoff) the minimum width of the combined riparian zone and grassed floodway is the greater of:
  - 15 m (minimum)
  - 5 times the land slope (i.e. 25 m width for a 5% land slope).



Minimum width based on bank stability

Minimum riparian width based on bank stability recommendations

- The minimum width of the riparian zone depends on numerous local factors, including bank stability requirements.
- It is suggested that the riparian zone should extend at least three (3) times the bank height from the toe of the bank.
- Alternatively, some guidelines recommend a minimum riparian width (measured from the top of bank) equal to the height of the bank.



Horton or Strahler ranking systems

Width based on waterway classification

- Some guidelines nominate a minimum riparian width based on the stream order (1:25,000 mapping), for example:
  - 1st order streams = 5 m (Vic, 2008), or 10 m (NSW, 2012)
  - 2nd order streams = 10 m (Qld, 2001), or 20 m (NSW, 2012)
  - 3rd order streams = 15 m (Vic, 2008), or 30 m (NSW 2012)
  - 4th order streams = 15 m (Vic, 2008), or 40 m (NSW 2012).

Bank revegetation (Qld)

Additional allowance based on the time required to establish new vegetation

- If the land near the top of the bank is largely absent of riparian vegetation, and new plantings are being proposed, then the minimum width of the riparian zone should take account of the expected movement (erosion) of the creek bank during the establishment period of this new vegetation.
- Depending on the local growing conditions, this establishment period may vary from 10 to 25 years.

Treatment of dispersive and slaking soils (refer to Part 3, Chapter 16)

Dispersive soil creek banks (NSW)

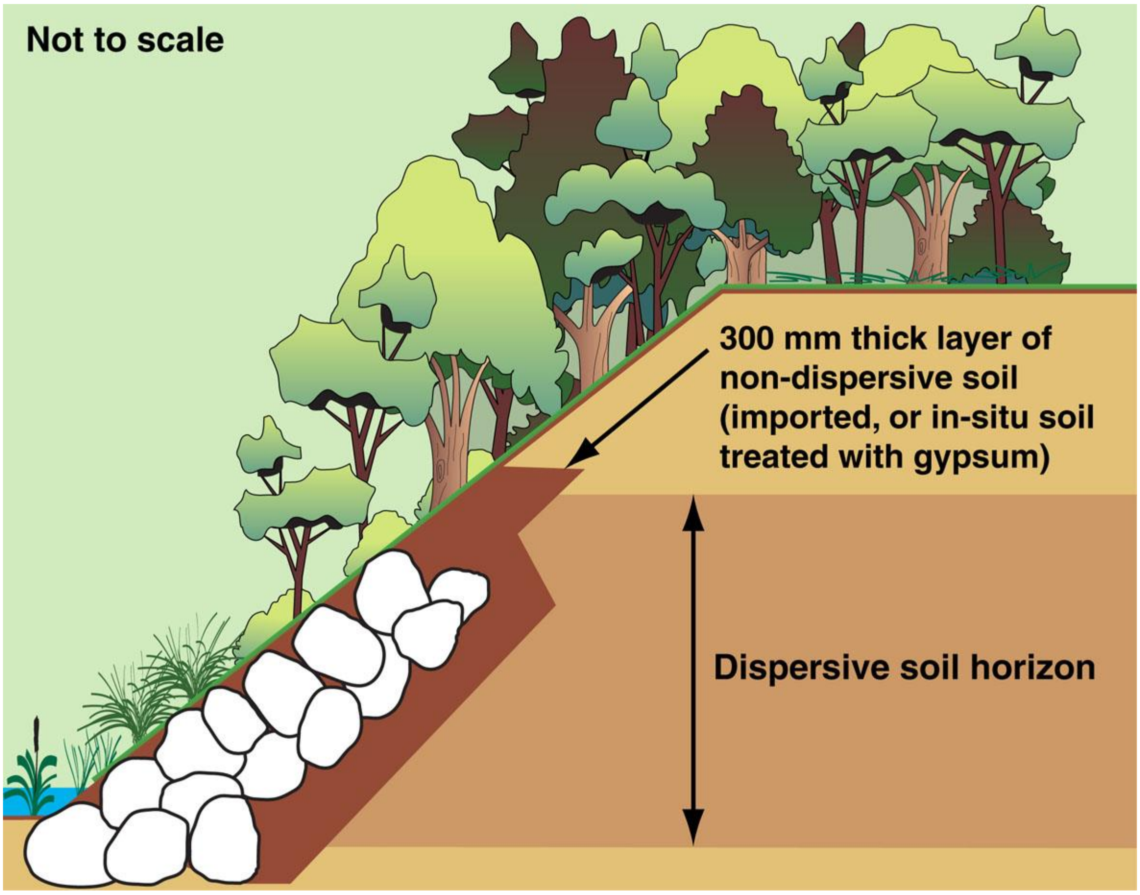
Dispersive soils

- Dispersive soils are structurally unstable when immersed in water, breaking down into their constituent particles (sand, silt and clay).
- Once exposed by bank erosion, these subsoils **must** be buried under a minimum 300 mm layer of non-dispersive soil (imported or treated) before placing any vegetation, rock, or other cover material.
- A 100 mm thick cover is often specified away from waterways, but is considered insufficient for creek rehabilitation.

Slaking soil gully erosion (Qld)

Slaking soils

- 'Slaking' is the natural collapse of a soil aggregate in water when its mechanical strength is insufficient to withstand the swelling of clay, and the expulsion of air from pore spaces.
- Slaking soils lack the dispersive clay content of a dispersive soil, so creek flows may not become highly turbid in a slaking soil area.
- Slaking soils are usually very sandy, and often associated with granite country.



Example of rock stabilisation over a dispersive subsoil

21. A Guide to the Selection of Bank Stabilisation Options

Bank stabilisation options based on the type of erosion

Bank scour (Qld)

Bank scour

- The primary cause of bank scour is excessive flow velocities, which means the preferred treatments are usually:
  - vegetated rock, or
  - battering of the bank followed by revegetation with appropriate species.
- Alternative treatment options include:
  - flow diversion techniques (to direct velocities away from the bank)
  - vegetated gabions and mattresses.

Bank slumping (Qld)

Bank slumping

- The primary cause of bank slumping is usually inappropriate vegetation cover, which means the preferred treatments are:
  - benching and revegetation
  - battering and revegetation
  - riparian management.
- Alternative treatment options include:
  - vegetated rock
  - vegetated gabions and mattresses.

Bank undercutting (Qld)

Bank undercutting

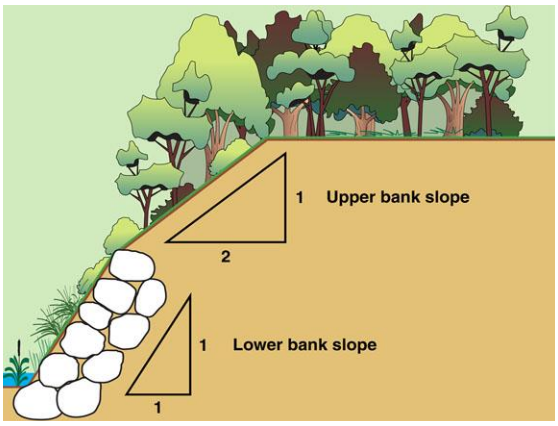
- The primary cause of bank undercutting is excessive flow velocities around the lower levels of the bank, which means the preferred treatments are:
  - vegetated rock
  - benching and toe protection.
- Alternative treatment options include:
  - flow diversion techniques
  - vegetated gabions and mattresses.

Gully erosion within a dispersive soil (Qld)

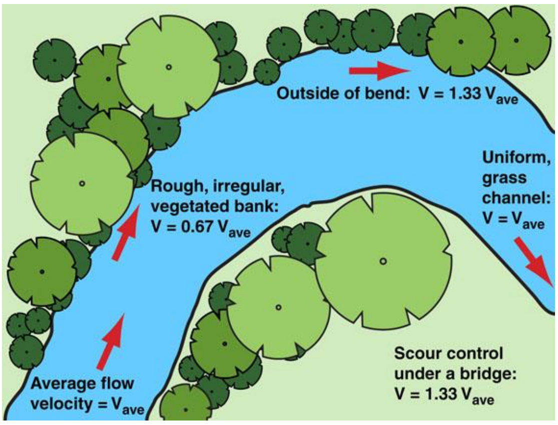
Soil dispersion and fluting

- If dispersive or slaking subsoils become exposed to stream flows, then the preferred bank treatments are:
  - battering, covering the bank with non-dispersive soil, then revegetation
  - as above plus vegetated rock
  - benching and toe protection.
- Alternative treatment options include:
  - riparian management
  - vegetated gabions and mattresses.

Bank stabilisation options based on bank slope and flow velocity



Bank slope



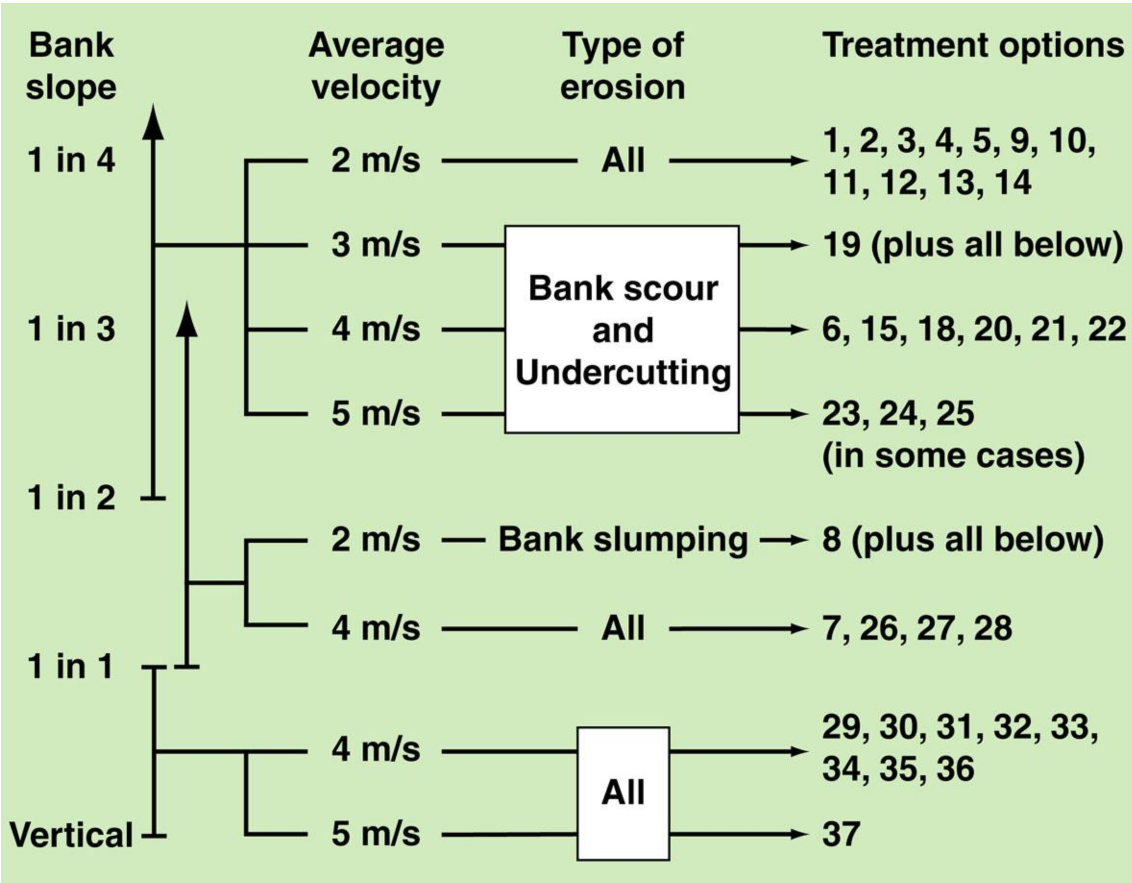
Velocity multipliers for channel bends

Design issues associated with bank slope

- The decision tree presented below provides a **simplified** procedure for the short listing of bank stabilisation options based on various site conditions.
- In this case, bank slope usually refers to the slope of the lower portion of the bank.
- The maximum slope of rock depends on its method of placement:
  - 1 in 2 slope for dumped rock
  - 1 in 1 slope for individually placed rock
  - near-vertical for stacked boulders.

Design issues associated with flow velocity

- The average velocity refers to the average channel velocity (not the local velocity).
- The nominated maximum flow velocity is just a guide (i.e. not absolute), and will vary with the size of the waterway, and whether the bank is located on the inside or outside of a channel bend.
- The treatment options recommended for a specific stream velocity can also be used for lower velocities (for the same bank slope).



Simplified decision tree for the selection of bank stabilisation options

Option 1. Battering, full vegetation, toe stabilisation, on inside of bend

Bank revegetation (Qld)

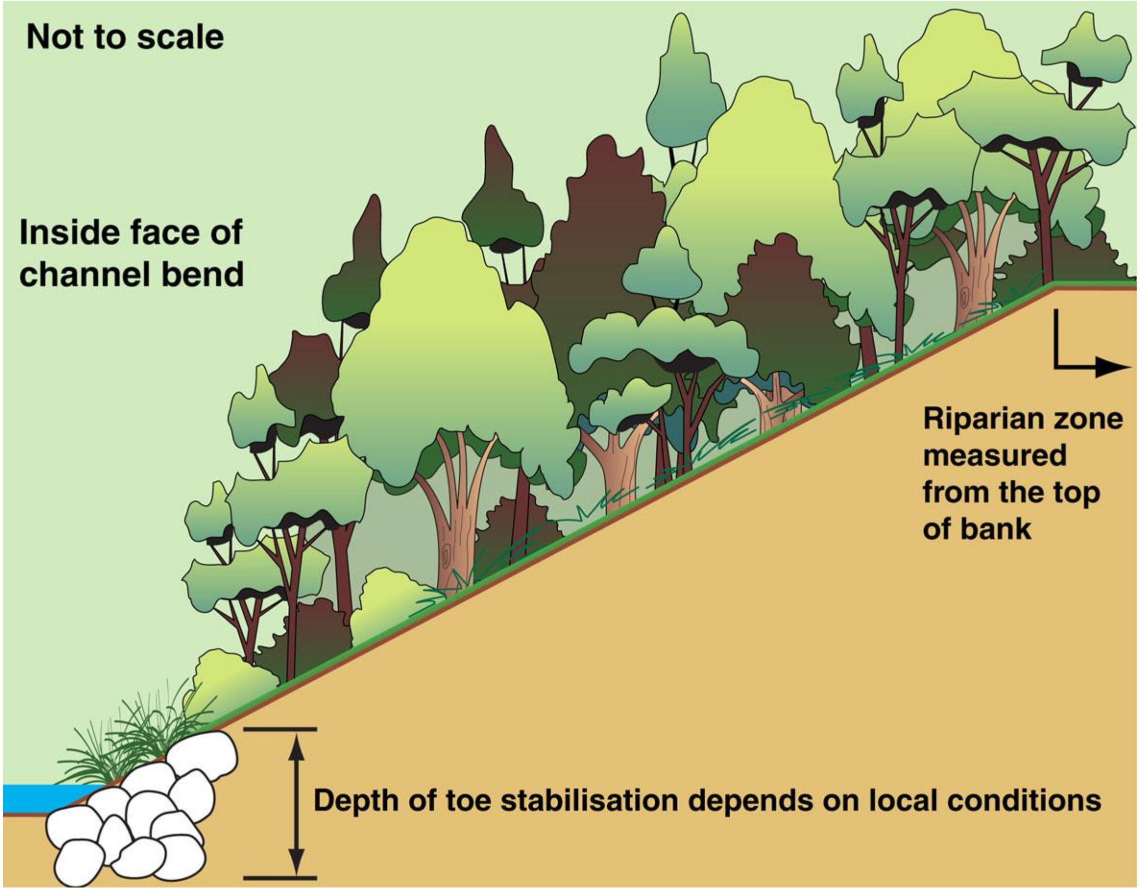
Inside bank with toe protection (Qld)

Description

- Bank stabilisation involves bank reshaping, possibly at a lower gradient:
  - either importing fill to replace soil previously washed away, or
  - requiring only the use of the existing soil.
- Finally the bank is revegetated, most likely with the aid of temporary erosion control blankets, mulch, and geo logs.
- Also refer to options 5 to 11.

Design issues

- On the inside of channel bends, bank slopes are usually flatter than along the outside of the same bend (but not always).
- Bank slopes of 1 in 3 to 1 in 6 (V:H) can be expected, which allows for safe working conditions during planting operations.
- Additional toe protection may or may not be required along the inside of channel bends, but is usually recommended (refer to Part 3, Section 14.8).



Option 1: Full vegetation on a low-gradient bank, on the inside of a channel bend

Option 2. Battering, full vegetation, toe stabilisation, on outside of bend

Bank revegetation (Qld)

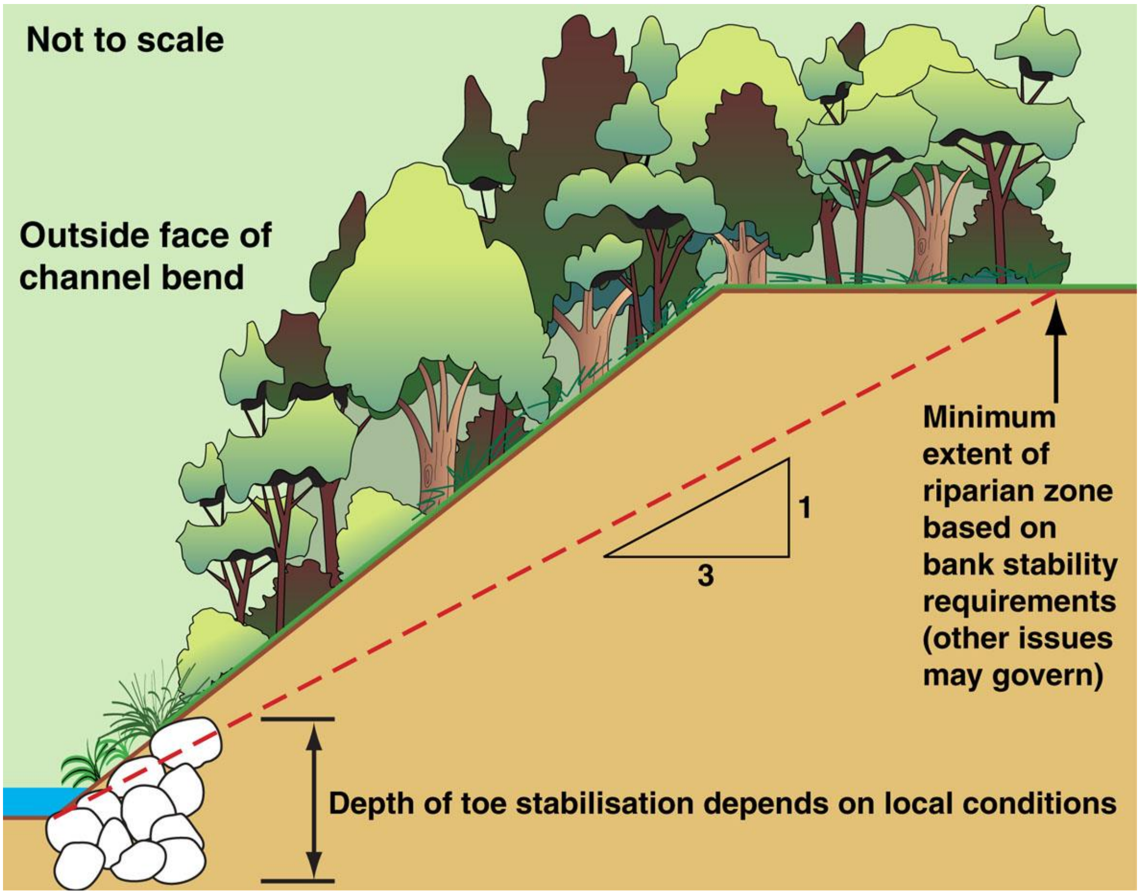
Bank revegetation with toe rock (Qld)

Description

- Bank stabilisation involves battering the outside of a channel bend:
  - possibly using imported fill to replace soil already washed away, or
  - requiring only the use of the existing soil.
- Finally the bank is fully vegetated, most likely with the aid of temporary erosion control blankets, mulch, and geo logs.
- Also refer to options 5 to 11.

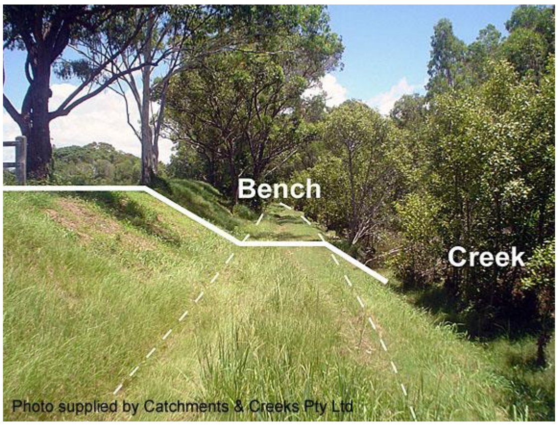
Design issues

- Bank slopes on the outside of bends are generally steep, possibly 1 in 1.5 to 1 in 2.
- Safety risks can exist for people working on banks taller than 2 metres if the bank slope is steeper than 1 in 2 (V:H).
- Benching the bank can reduce these safety risks.
- Some type of toe protection is normally required on the outside of bends, usually involving rock to a height of 1 metre, or higher, depending on the flow velocity.



Option 2: Full vegetation on a medium-gradient bank, on the outside of a channel bend

Option 3. Battered bank with bench and toe stabilisation



Benching of a creek bank (Qld)

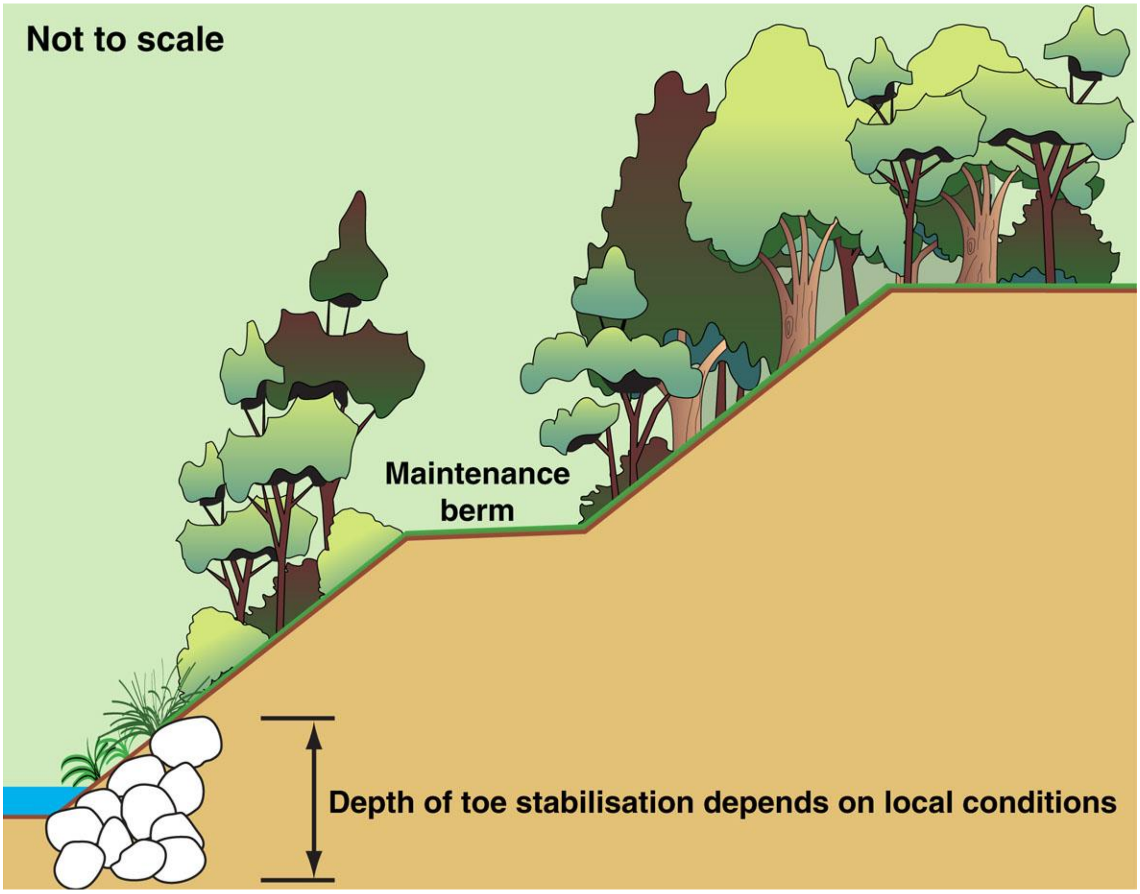
Description

- Bank stabilisation involves reshaping the bank to introduce either:
  - a safety berm to improve safety and provide maintenance access
  - a temporary vehicle access berm to aid construction access
  - a maintenance berm to provide access for maintenance vehicles.
- Benching the bank improves safety conditions and bank stability.

Benching of a river bank (Qld)

Design issues

- Width of a bench/berm is typically:
  - 1.5 m for safety berms
  - 3.0 to 3.5 m for construction access
  - 4.5 m for maintenance berms
- These maintenance berms can also be used as public access pathways, and possibly as bikeways.
- Benching can occur on both sides of channel bends; however, on the outside of bends, vegetation should not consist solely of soft grasses.



Option 3: Full vegetation with bench and toe stabilisation

Option 4. Battered bank with revegetation and geo log toe protection

Geo log toe protection (Qld)

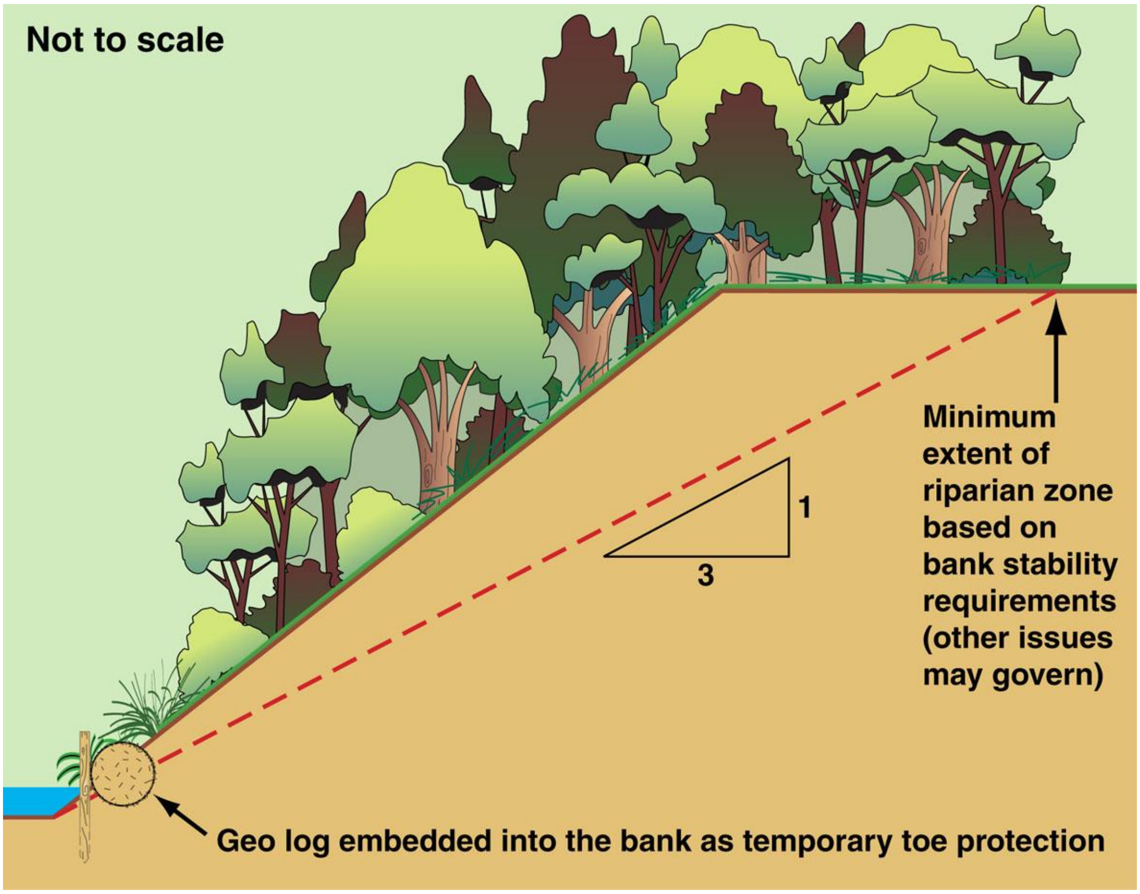
Description

- Temporary scour control is provided to the toe of a creek bank through the use of geo logs anchored (staked) in good contact with the bank.
- This is not a permanent scour control measure, but instead a component of bank revegetation.

Geo log toe protection (Qld)

Operational issues

- Geo logs should be appropriately integrated with toe vegetation so that as they decay, the creek bank remains stable (i.e. vegetation replaces the geo logs).
- The spacing of the anchoring stakes is normally around 1 metre, but should not exceed 1.5 metres.



Option 4: Full bank revegetation with temporary geo log toe protection

Option 5. Bank revegetation with the aid of geo logs

Geo logs placed on a creek bank (Qld)

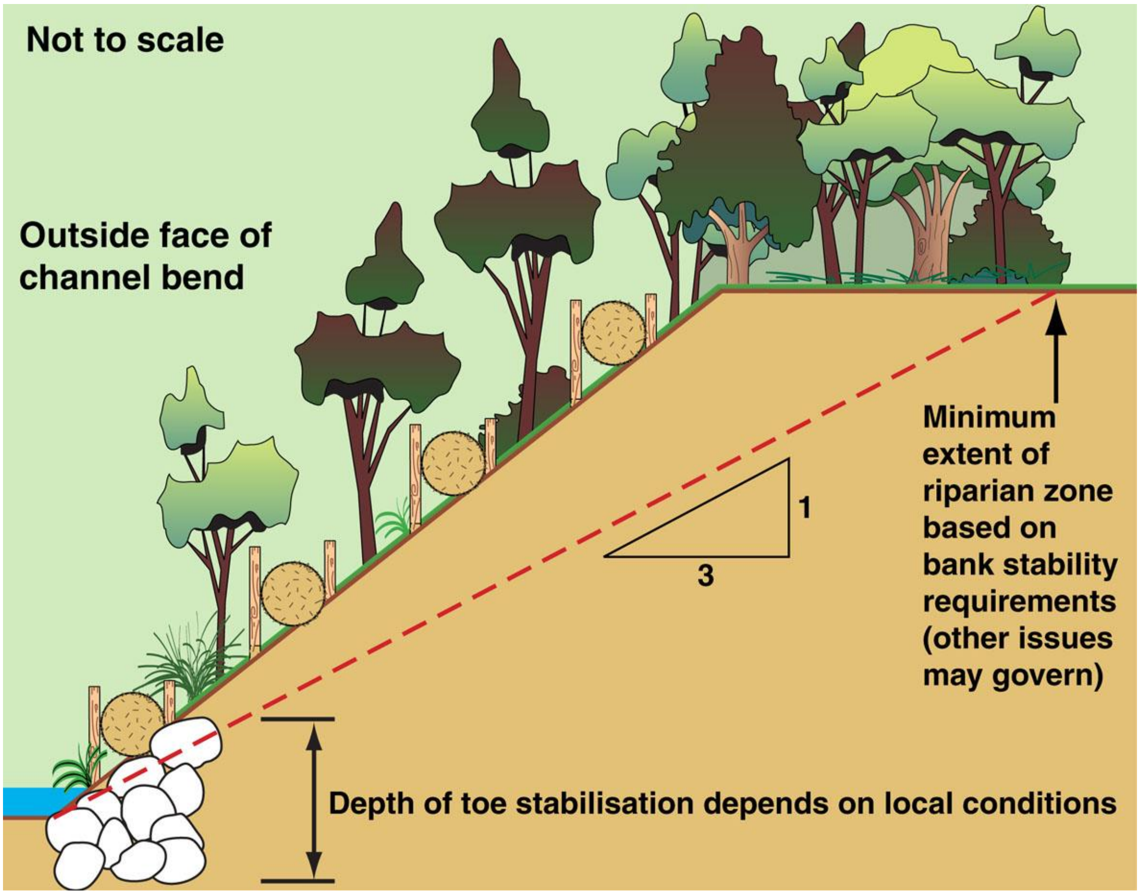
Geo logs placed on a creek bank (Qld)

Description

- This is a component of bank revegetation.
- When used in this manner, geo logs are likely to achieve the following outcomes:
  - control of stormwater runoff (reducing the risk of rilling and lateral bank erosion)
  - holding mulch on steep slopes
  - slowing and pooling stormwater runoff to increase water infiltration into the soil, thus aiding plant establishment.

Design issues

- Installation requirements are typically:
  - installed along the contour (i.e. across the slope)
  - ideally, installed with a vertical spacing not exceeding 2 metres (that is the difference in elevation of subsequent rows)
  - mulch should be pushed up against the up-slope face of the geo log to reduce the risk of stormwater runoff tunnelling under the logs.



Option 5: Full vegetation with toe stabilisation, and geo logs

Option 6. Bank revegetation utilising a monoculture of stiff grasses

Recent *Lomandra* planting (Qld)

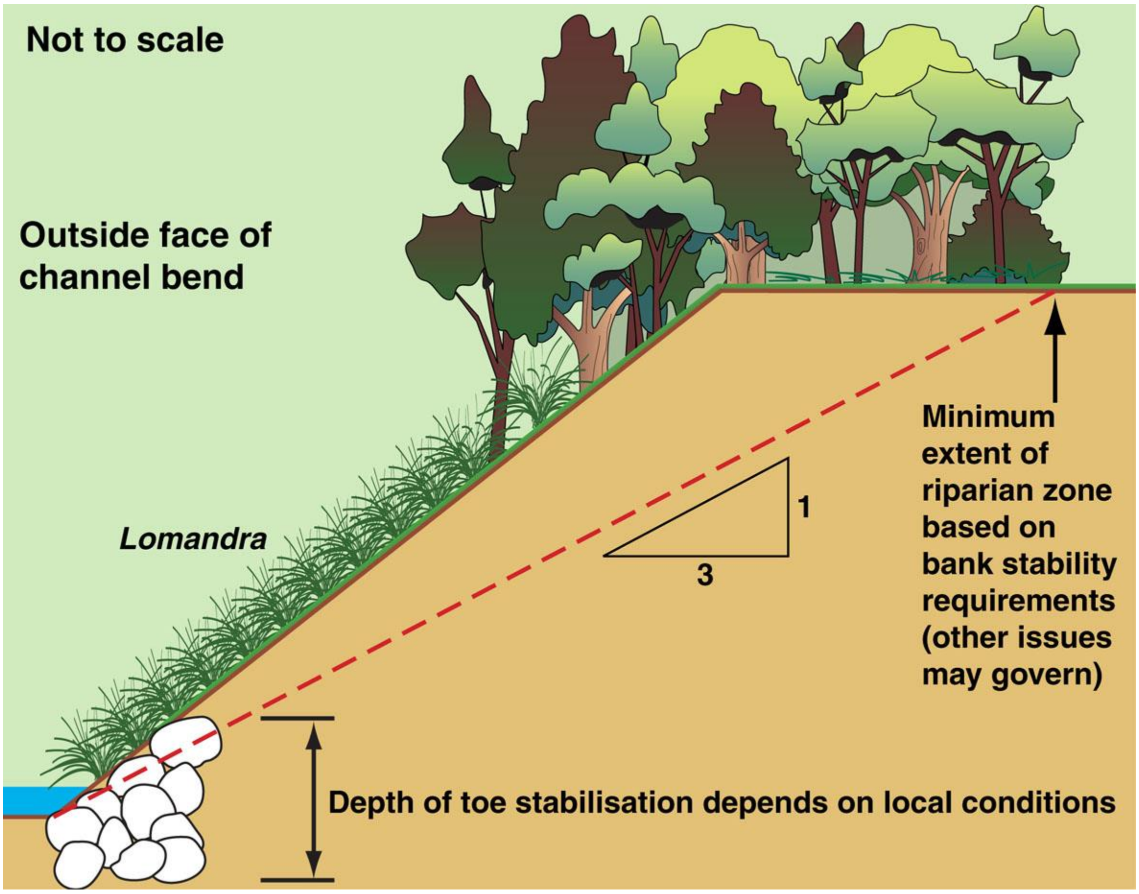
West Creek, Toowoomba, Qld

Description

- This is a bank revegetation option that focuses on the planting of stiff grasses, possibly as a monoculture, in order to gain the following benefits:
  - control bank scour in locations of high flow velocity (> 3 m/s local velocity)
  - minimise water turbulence caused by high-velocity flows passing around woody trunks and branches.
- Additional toe protection may be required (e.g. geo logs or rock).

Design issues

- The most commonly used stiff grass in waterways is *Lomandra hystrix*.
- Plant spacing is around 0.5 m.
- A monoculture may only need to cover the lower bank region, with shrubs dominating the upper bank area.
- The photo (left) shows a section of West Creek, Toowoomba after the 2011 flood, which caused severe scour along many parts of the creek, but this vegetation survived largely undamaged.



Option 6: Bank stabilisation using a monoculture of *Lomandra* plants

Option 7. Bank revegetation utilising a monoculture of vetiver grass

Recent planting of vetiver grass (Qld)

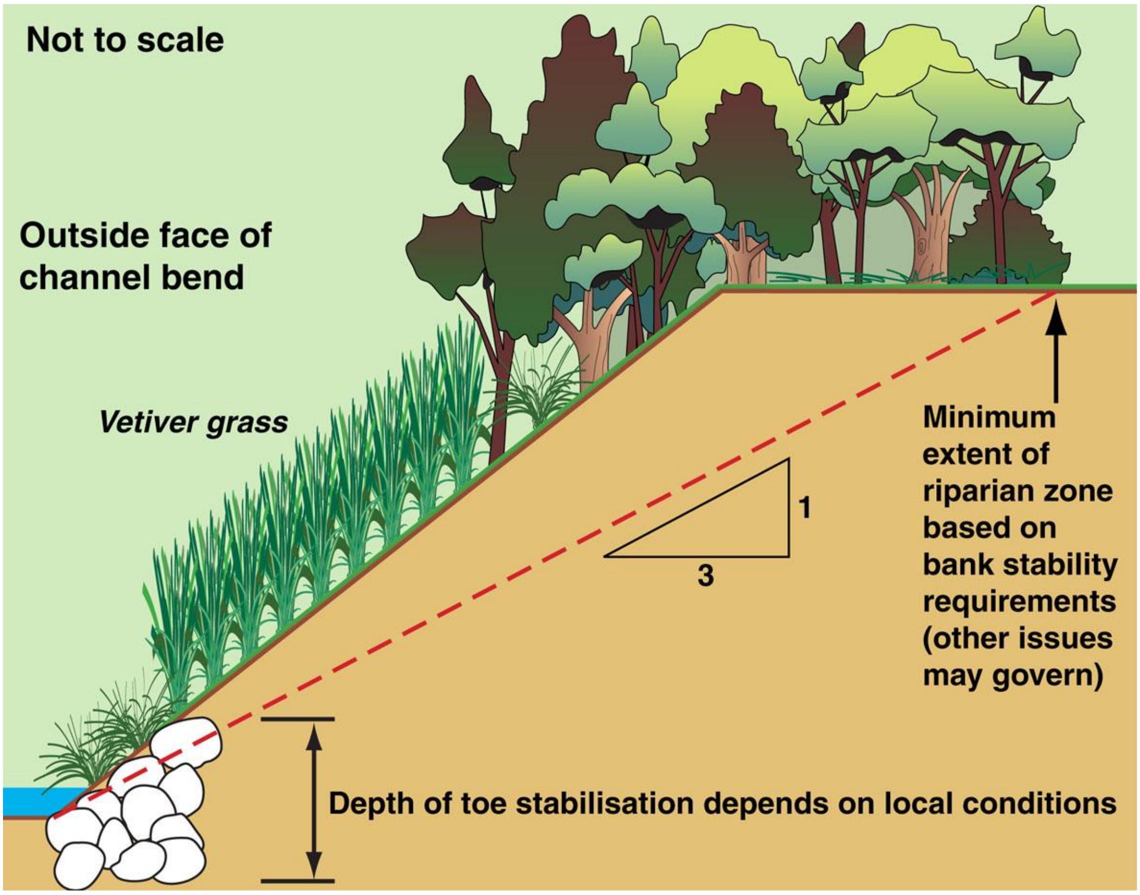
Mid-growth stage of vetiver grass (Qld)

Description

- This is a revegetation option that focuses on the planting of a specific stiff grass in order to gain the following benefits:
  - control bank scour in locations of very high flow velocity
  - stabilisation of deep, sandy soils
  - stabilisation of creek banks that face the risk of shallow bank slumping.
- Additional toe protection may be required (e.g. geo logs or rock).

Design issues

- The stiff grass used for this process is *Chrysopogon zizanioides* (vetiver grass).
- Planting is usually in rows spaced approximately 1 m apart, with individual plants spaced less than 0.3 m apart within a given row (the close spacing of seedlings is not an issue because the individual plants do not 'compete' with each other).
- Vetiver grass may only cover the lower bank region, with shrubs dominating the upper bank.



Option 7: Bank stabilisation using a monoculture of vetiver grass

Option 8. Bank battering with the aid of earth reinforcing mesh

Earth reinforcing mesh (Qld)

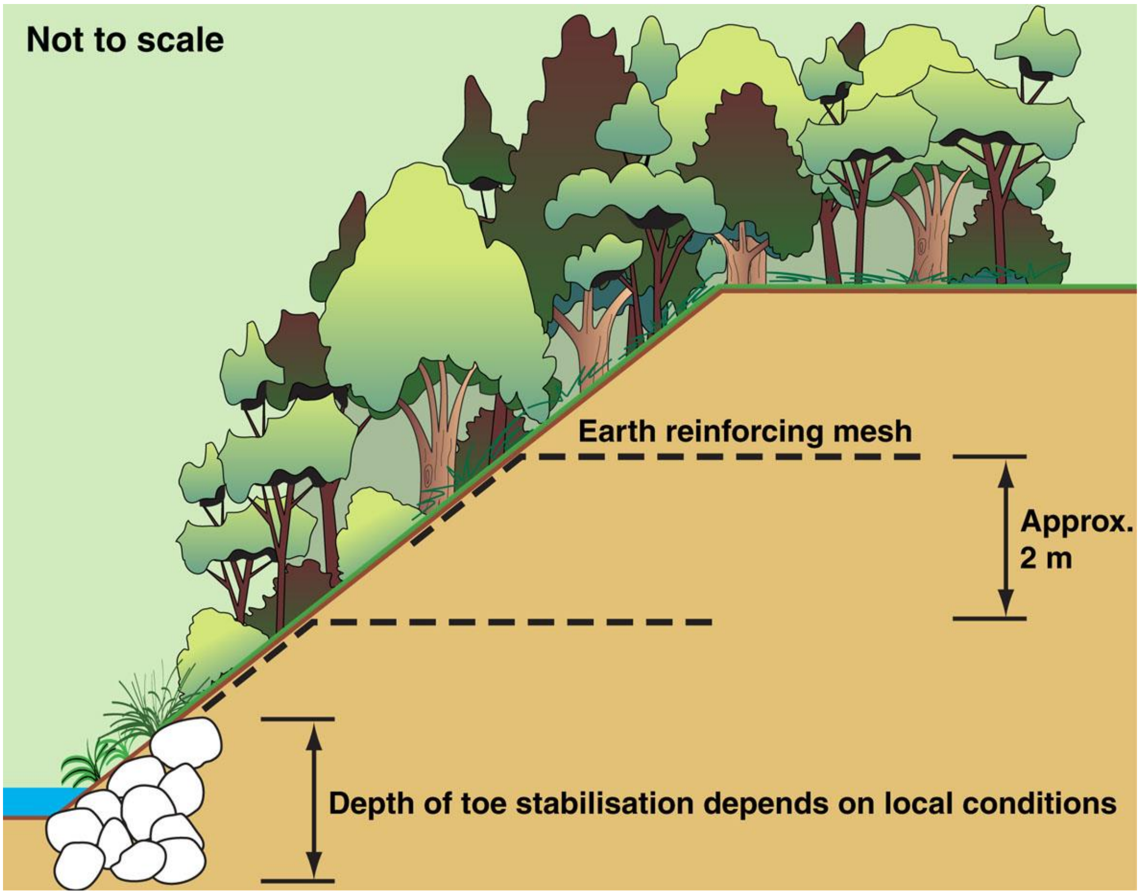
Description

- Bank stabilisation is achieved through the use of earth reinforcing mesh, possibly in association with deep-rooted plants.
- The earth reinforcing provides bank stability during the establishment phase of the deep-rooted plants.
- This type of bank repair is rare in waterway rehabilitation, but can be used when a roadway or other structure is positioned near the top of the bank.

Treated slope prior to planting (Qld)

Design issues

- Earth reinforcing systems should be designed by appropriately trained geotechnical engineers.



Option 8: Full vegetation with toe stabilisation and earth reinforcing

Option 9. Bank revegetation with the aid of temporary catch fencing

Mulch collecting on a wire mesh fence

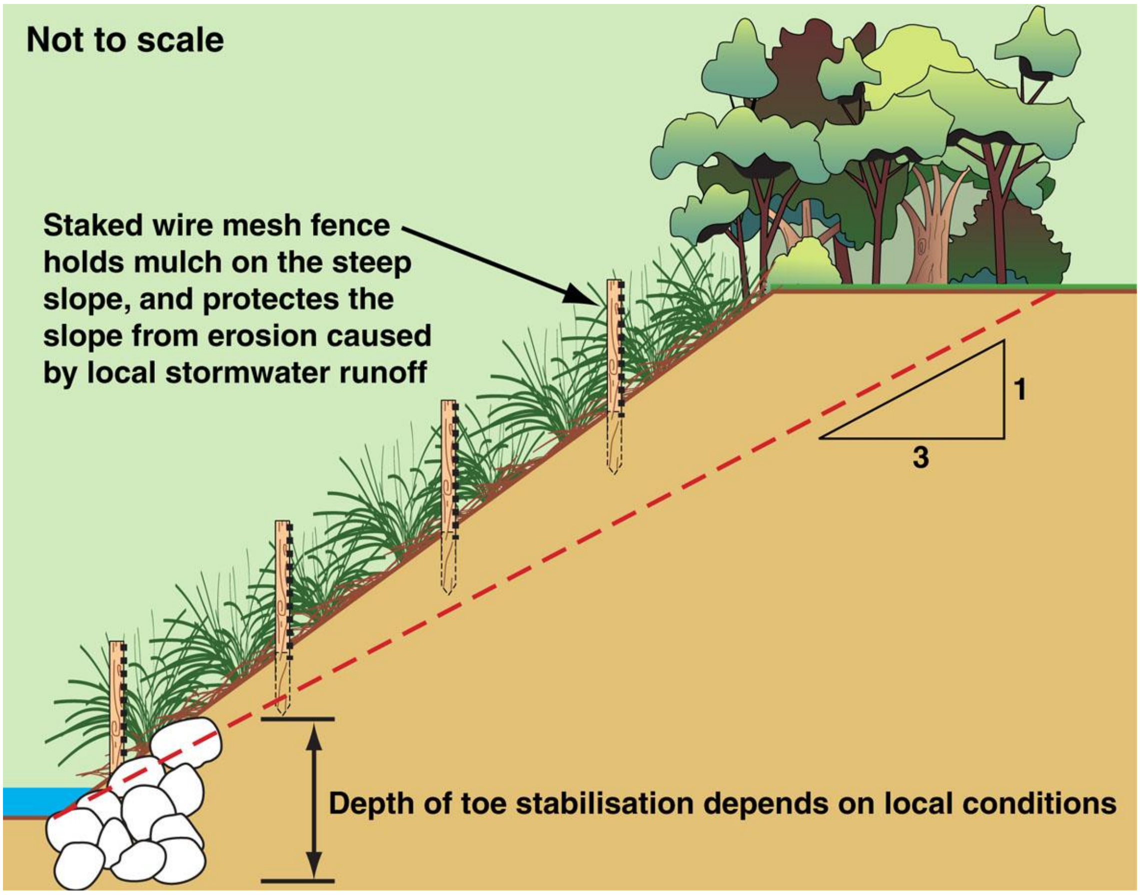
Terraced bank revegetation (Qld)

Description

- This is a revegetation option that aims to achieve the following outcomes:
  - the retention of loose mulch on steep creek banks
  - the slowing of stormwater runoff down creek banks in order to increase water infiltration into the soil
  - potentially providing safe working conditions for revegetation personnel working on steep slopes (additional design features may be required).

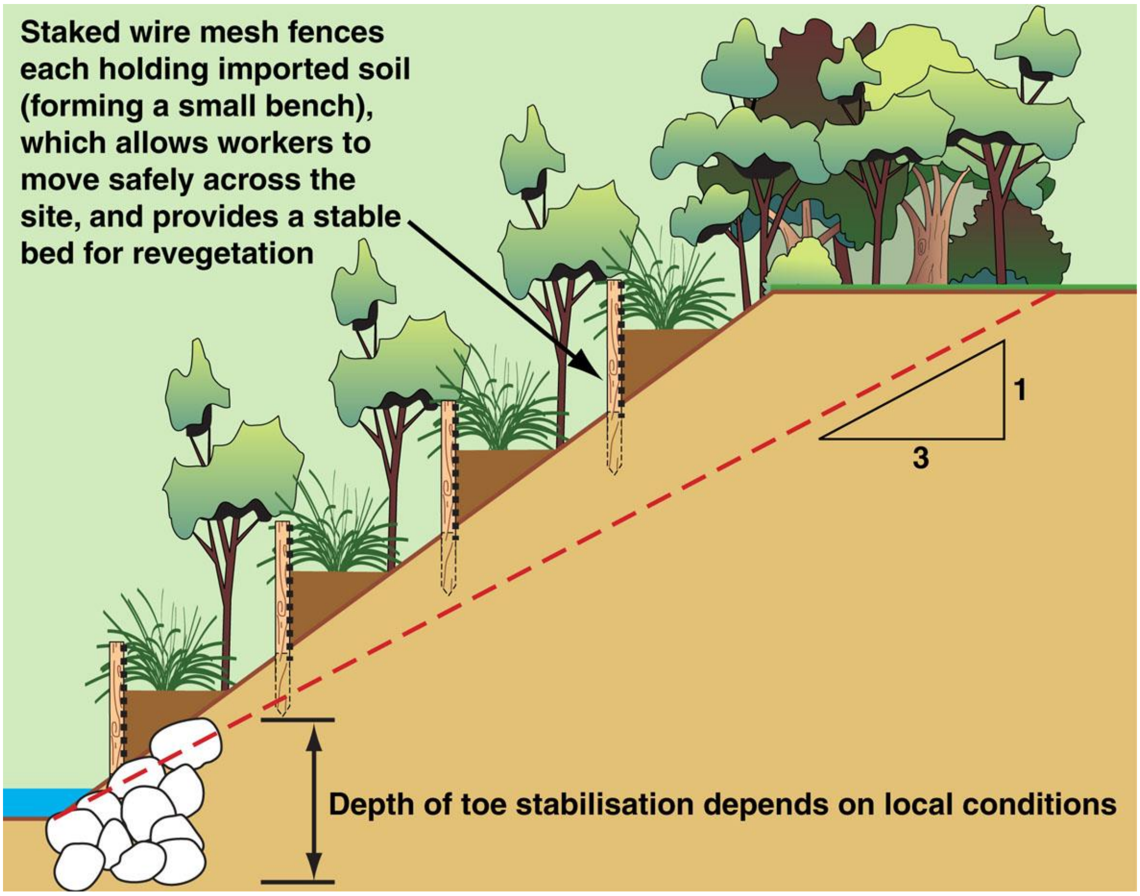
Design issues

- Used on bank slopes steeper than 1 in 3.
- No specific fence designs exist; instead, each case is individually designed to achieve the desired outcomes.
- Alternative designs (over page) involve using fencing or gabions to terrace steep slopes to aid bank revegetation.
- In some cases the fence can be used to protect recently established bank vegetation from minor flood flows.

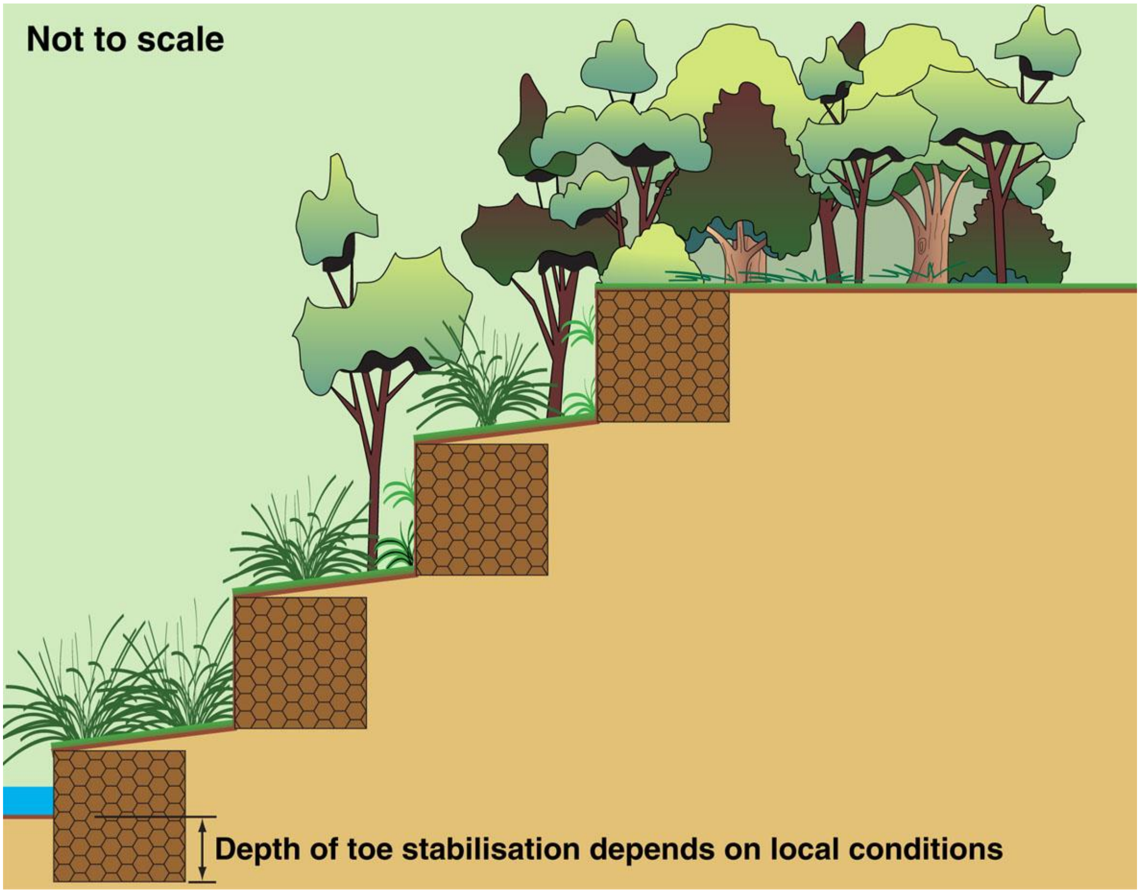


Option 9: Bank revegetation with the aid of wire mesh catch fencing

Options 10 & 11. **Terraced bank revegetation**



Option 10: Bank revegetation with partially backfilled catch fencing



Option 11: Bank revegetation using a terraced-gabion approach

Option 12. Lower bank brushing with upper bank vegetation

Brushwood bank stabilisation (Qld)

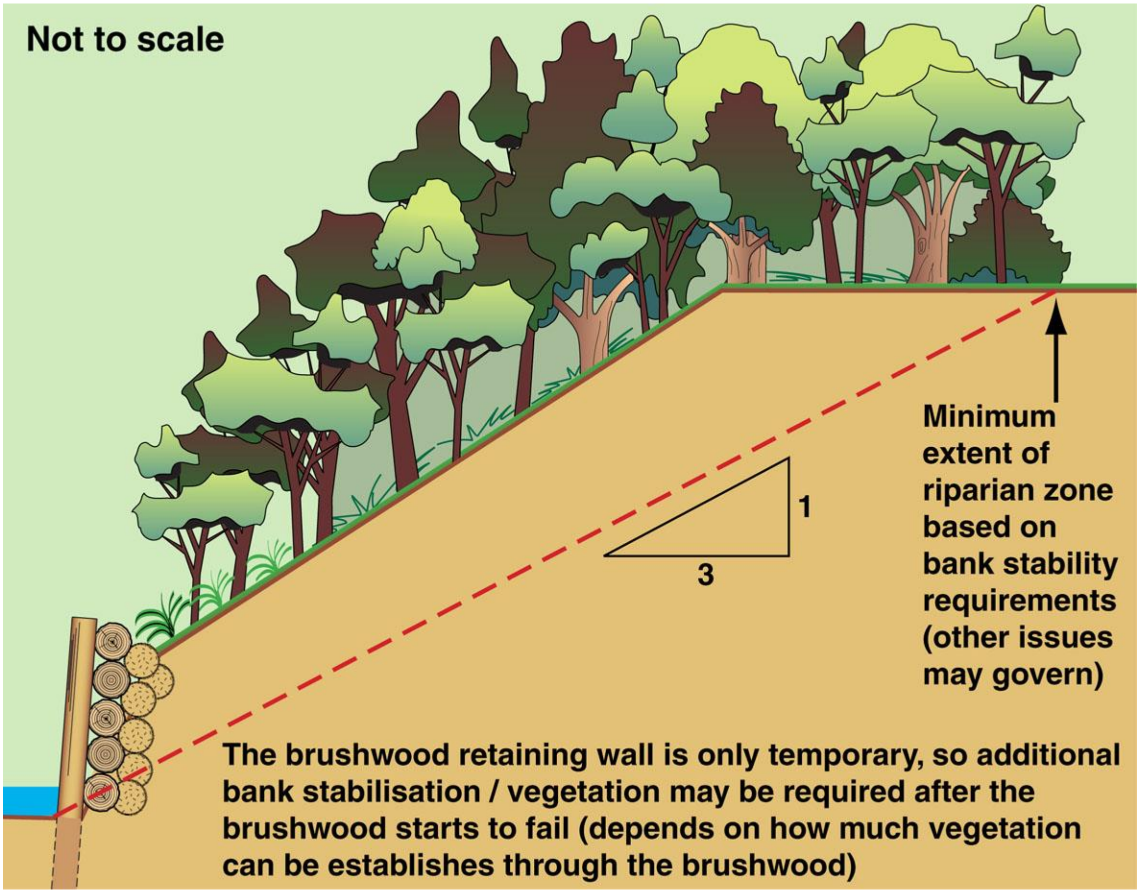
Description

- Brushwood banking (or brushing) is a temporary toe protection system that is likely to survive long enough to allow good growth of newly established bank vegetation.
- Locally-obtained brushwood is anchored to the toe of the bank with the aid of firmly-driven posts.

Brushwood bank stabilisation (Qld)

Design issues

- The brushwood can be loose or tied in bundles.
- Brushwood banking is typically placed along the outside of channel bends to a height of around 1 metre.
- The timber posts can be designed to act like a minor 'pile field' at the toe of the creek bank (which usually requires more than one row of posts).



Option 12: Lower bank brushing with upper bank vegetation

Option 13. Lower bank brushing with upper bank vegetation and bench

Brushing of overbank area (Qld)

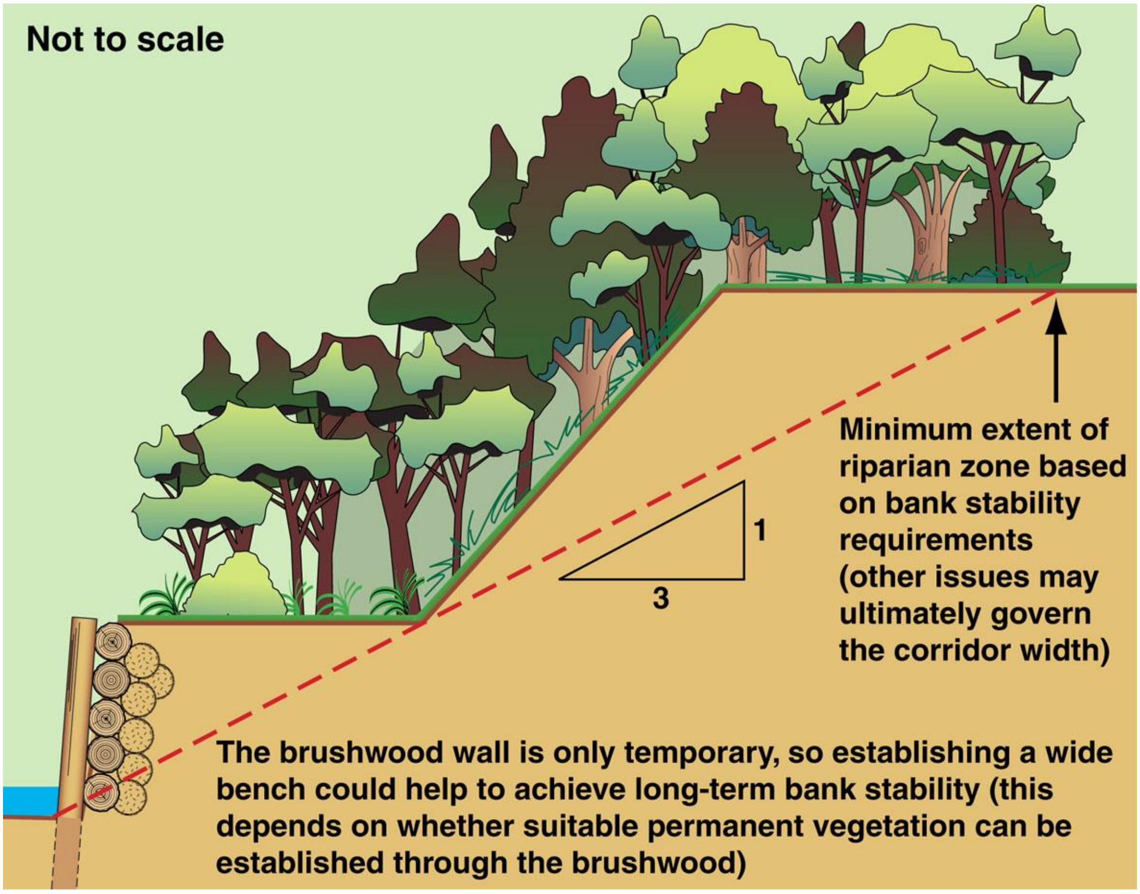
Old benched brushwood stabilisation (Qld)

Description

- Brushing is a temporary toe protection system, which is typically used in association with full bank revegetation.
- Brushing can also be applied to overbank areas with the aim of encouraging native seed to germinate within areas of cleared bushland.
- This option incorporates the benching of the slope to help:
  - push flows away from an eroded bank
  - reduce the risk of bank slumping.

Design issues

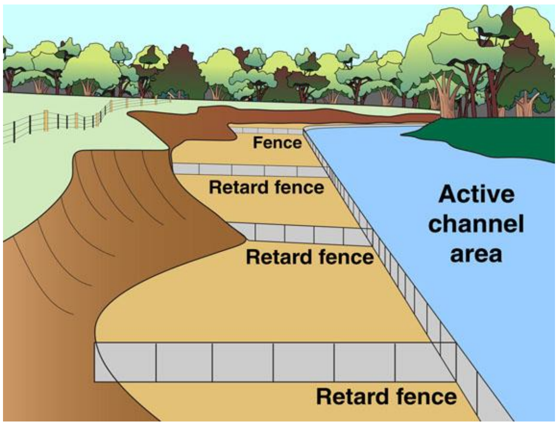
- Benching a creek bank can provide several benefits, including:
  - increase bank stability (especially if there is the risk of bank slumping)
  - provide equipment access during bank repairs (refer to Chapter 22)
  - improve worker safety during bank revegetation
  - provide permanent access for maintenance equipment.



Option 13: Lower bank brushing with upper bank vegetation and bench

Option 14. Stream alignment training using retard fencing

Retard fencing used in gully erosion (Qld)



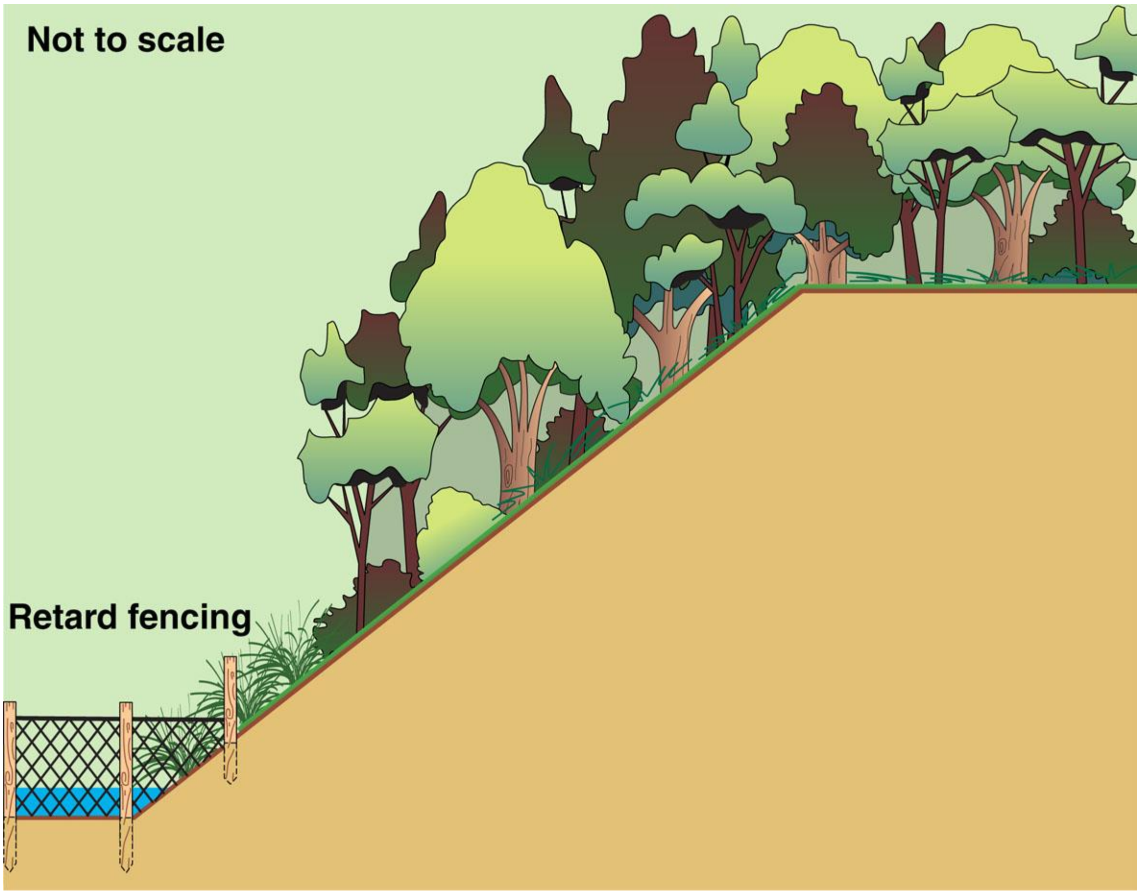
Retard fencing on a wide-bed river

Description

- Retards are low fences installed across the bed of waterway channels for the purpose of:
  - helping to guide a meandering or braiding channel away from an eroding river bank
  - helping to stabilise the toe of an unstable bank
  - helping to capture and hold natural river sediments at the base of an unstable bank in order to form a bench.

Design issues

- Retard fencing is most commonly used in wide-bed, alluvial (i.e. sand or gravel-based) waterways.
- The fencing is normally around 1.0 to 1.5 m high, but part of the fence may be recessed below the current bed level if the bed is unstable.
- Variations on retard fencing can be used in overbank areas to deflect floodwater away from newly established vegetation (e.g. using geo logs, low wire-mesh fencing, or sediment fence fabric).



Option 14: Retard fencing (only part of the retard fence is shown)

Option 15. Toe stabilisation using a pile field

Pile field (Qld)

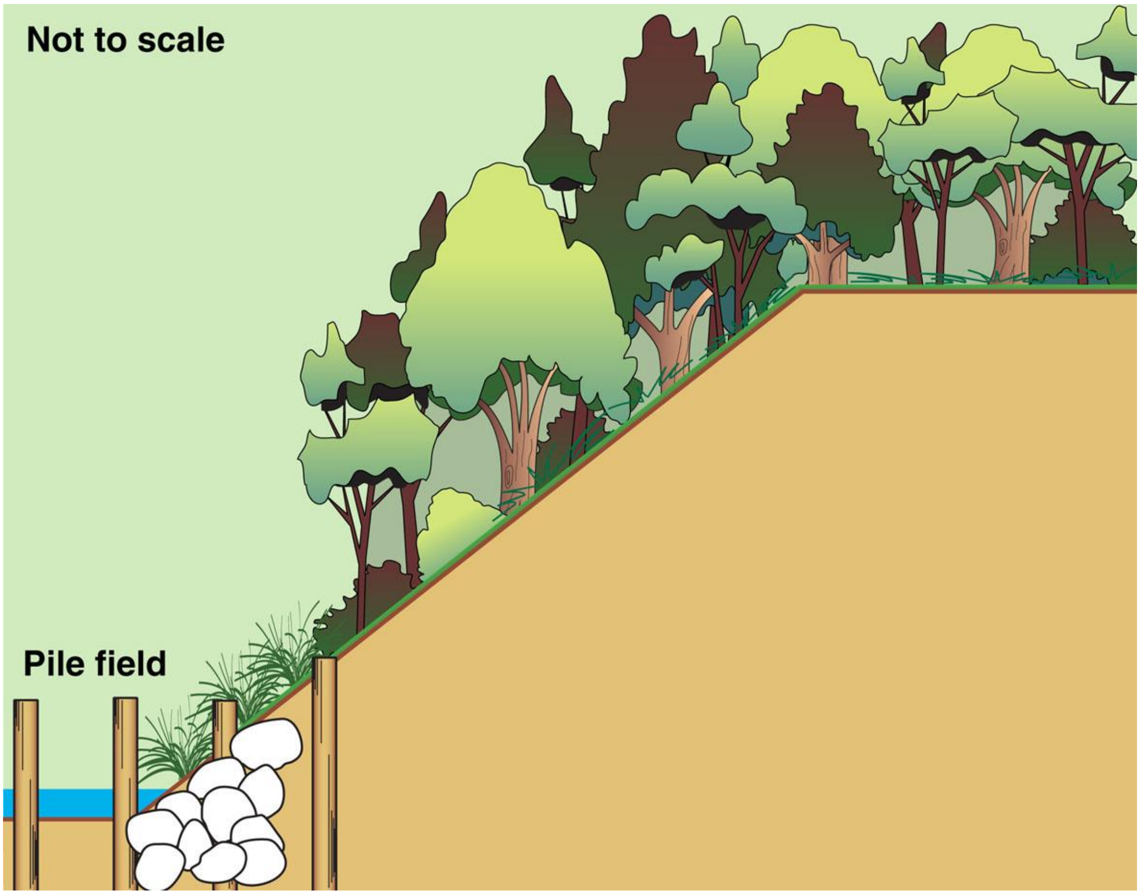
Pile field at the base of a creek bank (NSW)

Description

- When severe erosion impacts a creek bank, the root systems of undermined trees can become exposed to water flow, which helps to slow this flow, and ultimately helps to protect the soil under these trees from further erosion.
- A 'pile field' works in the same way as a collection of exposed tree roots, it slows the water flow, captures flood debris, and helps to divert stream flows away from the creek bank.

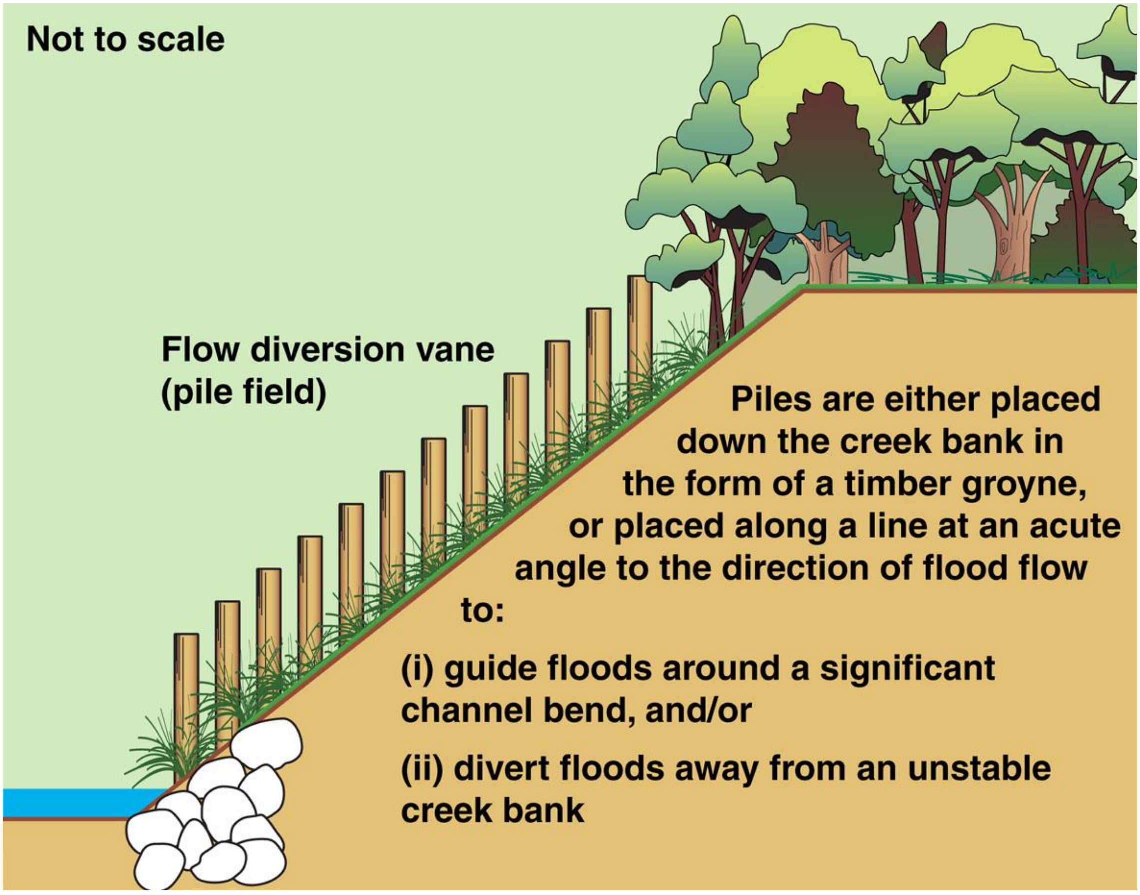
Design issues

- Pile fields consist of a collection of partially exposed timber posts that are either:
  - located in a narrow grid along the base of a creek bank (as toe protection), or
  - located in a line down the face of a creek bank to operate as a flow diversion vane, or as a timber groyne (Option 16), or
  - located in a narrow band across a channel to operate as a permeable grade control structure (Option 17).

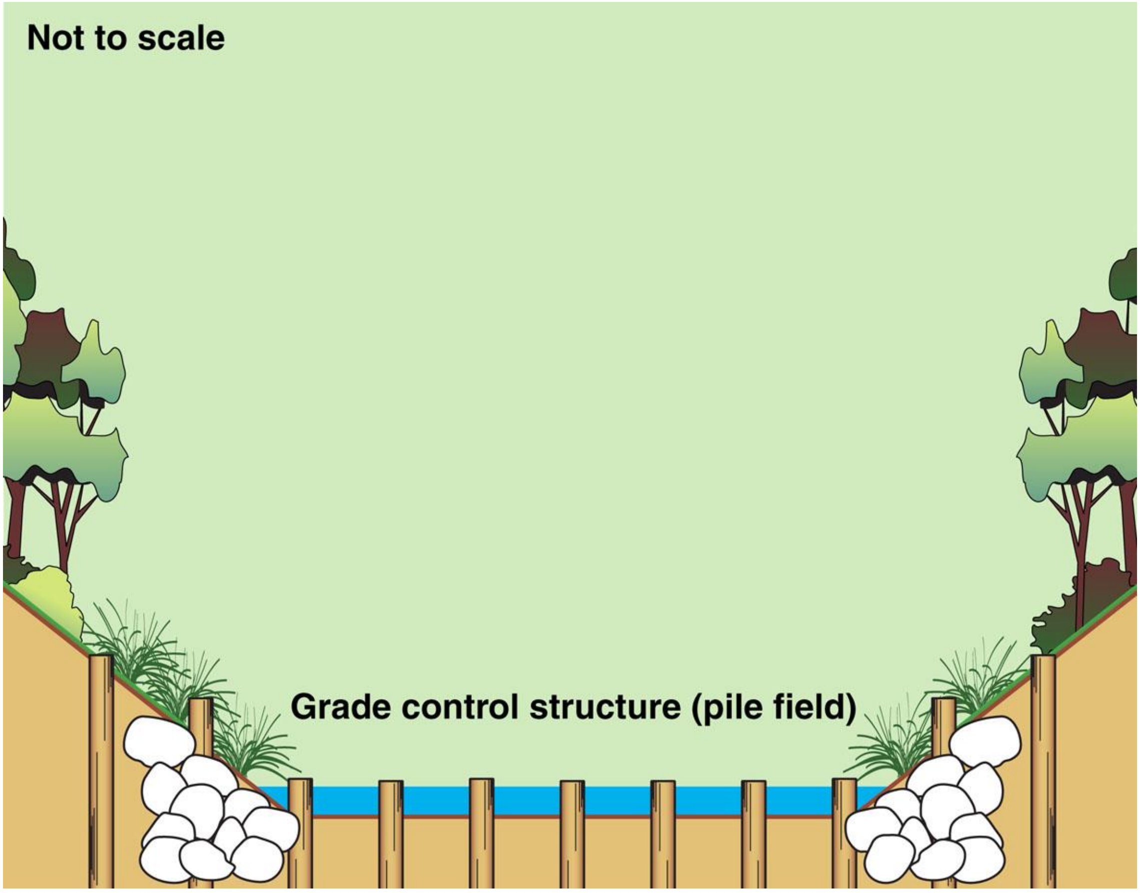


Option 15: Toe stabilisation using a pile field

Options 16 & 17. Alternative pile field arrangements



Option 16: Flow diversion vane (pile field)



Option 17: Grade control structure (pile field)

Option 18. Stream alignment training using rock or timber groynes

Boulder groynes (Qld)

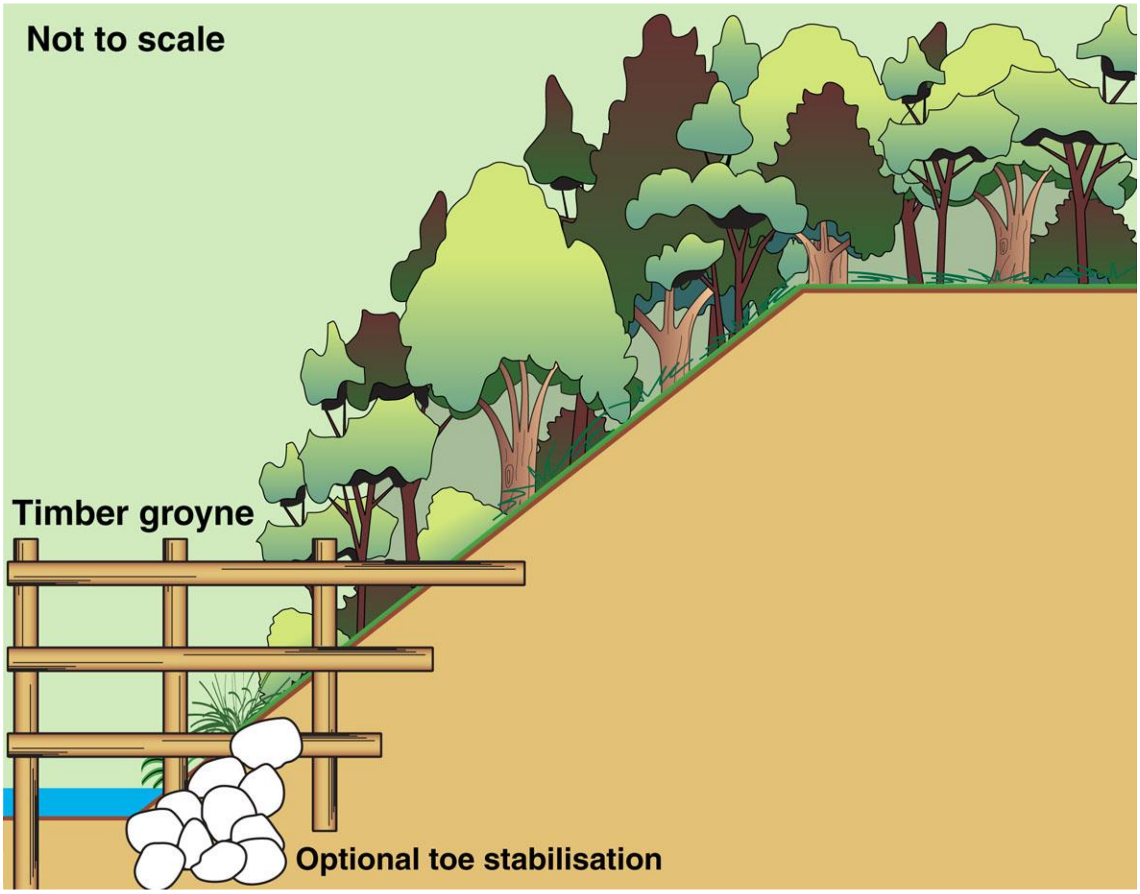
Timber groynes (Qld)

Description

- Flow diversion groynes may consist of:
  - boulder walls extending from the bank
  - permeable timber fences projecting from the bank.
- Groynes act to:
  - guide the alignment of a meandering or braiding waterway channel
  - divert stream flows away from newly established bank vegetation.

Design issues

- Groynes are generally taller and shorter (in length) than retard fencing, but similar outcomes can be achieved by both systems depending on the site conditions.
- Boulders typically consist of 600 to 1000 mm rock.
- Timber groynes are normally formed from non-treated timber to facilitate their slow decay while long-term woody vegetation (shrubs) establishes between the groynes.



Option 18: Toe stabilisation and alignment training using timber groynes

Option 19. Channel stabilisation using log jams

Log jam (Qld)

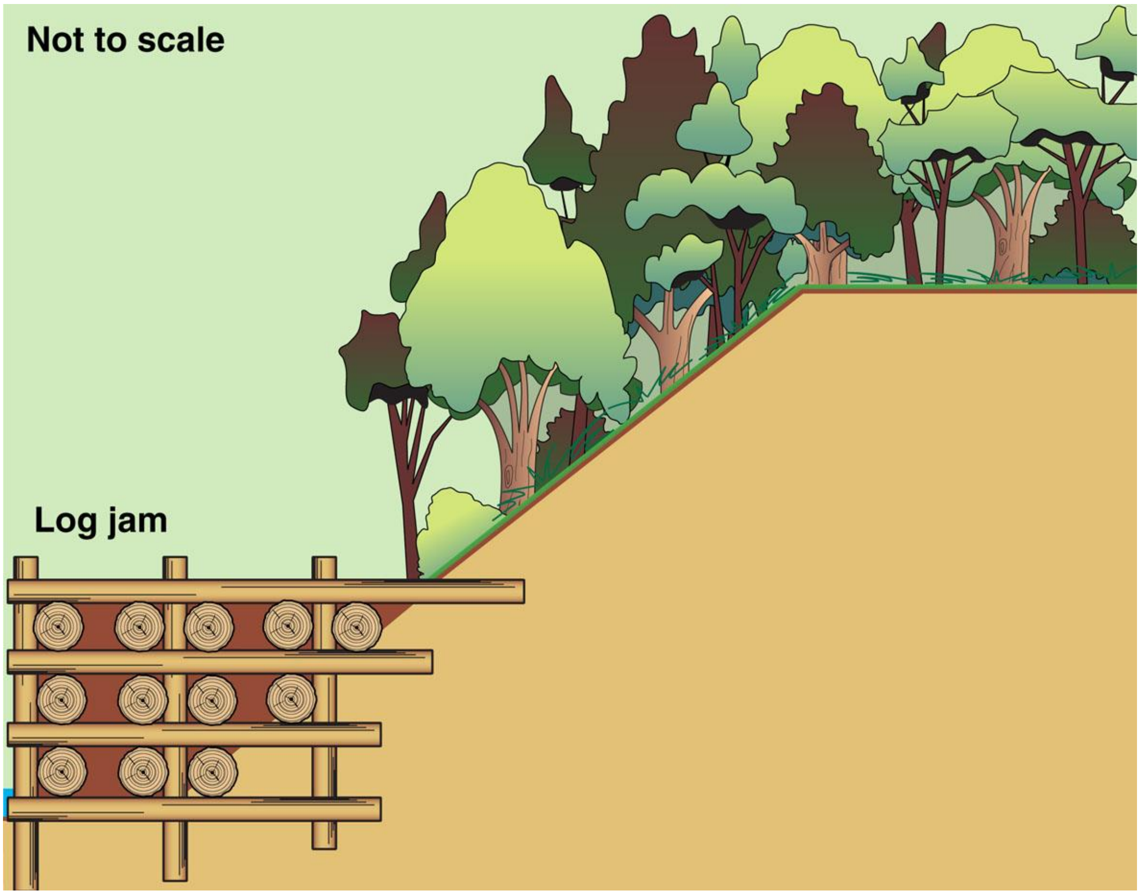
Log jams (Qld)

Description

- Log jams are constructed from well-anchored timber posts and tree trunks, typically taking the form of a wide triangular, or long narrow 'finger' groyne.
- Log jams typically perform the following functions:
  - deflect stream flows away from the outside bank of channel bends
  - contribute to the overall slowing of floodwater, thus helping to reduce erosion and downstream flooding.

Design issues

- Log jams are usually spaced further apart than traditional groynes, which:
  - reduces construction costs, but
  - increases the risk of bank erosion and vegetation damage in the area between each log jam.
- Consideration must be given to the potential for floodwaters to erode behind the log jams, a risk that can be reduced by installing a buried pile field behind those log jams at most risk of flood damage.



Option 19: Channel erosion control using log jams

Option 20. Vegetated rock stabilisation on the inside of a channel bend

Vegetated rock stabilisation (Qld)

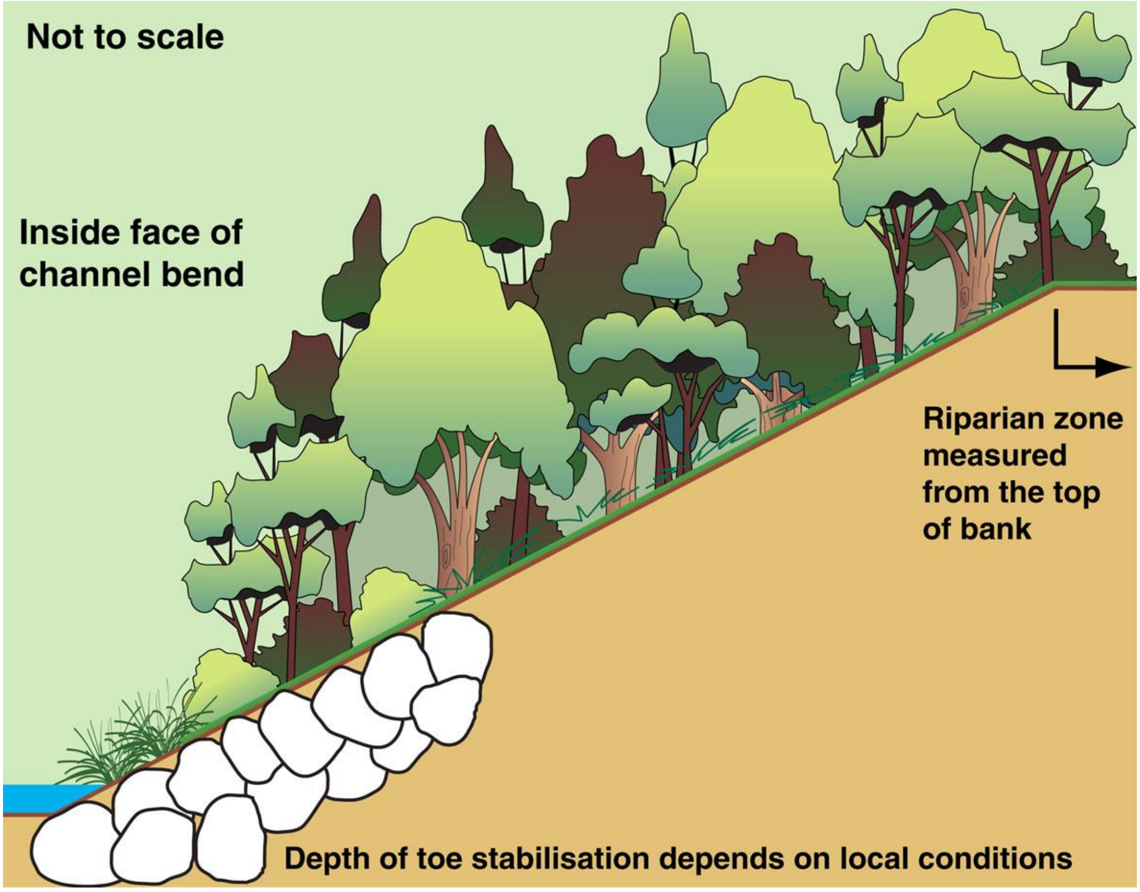
Vegetated rock stabilisation (NSW)

Description

- Vegetated rock stabilisation involves:
  - filling all voids with soil during the construction of the rock work
  - pocket planting into the soil-filled areas immediately after construction in order to reduce the potential for weed invasion.
- The rock should be extended only to the height considered necessary, thus allowing the rest of the bank to be planted with a greater array of species.

Design issues

- Bank slopes are generally flatter along the inside of channel bends compared to the outside of the same bend (but not always).
- Bank slopes of 1 in 3 to 1 in 6 (V:H) can be expected, which allows for safe working conditions during planting.
- On the inside of channel bends, the required height of the rock protection is likely to be in the range of 1 m high to one-third of the bank height (depending on the flow velocity).



Option 20: Vegetated rock stabilisation on the inside of a channel bend

Option 21. Vegetated rock stabilisation on the outside of a channel bend

Vegetated rock stabilisation (Qld)

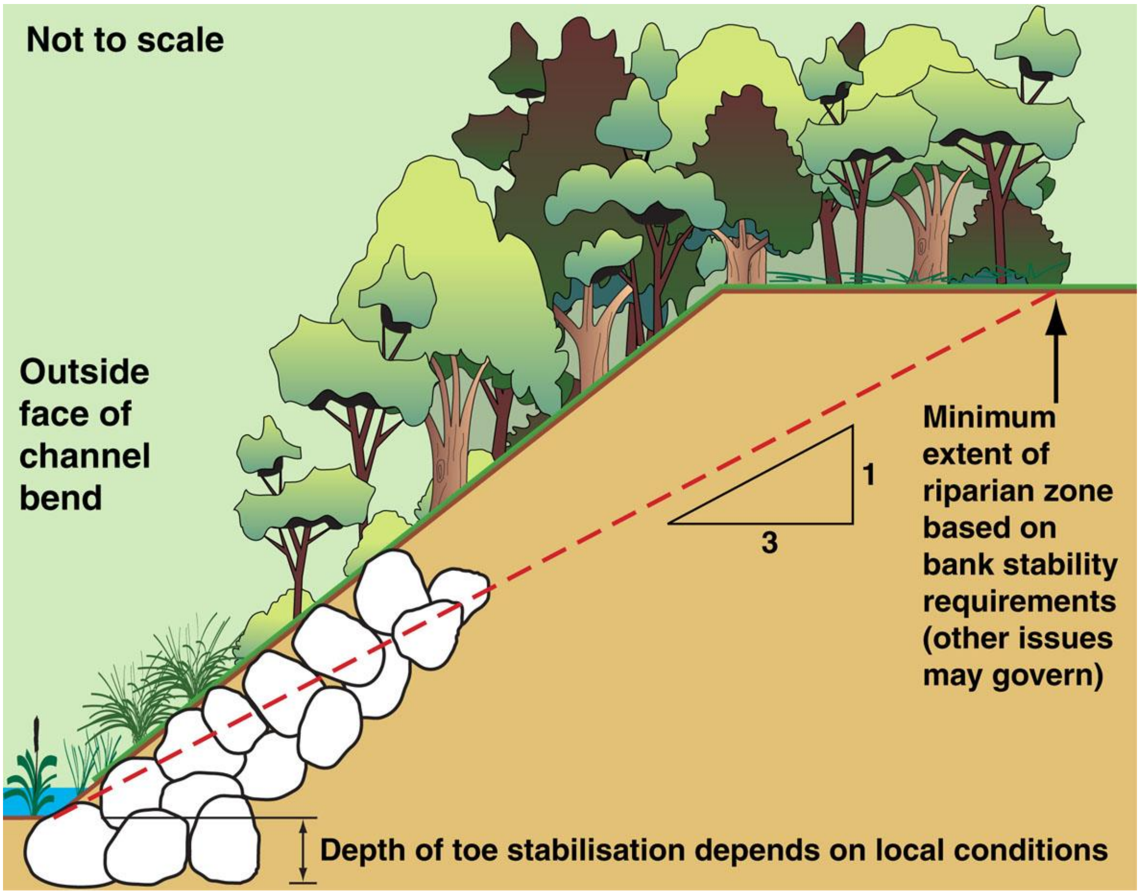
Vegetated rock stabilisation (Qld)

Description

- The choice of plant species can become a critical issue on the outside of channel bends.
- Stiff grasses, such as *Lomandra* are common in these locations, but there is the risk that a monoculture of ground covers could encourage high flow velocities, which can cause bank erosion at the end of the rock protection.
- On the outside of channel bends it is generally desirable to increase the use of shrubs to reduce potential velocity issues.

Design issues

- Bank slopes on the outside of bends are generally steep, possibly 1 in 1.5 to 1 in 2.
- Safety risks can exist for people working on banks taller than 2 metres if the slope is steeper than 1 in 2 (V:H).
- On the outside of channel bends, the height of the rock protection is likely to be between 1/3 and 2/3 bank height, but full bank height protection (Option 22) may be required in high-velocity, or turbulent-water channels.



Option 21: Vegetated rock stabilisation on the outside of a channel bend

Option 22. Full bank height, vegetated rock stabilisation

Rock stabilisation pre-planting (Qld)

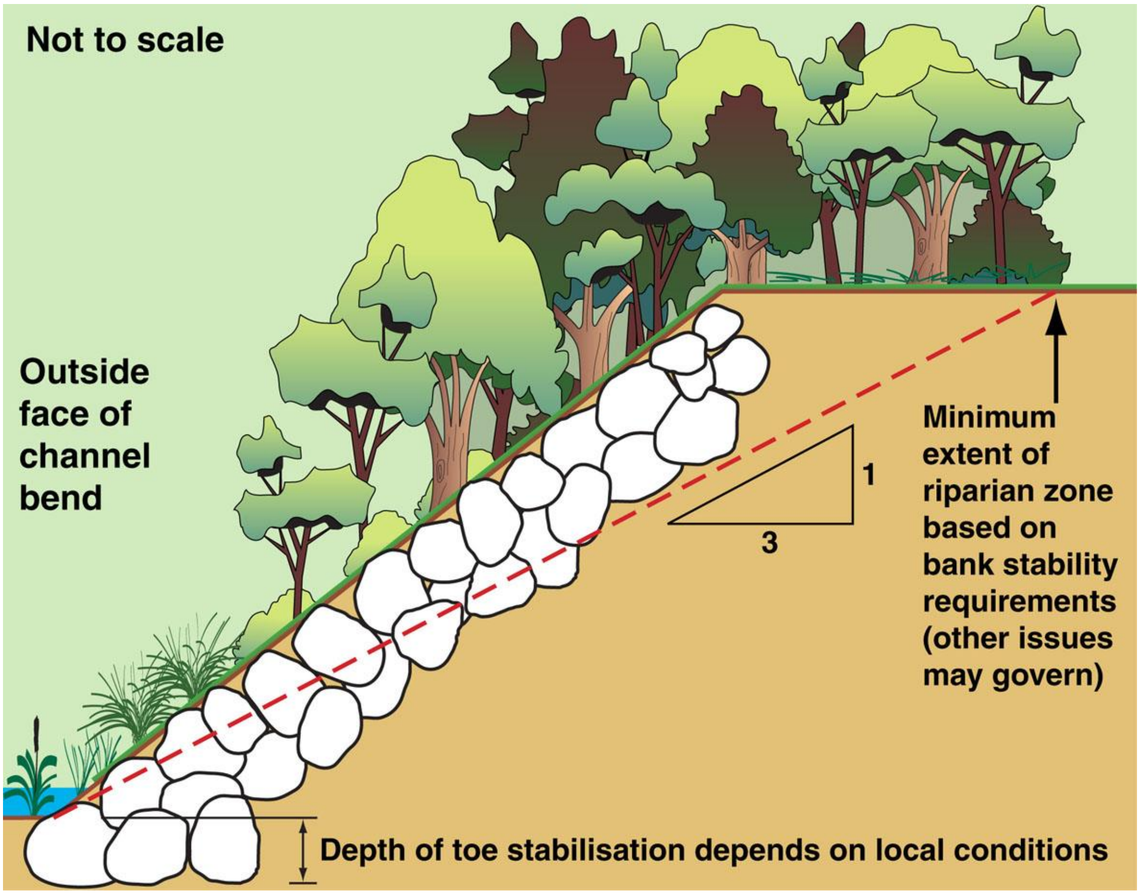
Description

- This treatment option involves extending rock placement to the top of the bank.
- Extending the rock stabilisation all the way to the top of the bank can significantly increase construction costs, and designers are encouraged to only choose this option when absolutely necessary.

Above site after planting (Qld)

Design issues

- Bank slopes on the <u>outside</u> of bends are generally steep, possibly 1 in 1.5 to 1 in 2.
- Full bank height protection is likely to be required if:
  - the channel velocity exceeds 4 m/s
  - the bank is on the outside of a tight channel bend (refer to Chapter 5)
  - the planned revegetation consists only of non-woody species that are likely to encourage high velocities to exist close to the bank.



Option 22: Full-height, vegetated rock stabilisation

Option 23. Full bank height, non-vegetated (open-void) dumped rock

Non-vegetated rock stabilisation (NSW)

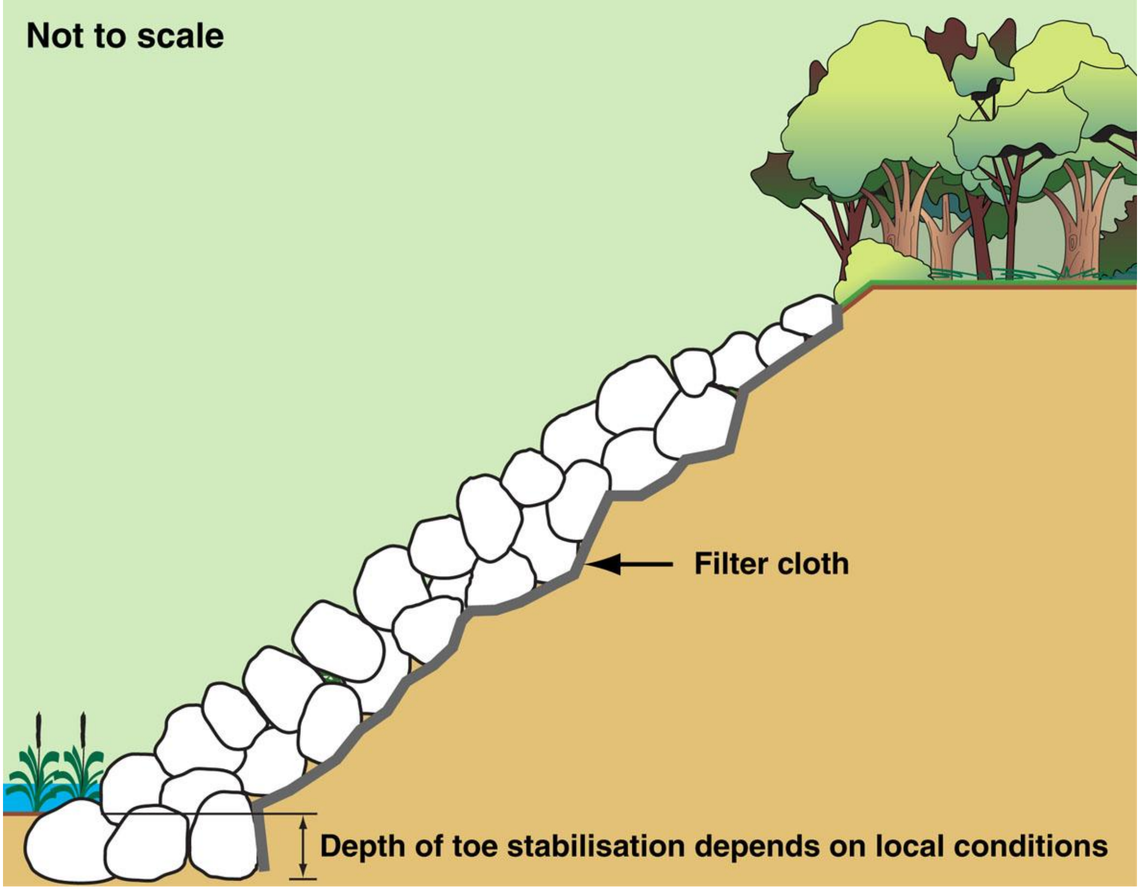
Non-vegetated rock stabilisation (Qld)

Description

- Rock placement without the addition of plant cover currently remains a popular treatment option due to reduced construction costs, but such a response to creek erosion should be discouraged.
- Potential problems include:
  - poor aesthetics
  - poor shading of the water
  - reduced potential for fish passage during flood events
  - higher risk of weed invasion.

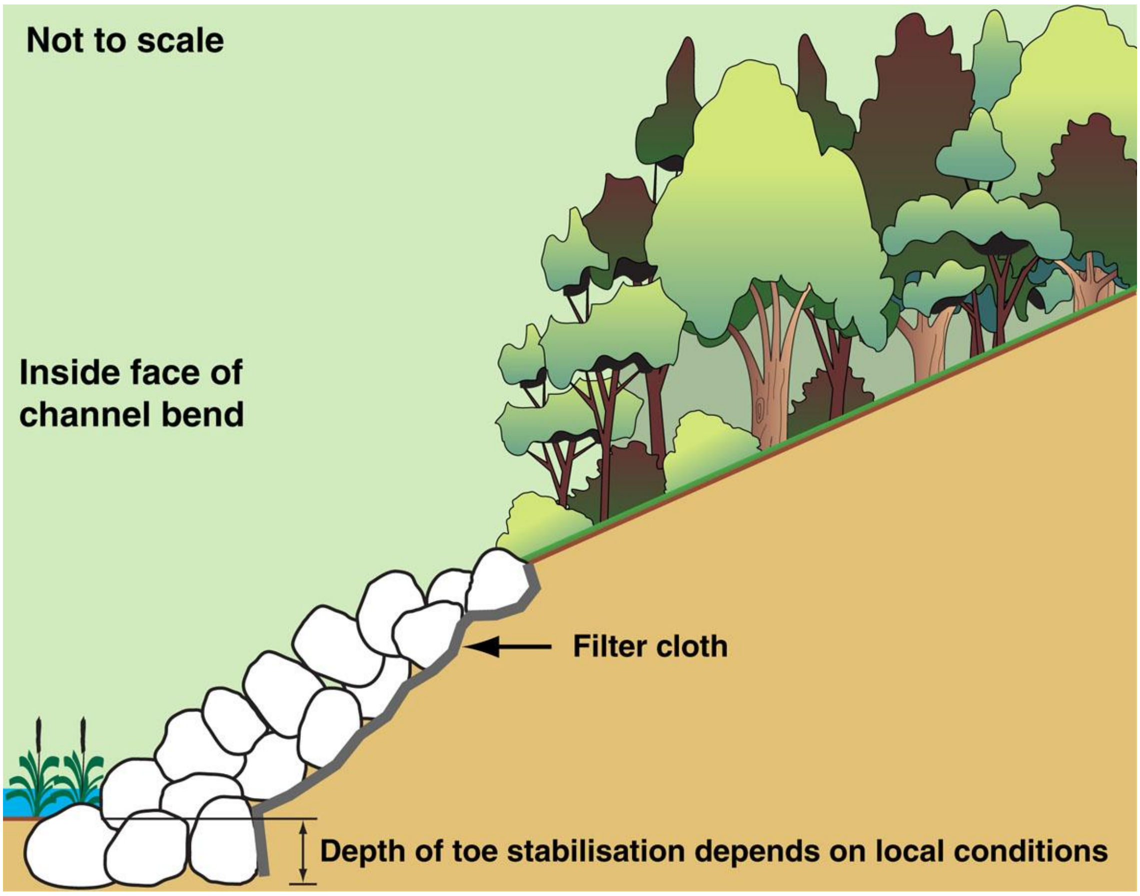
Design issues

- Bank slopes of 1 in 3 to 1 in 6 (V:H) can be expected on the inside of channel bends, which allows safe working conditions during revegetation.
- Bank slopes on the outside of bends are generally steeper (1 in 1.5 to 1 in 2).
- Filter cloth must be placed behind the rock if the voids are not filled with soil and planted, and this filter cloth must NOT be placed directly over a dispersive soil (refer to discussion at the end of Chapter 20).

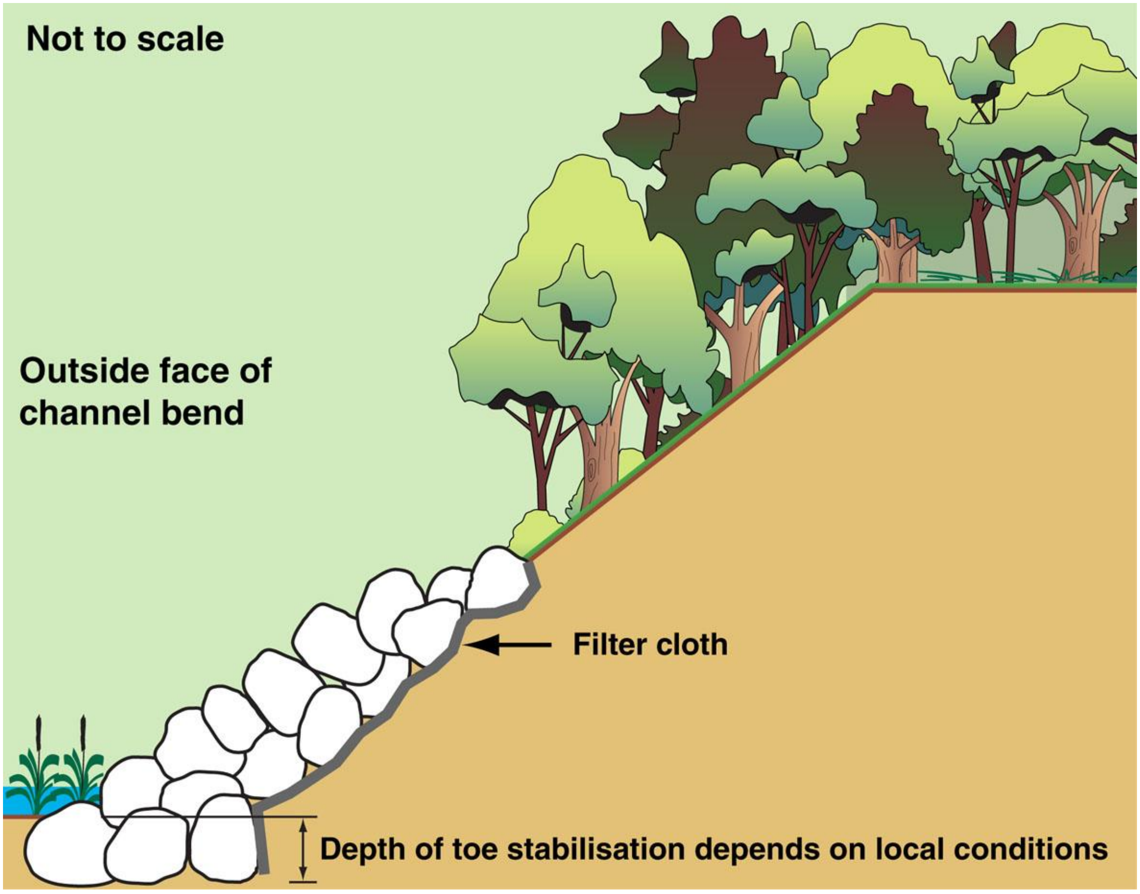


Option 23: Open-void, full bank height rock stabilisation

Options 24 & 25. **Partial-height, open-void, rock stabilisation**



Option 24: Open-void, dumped rock on the inside of a channel bend



Option 25: Open-void, dumped rock on the outside of a channel bend

Option 26. Placed rock on the outside of a channel bend

Rock placement (Qld)

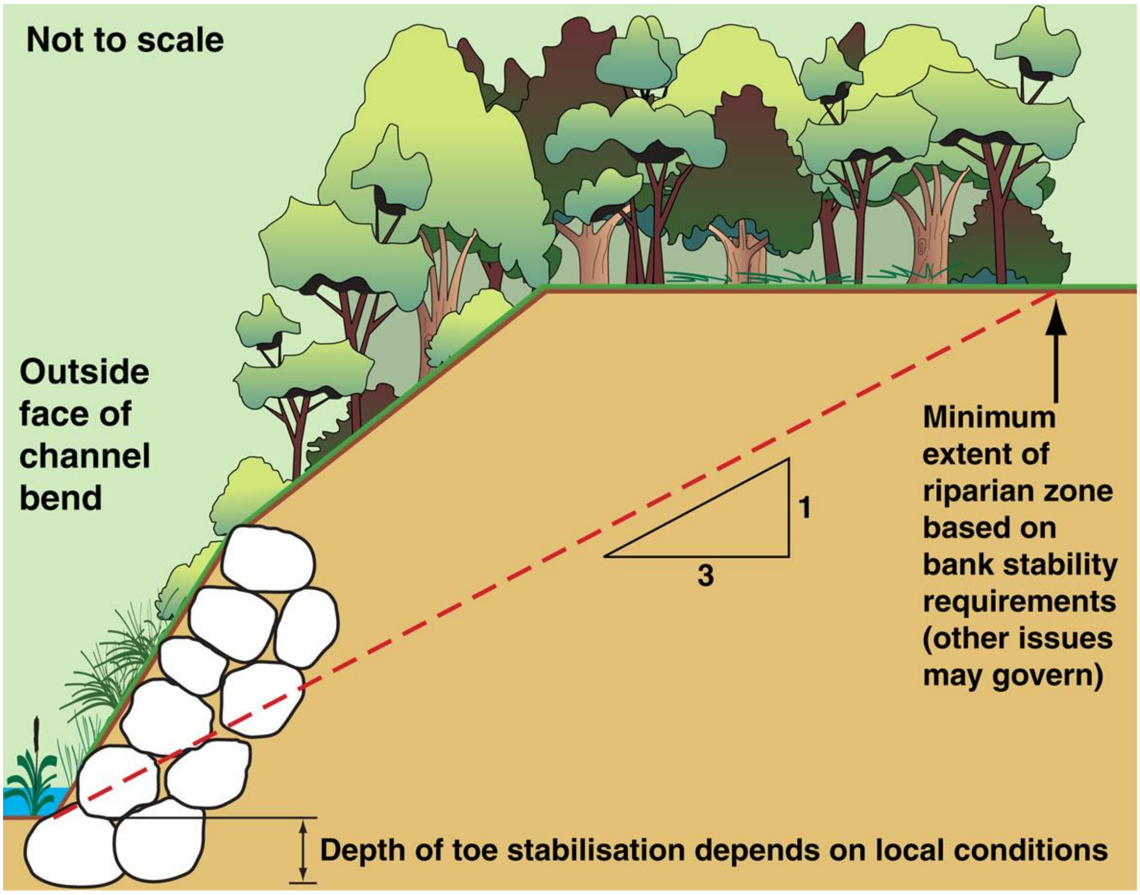
Placed rock bank stabilisation (Qld)

Description

- 'Placed rock' bank stabilisation means the rocks are individually placed such that:
  - the rocks remain stable on slopes up to 1 in 1 (i.e. 45-degrees)
  - individual rocks can be placed in a position of best usage, and in a manner that wedges the rock into a tight pack.
- 'Dumped rock' (Options 23 to 25) involves the placement of rock through the process of simply spilling the rocks from a truck or bucket.

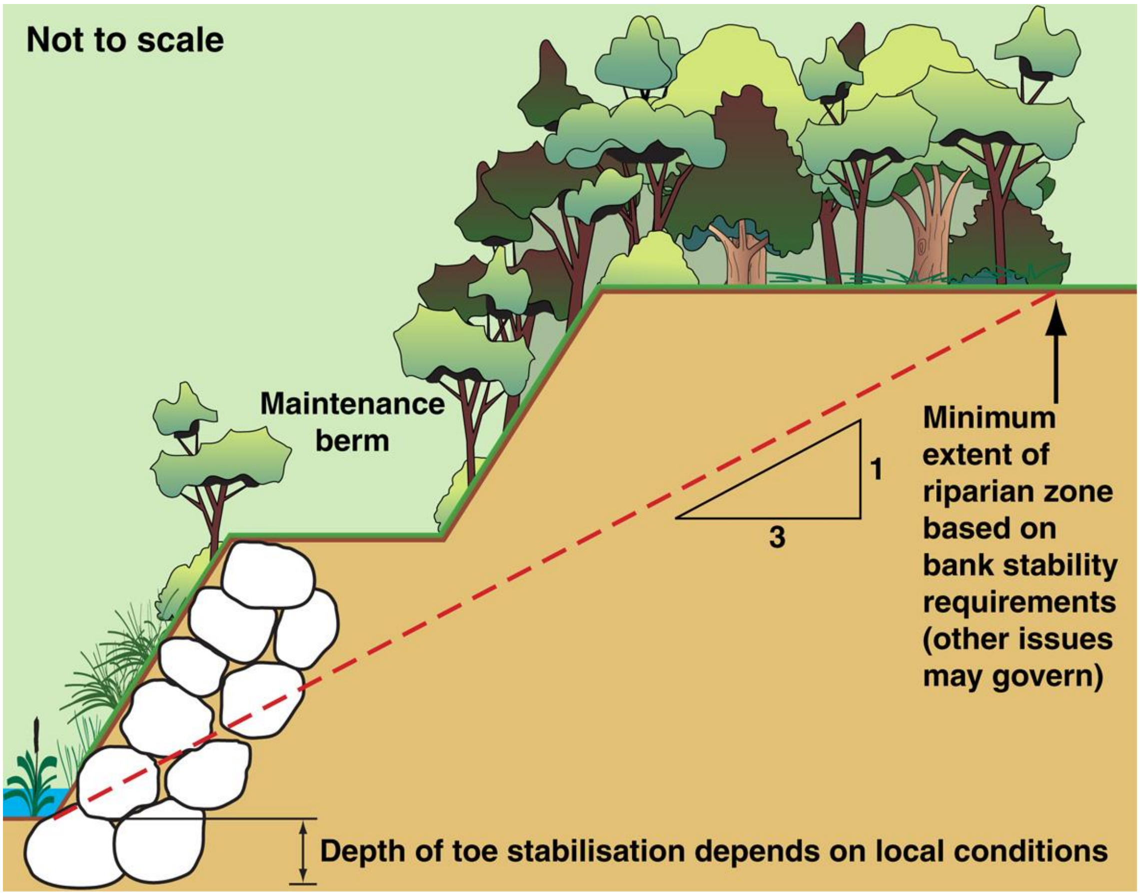
Design issues

- Bank slopes on the outside of bends are generally steep, possibly 1 in 1.5 to 1 in 2.
- Bank slopes as steep as 1 in 1 can be achieved if the rocks are individually placed, and the surface is fully vegetated.
- On the outside of channel bends, the height of the rock protection is likely to be between 1/3 and 2/3 bank height, but full bank height protection (Option 28) may be required in high velocity channels.

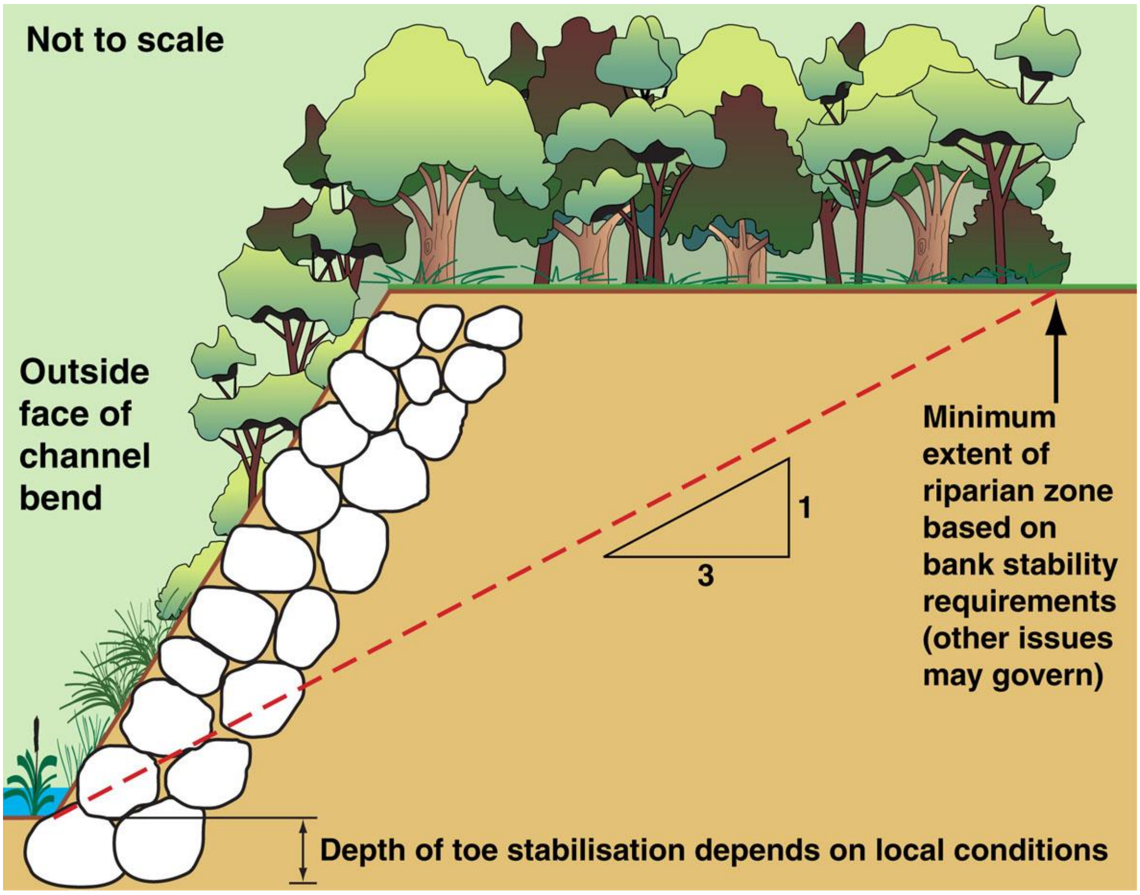


Option 26: Placed rock bank stabilisation on the outside of a channel bend

Options 27 & 28. Placed rock bank stabilisation



Option 27: Placed rock bank stabilisation with bench, on the outside of a channel bend



Option 28: Full-height, placed rock on the outside of a channel bend

Option 29. Partial-height, vegetated gabion retaining wall with bench

Planted rock mattress (Qld)

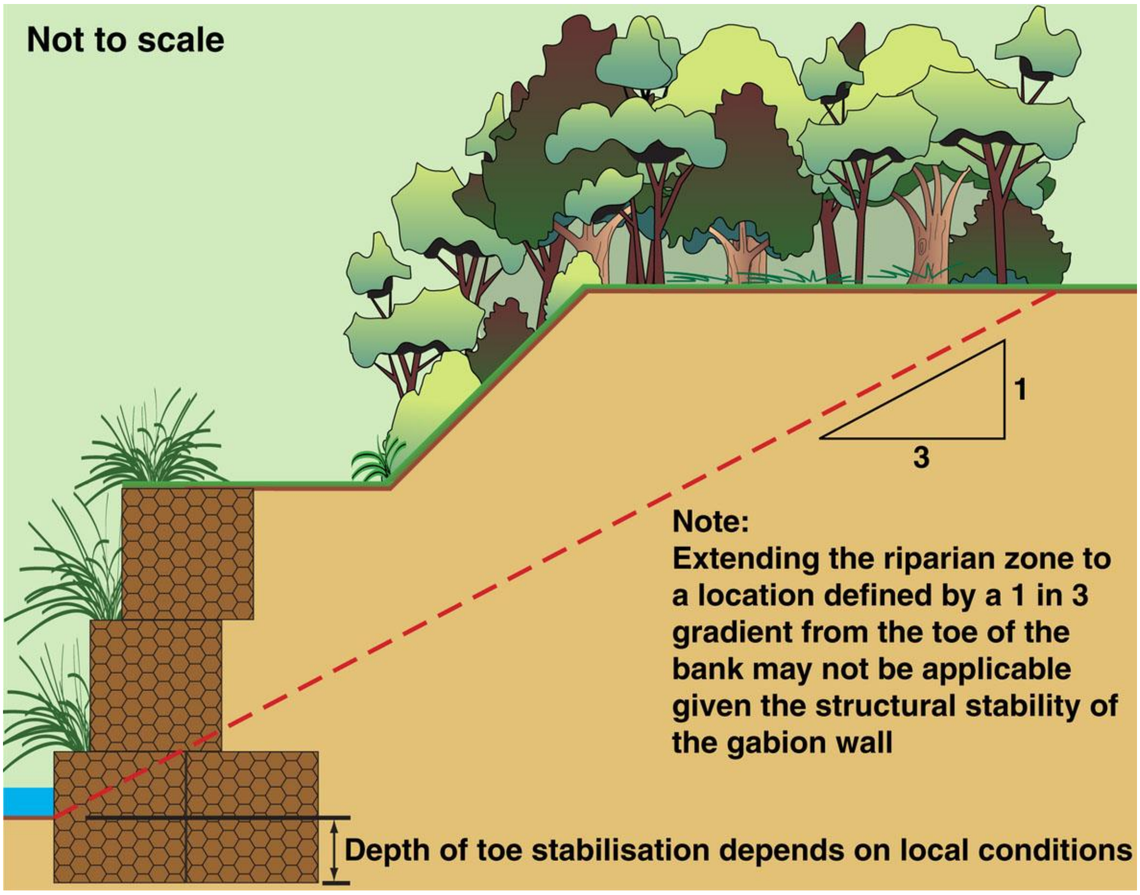
Planted gabion drainage channel (NSW)

Description

- In this context, a 'gabion' is a wire basket filled with rocks.
- A vegetated gabion is a wire basket filled with rocks and soil, over which plants are actively established.
- Actively encouraging vegetation provides the following benefits:
  - long-term bank stability following the eventual failure of the wire baskets
  - many of the benefits commonly associated with vegetated rock.

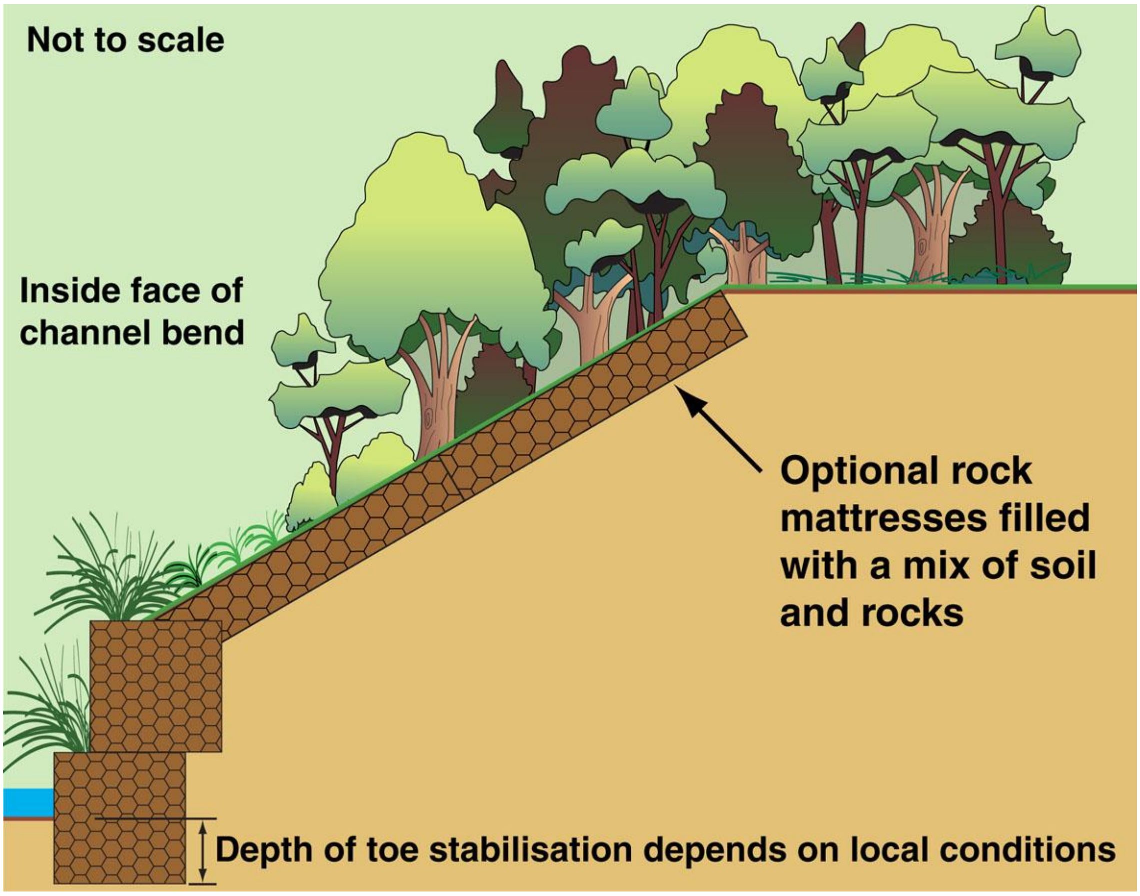
Design issues

- Gabion retaining walls can be built vertically, but this is generally not recommended on creek banks.
- The unstable nature of the creek bed and banks means that some slight movement (rotation) of the gabion wall is possible over time; therefore, gabion walls are normally constructed with a slight tilt away from the channel.
- A 'stepped' gradient of around 1 in 0.5 is recommended for vegetated gabion walls.

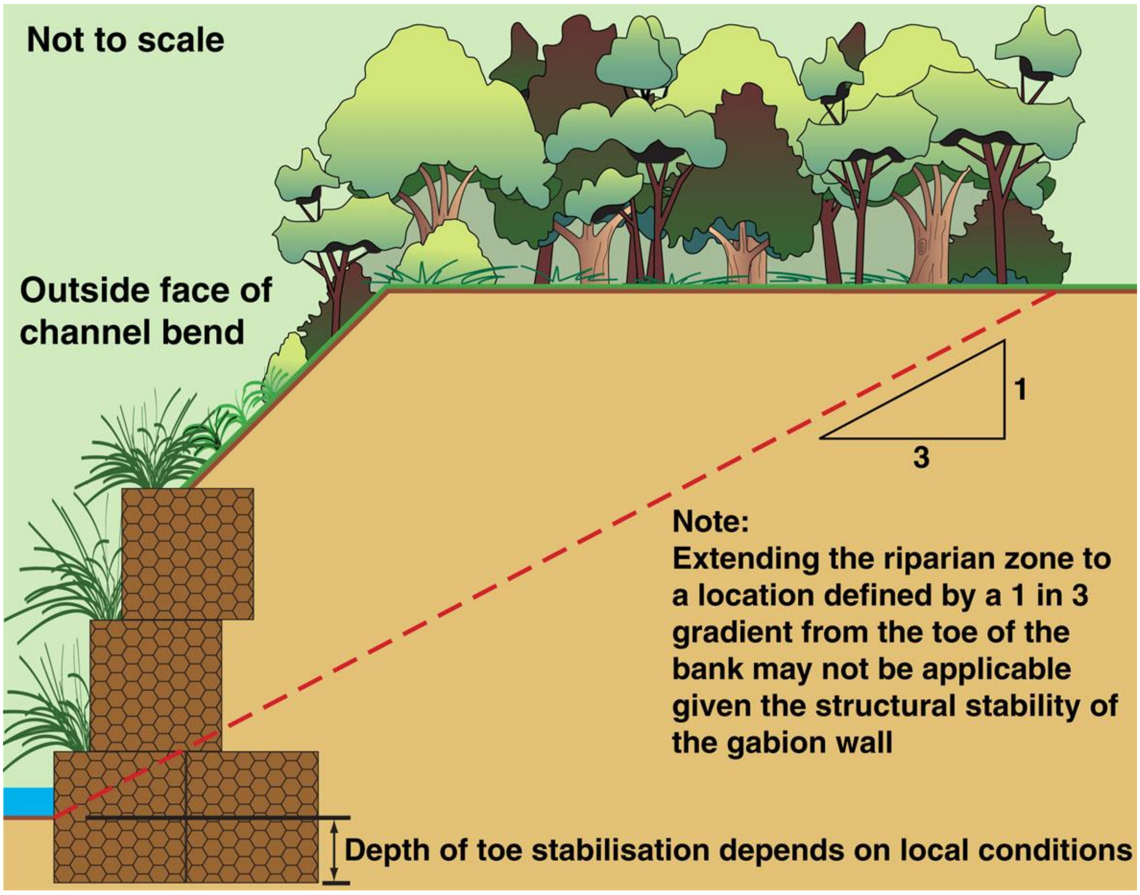


Option 29: Partial-height, vegetated gabion wall with bench

Options 30 & 31. Partial-height, vegetated gabion retaining wall

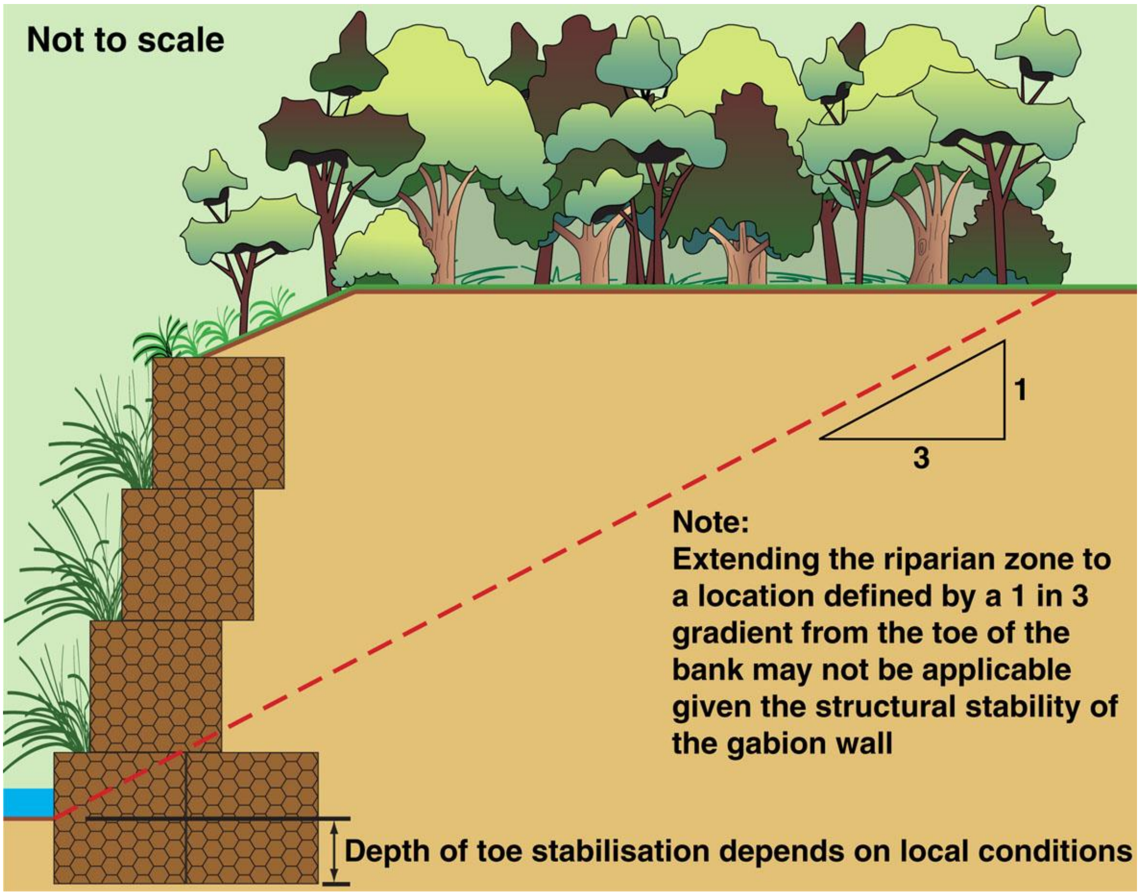


Option 30: Vegetated gabion and mattress protection on the inside of a channel bend

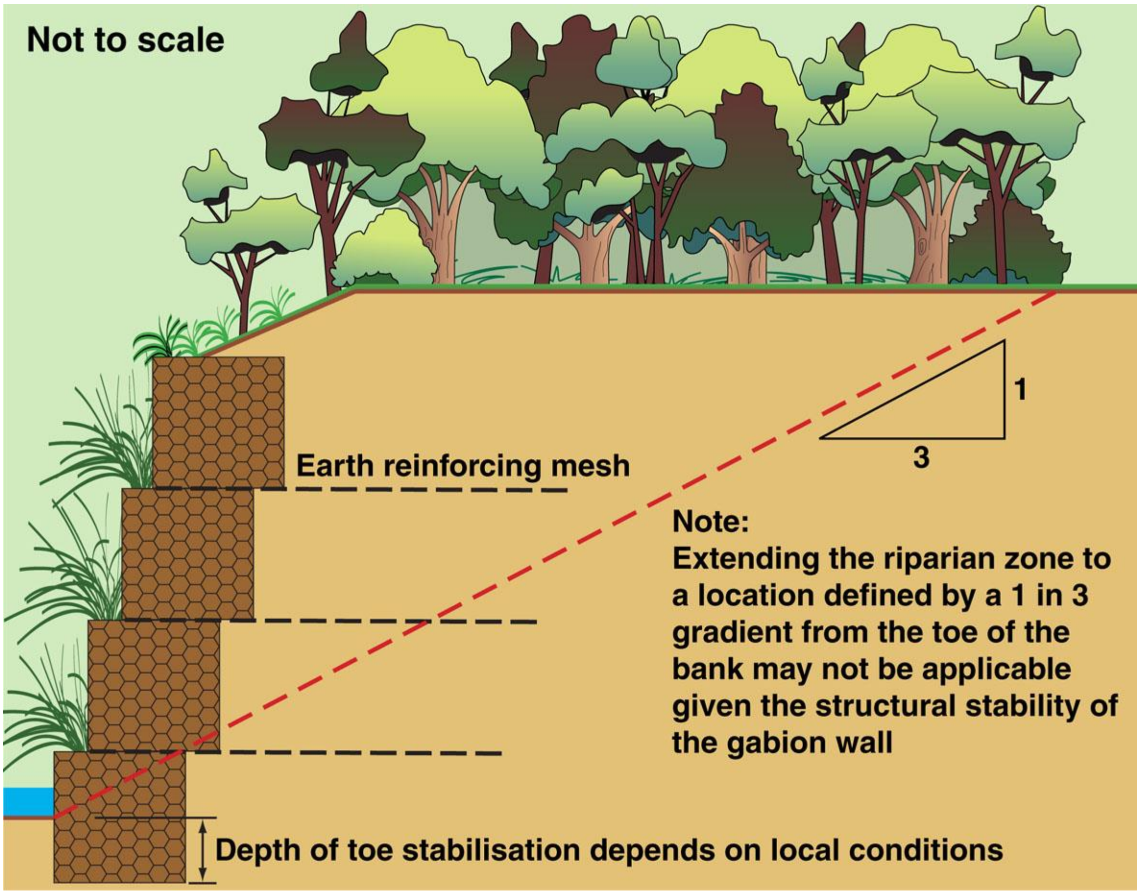


Option 31: Vegetated gabion wall on the outside of a channel bend

Options 32 & 33. Full-height, vegetated gabion retaining wall



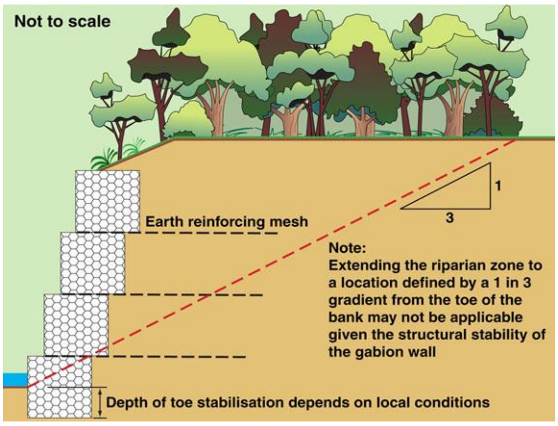
Option 32: Full-height, vegetated gabion retaining wall



Option 33: Full-height, vegetated gabion retaining wall with earth reinforcing

Option 34. Non-vegetated gabion retaining wall

Gabion retaining wall (Qld)



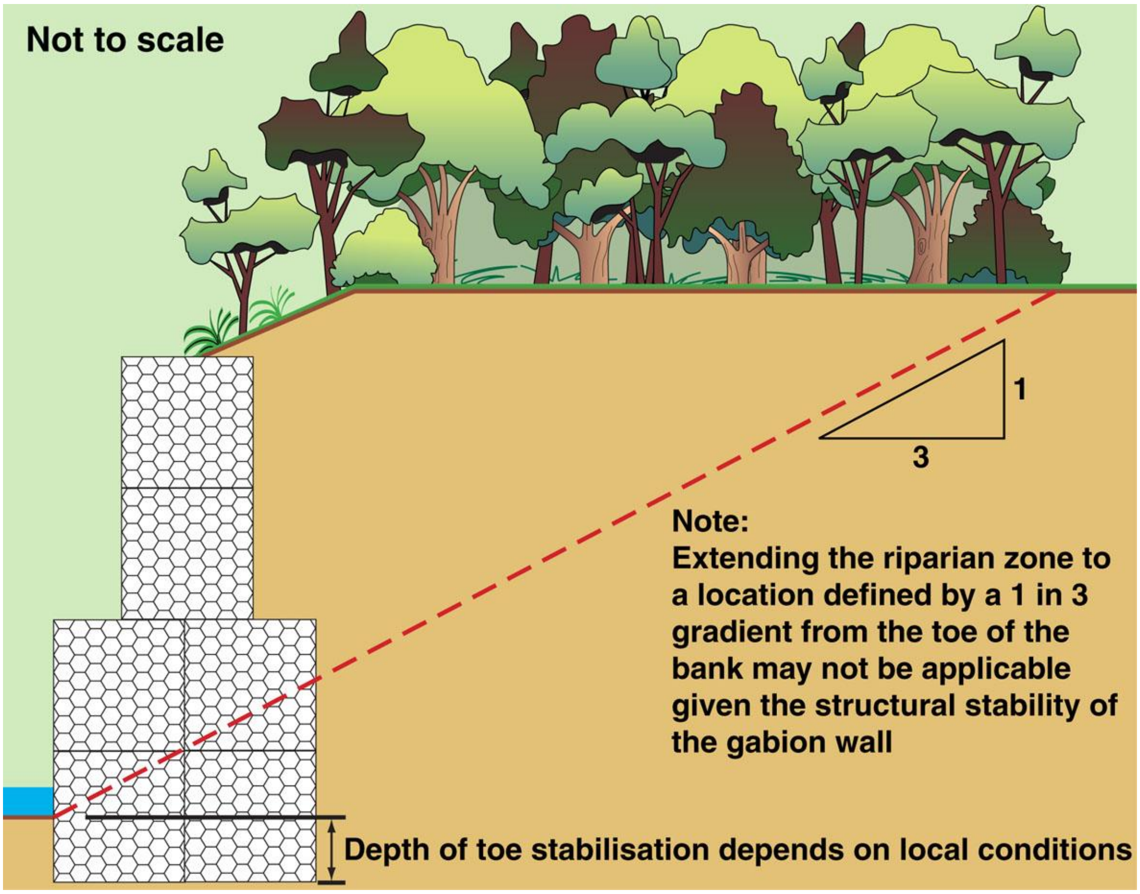
Option 34A: Use of earth reinforcing mesh

Description

- A gabion wall is a collection of stacked wire baskets filled with rocks.
- Within a waterway, a non-vegetated gabion wall can potentially experience the following problems:
  - long-term instability problems associated with the eventual failure of the wire baskets (e.g. damaged by rust, sediment, or flood debris)
  - invasion by weeds, which can prove expensive and problematic to remove.

Design issues

- Gabion retaining walls can be built vertically, but this is generally <u>not</u> recommended for creek banks.
- The unstable nature of the creek bed and banks means that some slight movement (rotation) of the gabion wall is possible over time; therefore, gabion walls are normally constructed with a slight tilt away from the channel.



Option 34: Full-height, non-vegetated gabion retaining wall

Option 35. Stacked boulder wall

Stacked boulder wall (Qld)

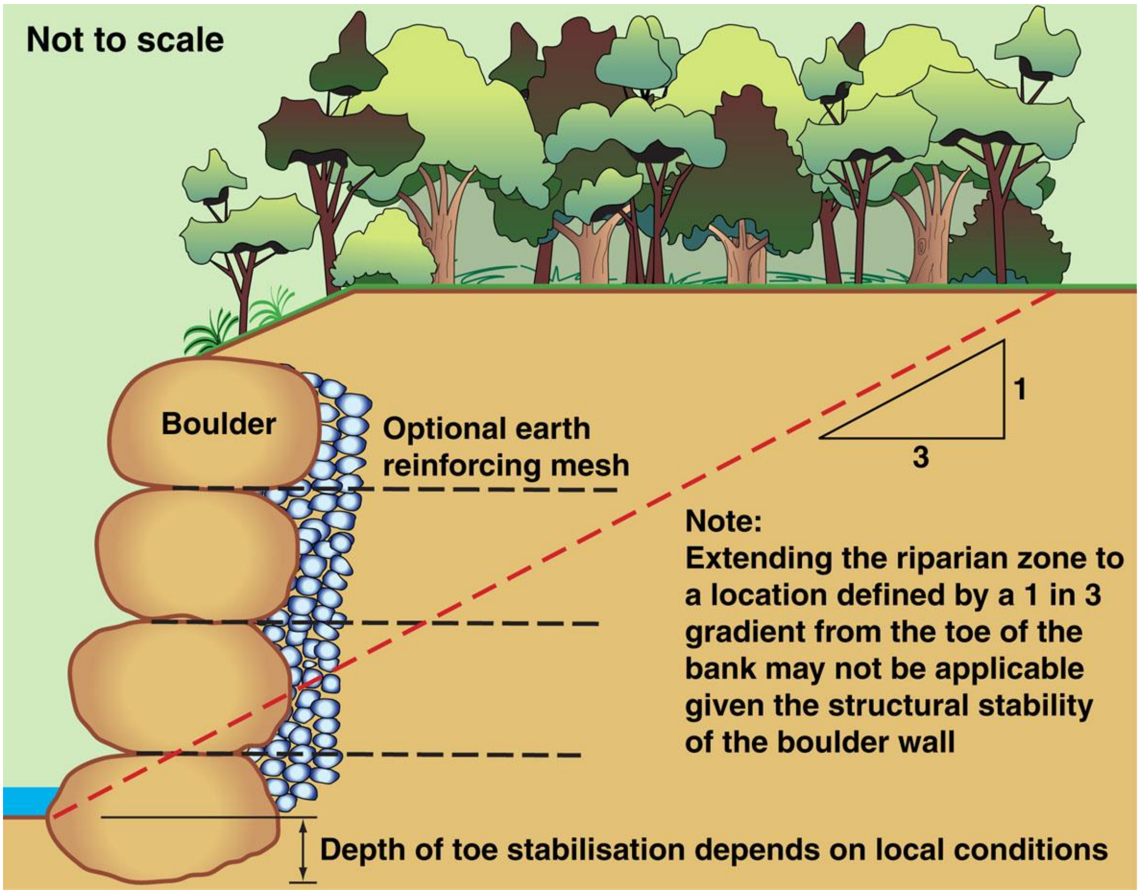
Stacked boulder wall (Qld)

Description

- This treatment option involves the stacking of large rocks (boulders) to form a retaining wall that protects the adjacent earth embankment from the effects of flood scour.
- The inclusion of an earth reinforcing system allows:
  - the boulder wall to act more like a traditional 'retaining wall', and
  - helps to minimise the risk of bank slumping.

Design issues

- Stacked boulder walls can be built almost vertically; however, boulder walls are normally constructed with a slight tilt away from the waterway channel.
- Stacking the rocks means:
  - the weight of the upper rocks rests on the lower rocks, which means . . .
  - the rocks can resist flow velocities higher than those predicted by a Shield's-based, rock-sizing formula.



Option 35: Stacked boulder wall

Option 36. Stacked boulder wall with bench

Benching of a river bank (Qld)

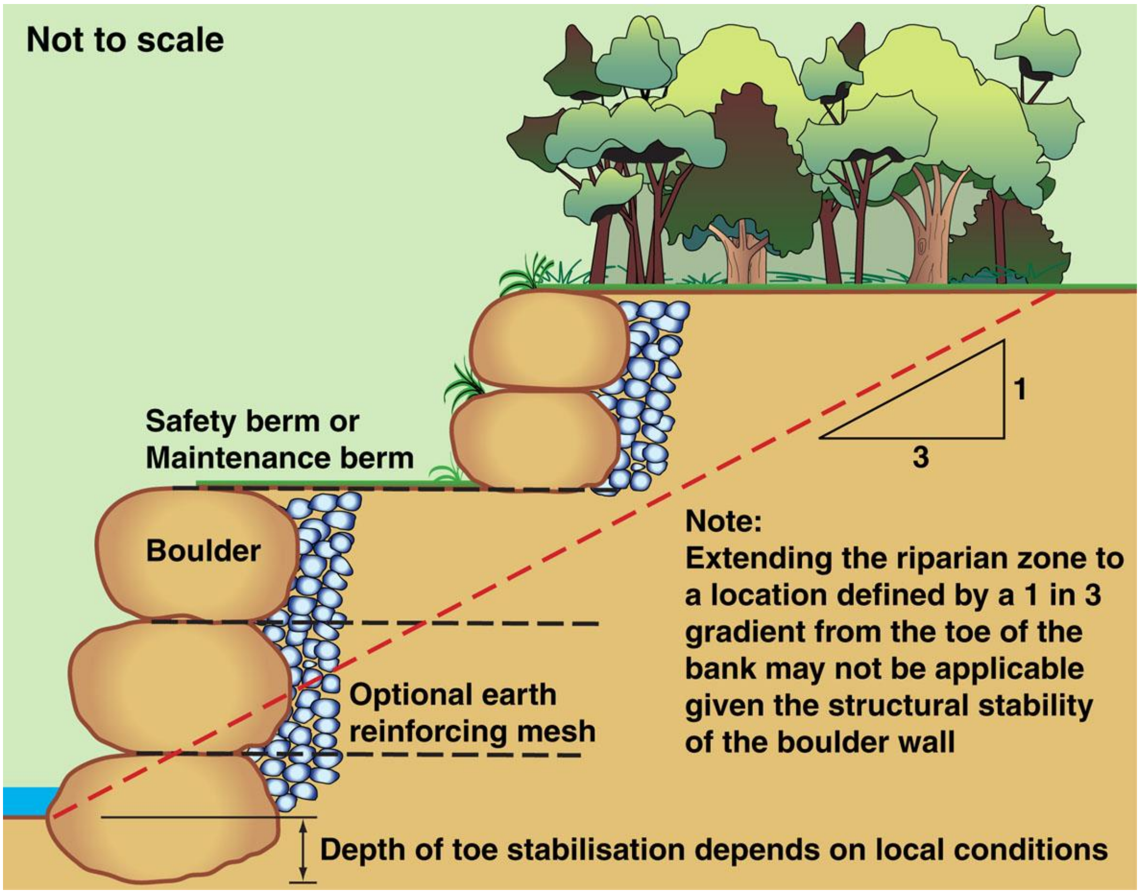
Benching of a river bank (Qld)

Description

- Benching a creek or river bank can provide the following benefits:
  - increased bank stability (especially if there is the risk of bank slumping)
  - better access for performing bank repairs
  - improved safety for workers and pedestrians
  - better access for maintenance equipment.

Design issues

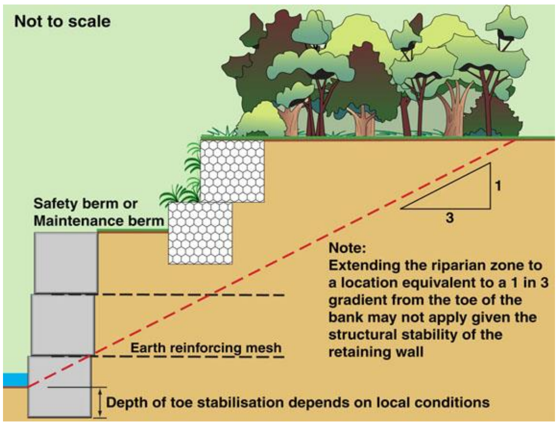
- Recommended minimum width of a pedestrian safety berm is 1.5 m.
- Recommended minimum width of a trafficable maintenance berm is 4.5 m.
- If the river bank is likely to experience post-flood slumping, then the height and minimum width of the bench should be determined by an appropriate geotechnical investigation.



Option 36: Stacked boulder wall with bench

Option 37. Retaining wall

Retaining wall (NSW)



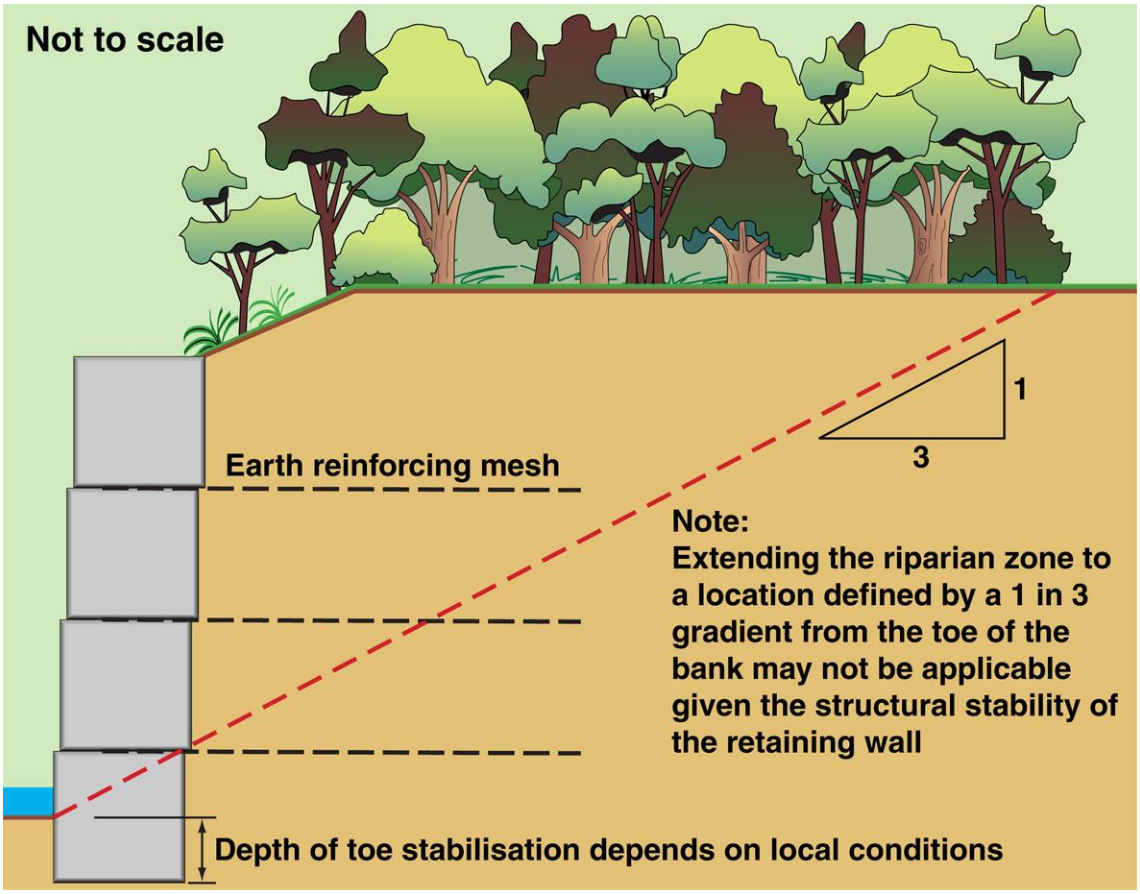
Option 37A: Benched retaining wall option

Description

- By definition, a 'retaining wall' must incorporate the function of 'holding back' the adjacent earth.
- Retaining walls can be:
  - free standing structures
  - reinforced cantilever-type structures
  - laterally supported or braced walls.
- Earth reinforcing:
  - laterally braces the wall, and
  - reduces the risk of bank slumping.

Design issues

- In-situ concrete walls can be built vertically.
- Modular retaining walls can also be built vertically; however, the unstable nature of the creek bed and banks means that some slight movement (rotation) of the wall is possible over time; therefore, modular walls are normally constructed with a slight tilt away from the channel.
- A 'stepped' wall can provide better public access, which may or may not be desirable.

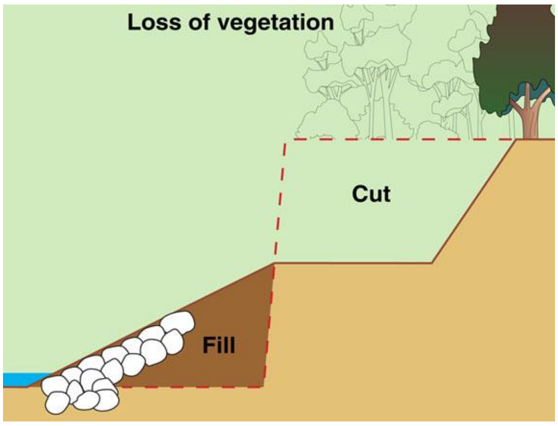


Option 37: Structural retaining wall

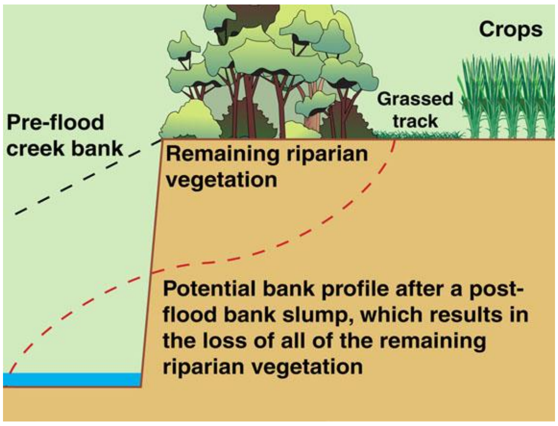
22. Examples of Construction Staging of Bank Repairs

Introduction

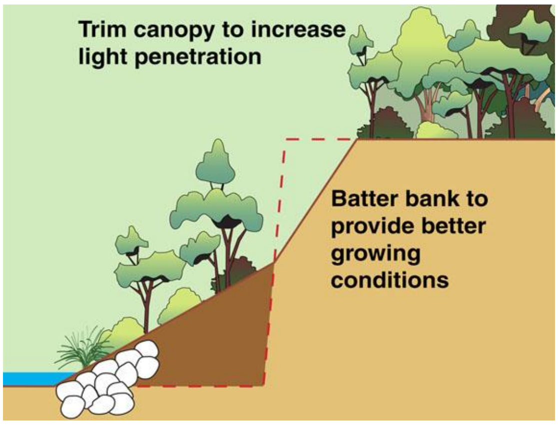
Outside of a channel bend (Qld)



Cut and fill bank stabilisation



Potential loss of riparian vegetation



Battering a creek bank

Outside bank of channel bends

- It can be difficult for a creek to self-repair (stabilise) bank damage on the outside of a channel bend.
- Each time the eroded bank slumps and attempts to revegetate itself, a new flood washes away the soil, and returns the bank to a near-vertical condition.
- This condition can be made a lot worse if the outside of the channel bend is also the northern bank, which regularly places the eroded bank in a shaded condition.

Treatment options

- The treatment of bank erosion in such cases includes the following options:
  - stabilise the bank in its current (eroded) location, or
  - return the bank to its previous location.
- If the bank is to be stabilised in its current location, then:
  - the bank could be battered using a cut and fill approach, which could result in a loss of overbank vegetation, or
  - the bank could be rebuilt using fill.

The difficulty of retaining the riparian vegetation along highly mobile creeks

- In many farming areas, riparian vegetation consists of just a narrow strip of trees and shrubs running along each side of a creek.
- If severe bank erosion were to occur along these creeks, all of the riparian vegetation may be lost from parts of the creek.
- If some vegetation does survive the flood, then this could be lost during bank repair measures, which could result in adverse ecological outcomes.

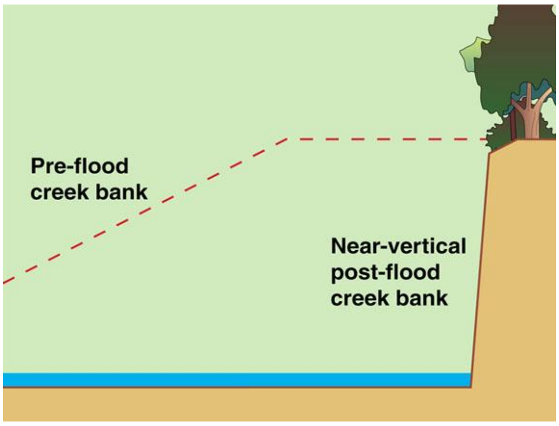
Treating a heavily-shaded creek bank

- In almost all circumstances, the long-term success of a waterway project will be strongly linked to the establishment of appropriate riparian vegetation.
- In order to deal with excessive bank shading, the options are:
  - battering and/or benching the bank
  - trimming canopy trees
  - stabilising the toe of the bank to avoid the reformation of a vertical bank.

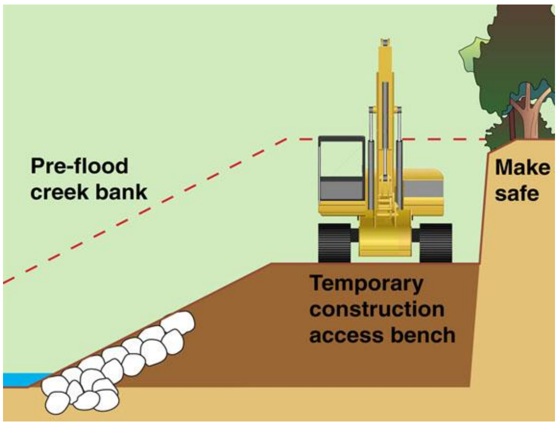
Bank repair Options A & B

Option A: Using imported fill

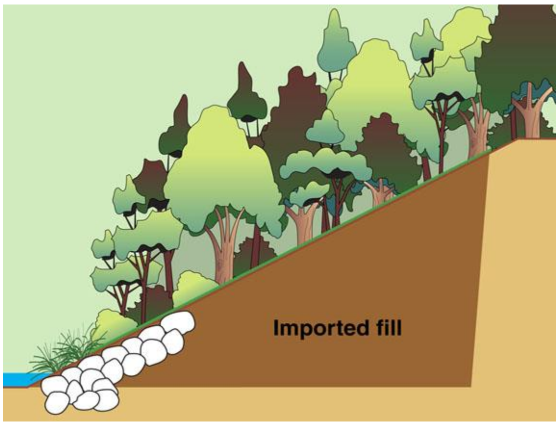
- If it is important to avoid any further loss of riparian vegetation, then:
  - construction vehicles must access the site along a temporary track (bench)
  - the new bank must be formed from imported fill, or won from a local excavation.
- Providing sufficient width for vehicle access can sometimes determine the bench height and the final bank gradient.



Stage 1: Post-flood bank condition



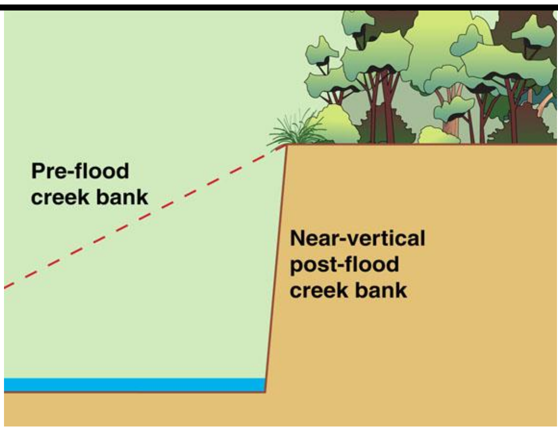
Stage 2: Construction access bench



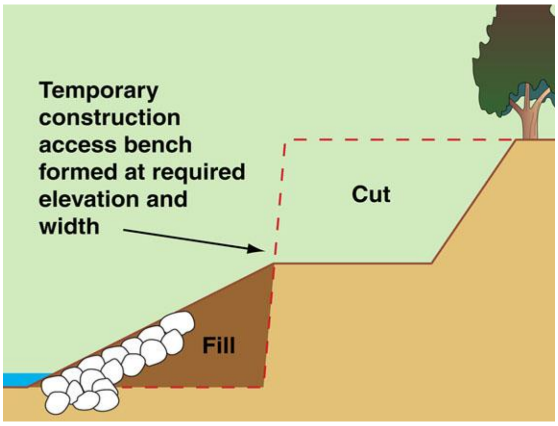
Stage 3: Final shaping and revegetation

Option B: Cut and fill process

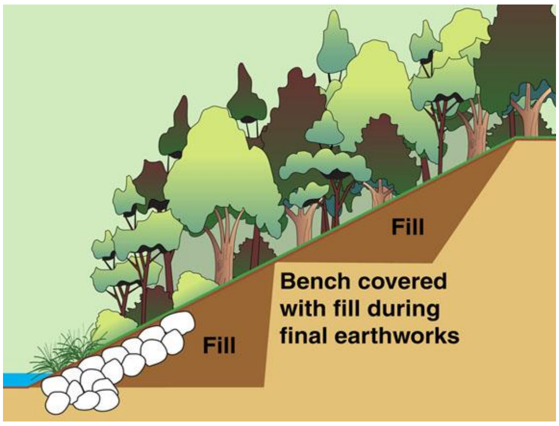
- The use of a cut and fill process can avoid the cost of importing soil, but it usually results in the further loss of riparian vegetation, which could include critical habitat trees.
- The bench needs to be wide enough for the proposed construction vehicles.
- Part of the access bench can be removed or reshaped during final bank shaping and revegetation.



Stage 1: Post-flood bank condition



Stage 2: Initial cut and fill to form a bench

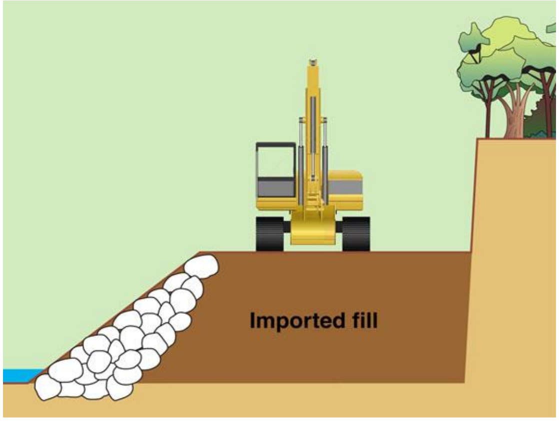


Stage 3: Final shaping and revegetation

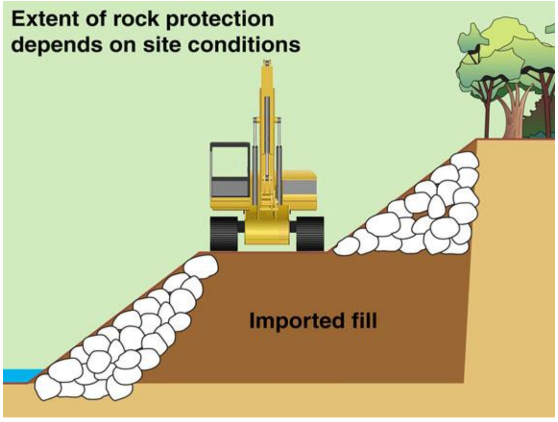
Bank repair Options C & D

Option C: Benching

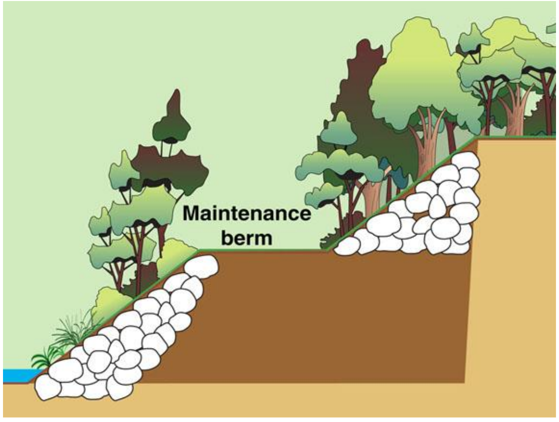
- Benching a creek bank provides benefits during the construction period, as well as improving the long-term stability of the bank.
- However, a wide bench on the outside of a tight channel bend may not be consistent with the desirable flow patterns for such a channel bend, so make observations of any stable bends along the waterway.
- Rock may or may not be required above the bench.



Stage 1: Construction access bench



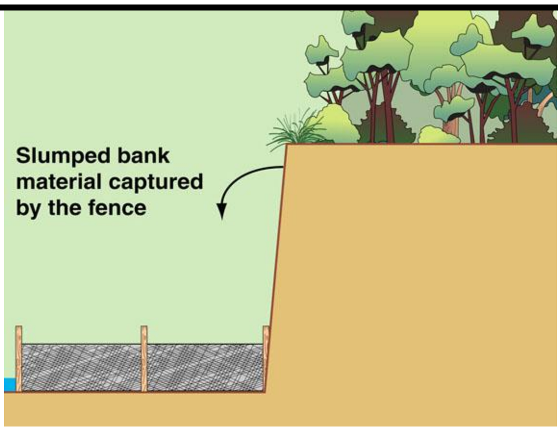
Stage 2: Placement of rock



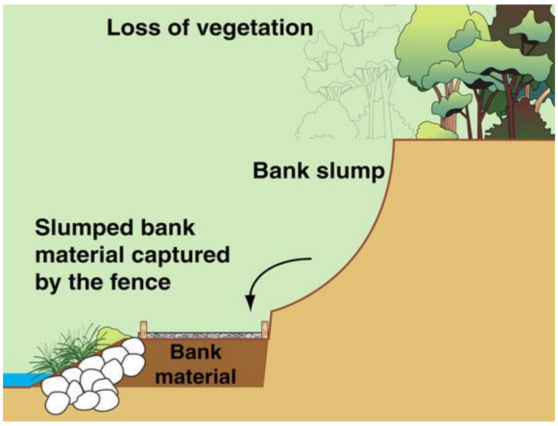
Stage 3: Bank revegetation

Option D: Retard fencing (unconventional use)

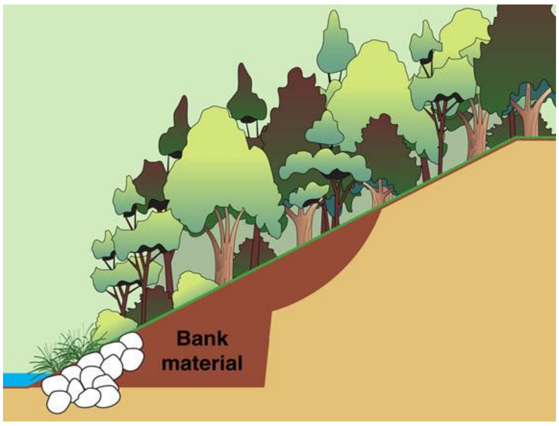
- Using a retard fence to capture and retain soil that slumps from an unstable creek bank is not the normal use of a retard fence, but such an operation is possible in gullies and creeks that do not have significant natural bed sediment.
- There is the risk of significant fence damage as the result of a bank slump.
- This approach requires the landowner to adopt a watch-and-act approach to ongoing repairs.



Stage 1: Installation of a retard fence



Stage 2: Bank soil captured by the fence

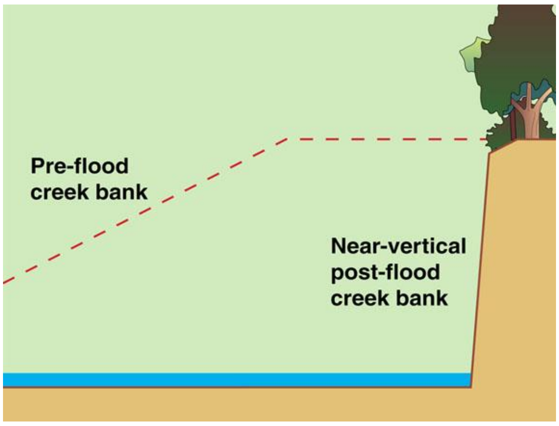


Stage 3: Final shaping and revegetation

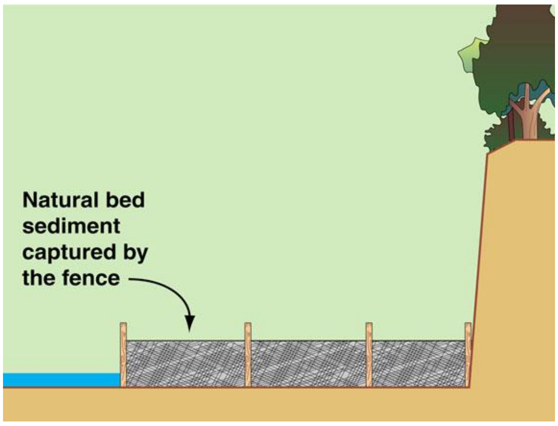
Bank repair Option E

Option E: Retard fencing placed in an alluvial waterway

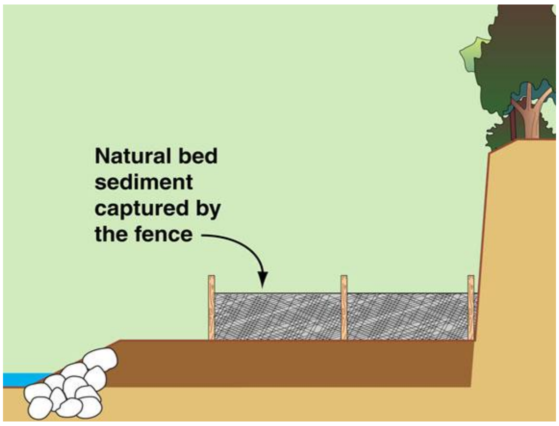
- Retard fencing is traditionally used in wide, sand-based waterways.
- Clay-based creeks do not have sufficient sediment flow to fill the fence with soil.
- Gravel-based creeks are likely to experience excessive fence damage during flood events.
- The installation sequence shown below would likely take many years to finalise, so attention must always be paid to the ongoing erosion of the main bank.



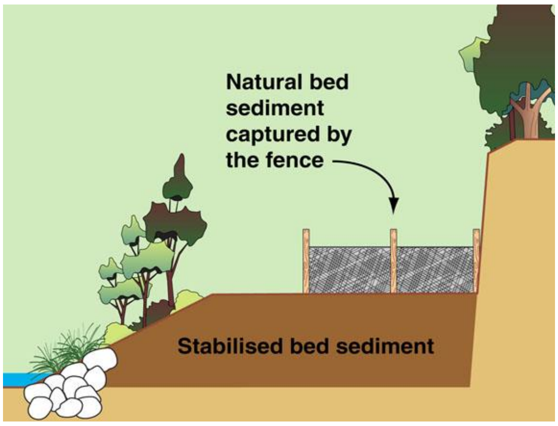
Stage 1: Post-flood bank condition



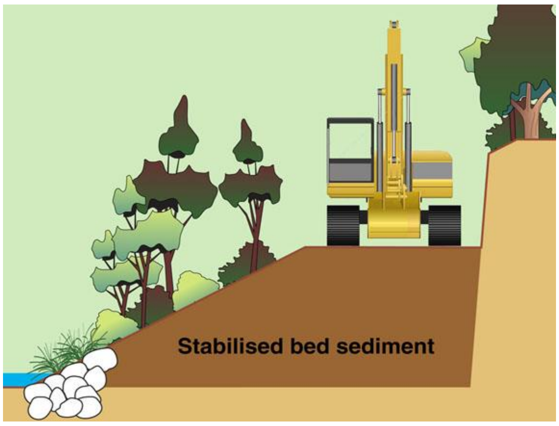
Stage 2: Installation of first retard fence



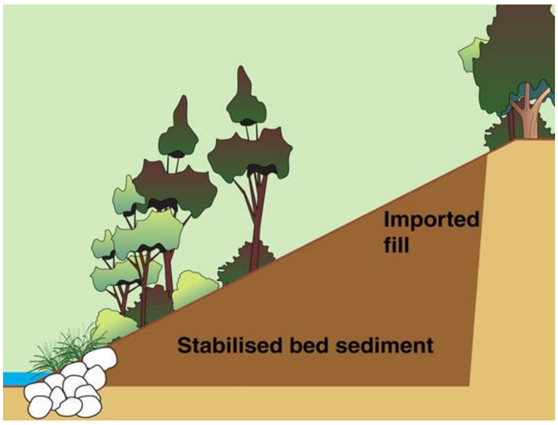
Stage 3: Second fence built on sediment



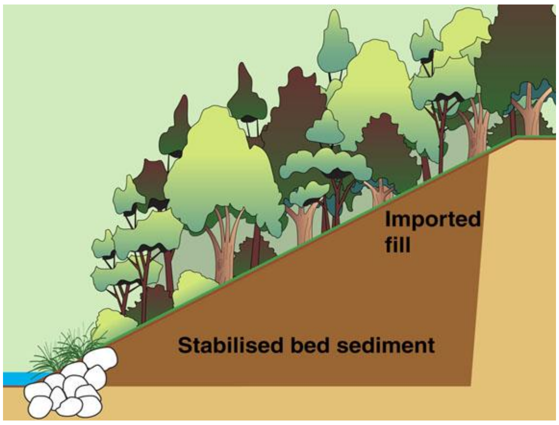
Stage 4: Third fence built on sediment



Stage 5: Bench compacted and planted



Stage 6: Final earthwork with imported fill

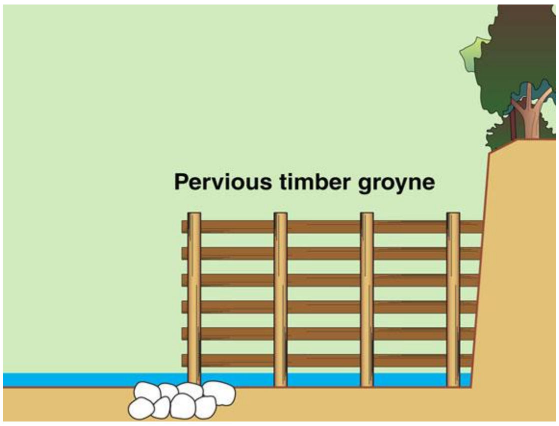


Stage 7: Final bank revegetation

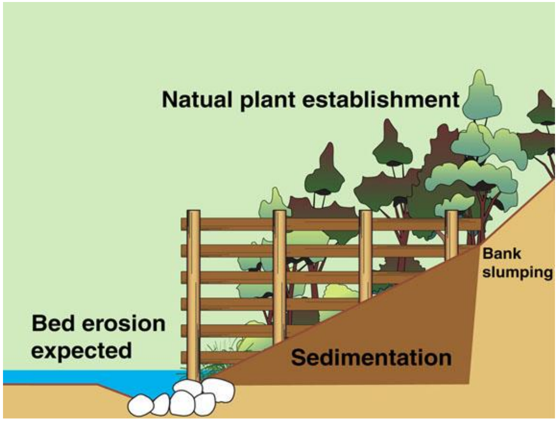
Bank repair Options F & G

Option F: Timber groyne

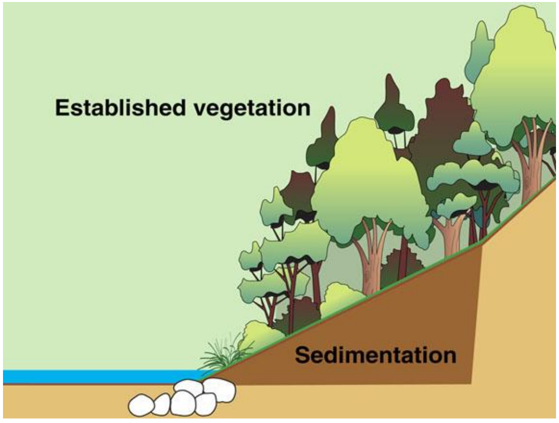
- Tall timber groynes are normally used to repair flood damage to a bank, or to help slow channel migration.
- Rock groynes are normally used in shallow creeks, or to divert minor stream flows away from a recently repaired bank.
- Treated timber should not be used to form the groynes (as these timbers can release undesirable chemicals into the waterway); instead, the groynes should be removed or allowed to decay over time.



Stage 1: Installation of groynes



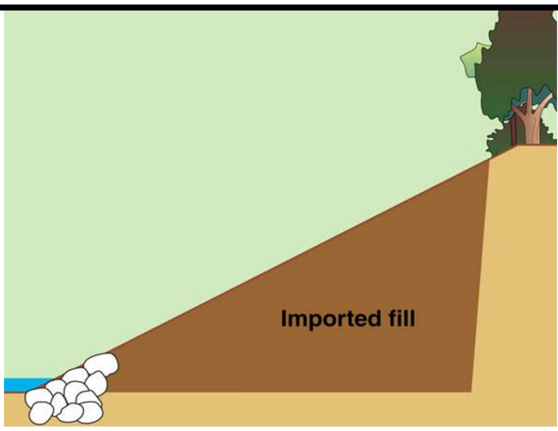
Stage 2: Sedimentation and revegetation



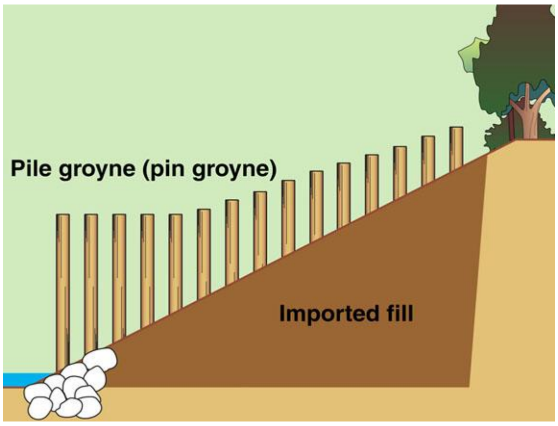
Stage 3: Removal of the groynes

Option G: Pile groyne

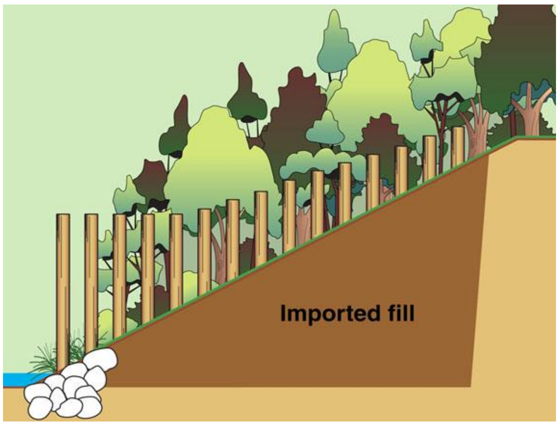
- If different landowners exist on each side of the creek, then there is often the desire to maintain the creek in a given position (i.e. not allowing floods to change the meander pattern of the creek).
- If a flood causes severe bank damage, then imported fill is usually required in order to quickly restore the bank back to its pre-flood condition.
- Pile groynes can help to prevent ongoing flood damage (but some degree of flood damage should always be expected).



Stage 1: Bank repaired with imported fill



Stage 2: Installation of pin groynes

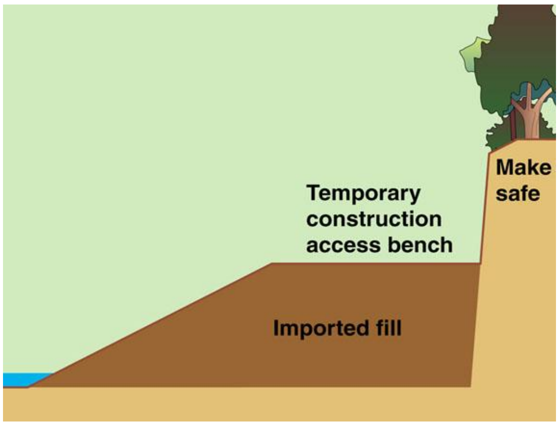


Stage 3: Bank revegetation

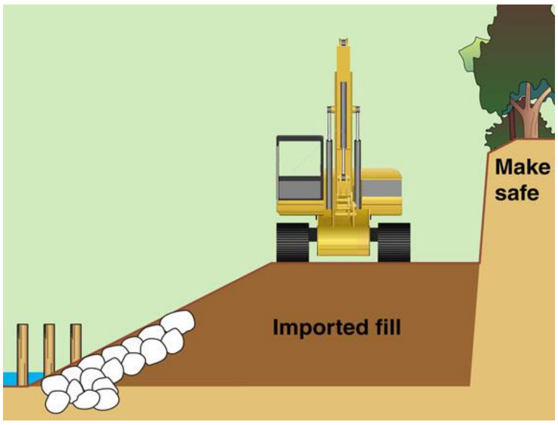
Bank repair Options H & I

Option H: Pile field toe protection

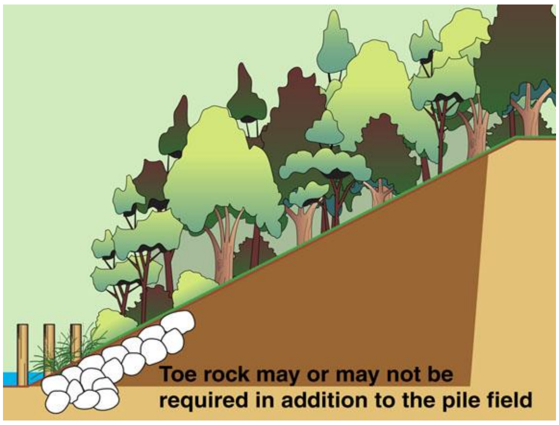
- This approach uses imported fill to construct a vehicle access bench.
- Construction vehicles will also require access down the creek bank at some point along the bench, which will mean some loss of riparian vegetation.
- The toe of the new bank can be stabilised with a pile field and/or rock.
- During final earthworks, the access bench is slowly covered with imported fill.



Stage 1: Construction access bench



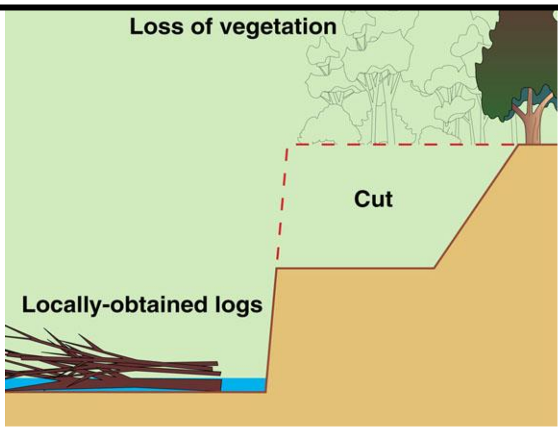
Stage 2: Install pile field toe protection



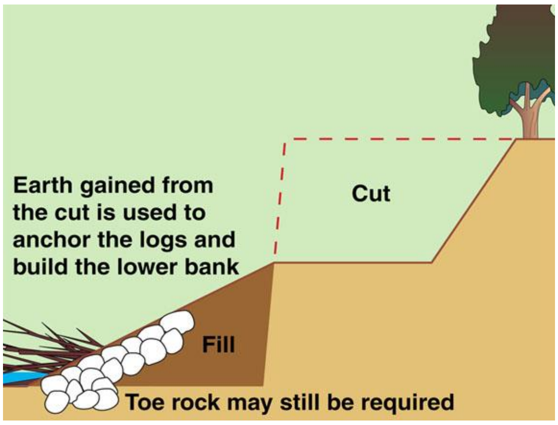
Stage 3: Final shaping and revegetation

Option I: Alternative log jam option

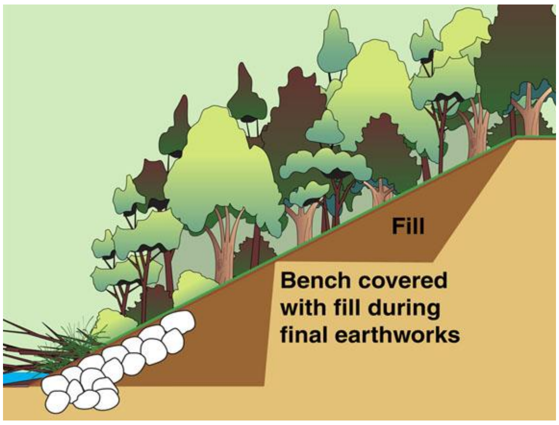
- In general, 'cut and fill' operations are cost effective because they do not require the purchase and transportation of imported fill.
- However, cut and fill operations can result in the loss of established riparian vegetation.
- Some of the trees removed from the floodplain can potentially be used to form a series of log jams.



Stage 1: Cut bank and place felled trees



Stage 2: Anchor trees and place fill

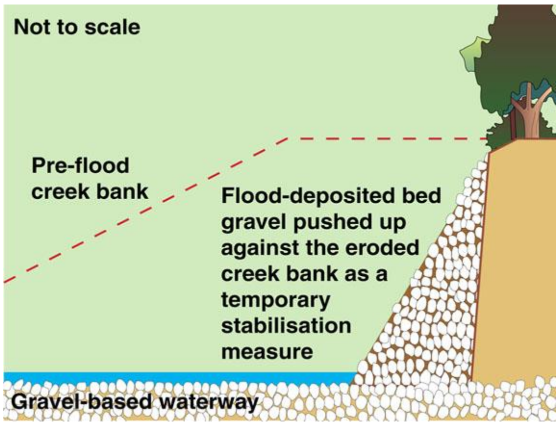


Stage 3: Final shaping and revegetation

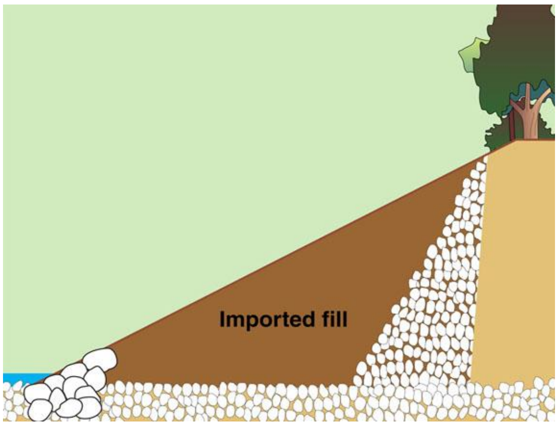
Bank repair Option J

Option J: Gravel bed treatment

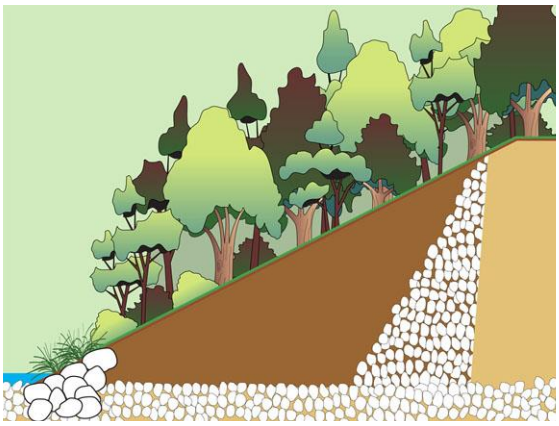
- In this approach, if flood damage to a gravel-based creek causes the formation of high, unstable banks, and if the eventual slumping of these banks could result in the loss of the last remaining riparian trees (a bad outcome), then:
  - flood-deposited bed gravel can be pushed up against the banks as a short-term solution, and . . .
  - once final bank rehabilitation plans and funding have been finalised, the long-term bank treatment can be applied.



Stage 1 Push gravel against unstable bank



Stage 2: Cover gravel with imported fill



Stage 3: Bank revegetation

Potential issues associated with the above post-flood bank treatment

- It should be noted that not all waterway authorities agree with the post-flood treatment option described above.
- The advantage is:
  - retention of mature riparian trees.
- The disadvantages are:
  - bed gravel is highly unstable
  - soil needs to be mixed with the bed gravel to provide a good growing media.

Post-flood bank erosion (Qld)

Gravel pushed up against the bank (Qld)

Protected riparian vegetation (Qld)

23. Glossary of Terms

Glossary of terms

1% flood	A flood that has a 1% probability of being equalled or exceeded within any 12 month period at a given location.
100 year flood	Another way of describing a 1% flood as above. Also referred to as a 1 in 100-year flood.
Aggradation	General and progressive build-up of the longitudinal profile of a channel bed due to sediment deposition.
Allowable flow velocity	A nominated velocity used in the design of hydraulic structures, and where this velocity is less than the critical (failure) velocity.
Alluvial channel	Channel wholly in alluvium; no bedrock is exposed in channel at low flow or likely to be exposed by erosion.
Alluvial waterway	A natural waterway channel formed primarily from flood-laid deposits of sand, silt and gravel, or a constructed channel primarily lined with alluvial material extracted from a waterway or floodplain.
Alluvium	Unconsolidated material deposited by a stream in a channel, floodplain, alluvial fan, or delta.
Armour (armouring)	Surfacing of channel bed, banks, or embankment slope to resist erosion and scour. (a) Natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambed due to the removal of finer particles by stream flow; (b) placement of a covering to resist erosion.
Average velocity	Velocity at a given cross-section determined by dividing discharge by cross-sectional area.
Backwater area	The low-lying lands adjacent to a stream that may become flooded due to backwater.
Backwater effect	The increase in water surface elevation relative to the elevation occurring under natural channel and floodplain conditions. It is induced by a bridge or other structure that obstructs or constricts the free flow of water in a channel.
Bank toe	Bank toe is the junction of the bank with the bed of the channel. The bank toe is usually marked by a break in slope but often the transition from bank to bed is gradual and the toe is difficult to determine.
Bankfull discharge	Discharge that, on the average, fills a channel to the point of overflowing.
Bankfull flow	The channel flow rate that exists when the water surface is level with the channel bank elevation above which the water would spill out of the channel or begin to enter the floodplain. Bankfull discharge is often used as one of the critical design parameters in Natural Channel Design and sediment transport calculations. The frequency of bankfull conditions will vary according to climate regions.
Bed layer	A flow layer, several grain diameters thick (usually two) immediately above the bed.
Bed load	The quantity of bed material passing a cross section of a stream in a unit of time.
Bed material	Material found in and on the bed of a stream (may be transported as bed load, or in suspension).
Bed rock	Loose rock found on the bed
Bed shear (tractive force)	The force per unit area exerted by a fluid flowing past a stationary boundary.
Bed slope	The longitudinal inclination of the channel bottom.
Bed	The bottom of a channel bounded by banks.

Bedrock	The solid rock exposed at the surface of the earth or overlain by soils and unconsolidated material.
Bench	A low-level bank (or shoulder) located below the top of the main bank typically formed by sediment deposits rather than by bank erosion, but may also be constructed (such as a berm).
Berm	A ledge constructed at one or more levels between the top and bottom of a batter with the purpose of intercepting runoff and reducing slope instability.
Boulder	A rock fragment whose diameter is greater than 250 mm.
Boundary layer	A relatively thin layer of water flow that forms adjacent to all solid surfaces over which the fluid passes. Inside the boundary layer the water velocity is less than the adjacent free-flowing water flow.
Braided channel	A stream whose flow is divided during low-flow conditions by small mid-channel bars or small islands; the individual width of bars and islands is less than about three times water width; a braided stream has the aspect of a single large channel within which are subordinate channels.
Catchment	That area of land from which stormwater runoff contributes to stream flow at the most downstream point of the catchment.
Channel pattern	The aspect of a stream channel in plan view, with particular reference to the degree of sinuosity, braiding, and anabranching.
Channel width	Channel width is measured from bank crest to bank crest.
Channelisation	Straightening or deepening of a natural channel by artificial cut-offs, grading, flow-control measures, or diversion of flow into an engineered channel.
Check dam (rock)	Small, regularly spaced, flow control structures that reduce the velocity of water. Typically used to control soil erosion in newly formed drains, and/or to act as minor sediment traps.
Choking (of flow)	Excessive constriction of flow which may cause severe backwater effect.
Clay (mineral)	A mineral-based particle with a diameter less than 0.002 mm.
Clay-based watercourse	A watercourse where clayey soils dominant within the stream channel.
	In this type of watercourse, stability is usually dominated by the existence of bed and bank vegetation. In their natural condition there is usually little, if any, sediment flow along clay-based creeks during most flood events (not the case for clay-based rivers).
Cobble	A fragment of rock whose diameter is in the range of 64 to 250 mm.
Cohesive streambed	Cohesive bed material can include caliche, hardpan, loess, highly compact and dense clays, and in the broader sense, erodible rock.
Critical flow	The state of flow in a section of a channel or partial-full conduit when the flow is at critical depth. Flow in which the Froude Number is equal to unity (1) and the specific energy (of the mean flow) is a minimum.
Critical flow velocity	[1] The average velocity of flow in a section of a channel or partial-full conduit when the flow is at critical depth.
	[2] The stream flow that initiates sediment movement.
Critical shear stress	The minimum amount of shear stress required to initiate soil particle motion (i.e. the point of incipient motion).
Critical storm duration	The design storm duration that produces the maximum peak discharge at a given location within a given catchment.
Cross-section (channel)	A channel section typically normal to the direction of flow.
Debris (flood)	Floating or submerged material, such as logs, vegetation, or trash, transported by a stream.

Degradation (bed)	A general and progressive (long-term) lowering of the channel bed due to erosion, over a relatively long channel length.
Depth of scour	The vertical distance a streambed is lowered by scour below a reference elevation.
Depth-average flow velocity	The average of the local flow velocities measured down through a given vertical plain.
Design flow (design flood)	The discharge that is selected as the basis for the design or evaluation of a hydraulic structure.
Discharge	Volume of water passing through a channel during a given time.
Dispersive soil	A soil that is structurally unstable in water, breaking down into its constituent particles (sand, silt and clay) and consequently allowing the dispersive clay fraction to disperse and cloud the water. The dispersion is caused by the high, negative, electro-magnetic charge on the surface of clay particles typically less than 0.005 mm in diameter.
Drainage line	A natural or constructed stormwater drainage path that carries 'concentrated' rather than 'sheet' flow, and is likely to flow only during periods of rainfall, and for short periods (hours) after rain has stopped, and is a drainage path that cannot be classified as a 'watercourse' based on a locally or state-adopted classification system.
Dry-cracking	The erosion experienced by a particular clayey soil that experiences significant swelling and shrinkage as the soil's moisture levels change. The erosion results in the soil crumbling when it is allowed to dry excessively.
Ephemeral waterway	A stream or reach of stream that does not flow for parts of the year. As used here, the term includes intermittent streams with flow less than perennial.
Filter fabric (cloth)	Geosynthetic fabric that serves the same purpose as a granular filter blanket.
Filter	Layer of fabric (geotextile) or granular material (sand, gravel, or graded rock) placed between bank revetment (or bed protection) and soil for the following purposes: (1) to prevent the soil from moving through the revetment by piping, extrusion, or erosion; (2) to prevent the revetment from sinking into the soil; and (3) to permit natural seepage from the stream bank, thus preventing the build-up of excessive hydrostatic pressure.
Fish-friendly	A term commonly used to describe a design process that promotes appropriate consideration of aquatic life within the design of waterway structures.
Flood hydrograph	A plot or recording of stream discharge versus time over the duration of a flood at a given location along a watercourse. A design flood hydrograph represents the discharge from a theoretical design storm. The highest point of the flood hydrograph represents the peak discharge.
Floodplain	A nearly flat, alluvial lowland bordering a stream, that is subject to frequent inundation by floods.
Floodway	The channel of a stream and that portion of the floodplain that must be kept free of encroachment by development or excessive vegetation so that a defined flood—typically the 1 in 100-year flood—can pass through without damage to the surrounding land or an unacceptable increase in flood heights. The floodway represents that portion of the floodplain where the appropriate management of its hydraulic (discharge) capacity is critical.

Fluting	A series of vertically elongated grooves (flutes) down gully sides caused by rill erosion. Most commonly experienced in dispersive soils. In severe cases the rills may become isolated from the gully walls to form narrow tapered pinnacles.
Fluvial geomorphology	The science dealing with the morphology (form) and dynamics of streams and rivers.
Fresh (stream flow)	A 'fresh' is an elevated stream flow that does not spill over the banks.
Fretting	Fretting is the erosion of a bank at a specific elevation, or at a point of weak soil, as a result of wave action. This form of bank erosion is primarily caused by waves generated from power boats or water skiing.
Froude number	A dimensionless parameter defined by ratio of inertial and gravitational forces acting on the water. The Froude Number (F) provides a criterion for determining whether a given flow is subcritical (F<1), critical (F=1) or supercritical (F>1).
Gabion	A basket filled with rock, or similar material, usually rectangular in profile, used in the construction of retaining walls and erosion-control structures. Gabion baskets are most commonly made from specially coated wire baskets, but can be made from gabions filled with soil and brush cuttings (termed soft gabions) and used for stream stabilisation.
Geomorphology (morphology)	That science that deals with the form of the Earth, the general configuration of its surface, and the changes that take place due to erosion and deposition.
Grade-control structure	Structure placed bank to bank across a stream channel (usually with its central axis perpendicular to flow) for the purpose of controlling bed slope and preventing scour or head-cutting.
Gravel	A rock fragment whose diameter ranges from 2 to 64 mm.
Gravel-based watercourse	A watercourse with a channel bed primarily consisting of gravel, cobbles and boulders. Flood events generally cause a slow, progressive movement of the gravel and cobbles down the watercourse. Gravel-based systems commonly contain pool-riffle systems along the bed.
Gully	An open, incised erosion channel in the landscape generally greater than 30 cm deep. Active gullies are characterised by moderately to very gently inclined floors and precipitous walls.
Hard engineering	A form of bed or bank stabilisation that is likely to result in a hard surface formed from synthetic materials. The surface may be porous, flexible, and even vegetated, and still considered as hard engineering.
Head-cut erosion	A condition of soil erosion represented by a sudden change in the bed elevation within a gully or stream forming an obvious downward step (in the direction of flow). The erosion of the gully or stream primarily results from this 'step' migrating up the gully line or stream channel. A head-cut often forms the upper limits of gully erosion, but may also appear within boundaries of an existing gully.
Hydraulic radius	The cross-sectional area of a stream divided by its wetted perimeter.
Incised stream	A stream which has deepened its channel through the bed of the valley floor, so that the floodplain is a terrace.

Invert	The lowest point in the channel cross-section or at flow control devices such as weirs, culverts, or dams.
Jute bagging	A method of revegetation that involves the use of small biodegradable bags formed (sewn) from jute blanket.
Lateral bank erosion	Erosion in which the removal of material is extended horizontally into the bank, ultimately forming a gully or new tributary.
Left bank	The creek bank on the left-hand side when looking downstream.
Liquefaction	The action of a soil (or other material) developing the behaviour of a slurry.
Local flow velocity	The flow velocity at a specific location (point) within a cross-section.
Macrophyte species	A term commonly used to describe emergent aquatic plants, such as some sedges, rushes and reeds, are shallow-rooted species which grow at the margins of the mean water level. Literally it means a plant that is large enough to be visible to the eye, as compared to algae.
Manning's equation	A formula used to predict the velocity of uniform fluid (water) flow in an open channel or other conduit.
Manning's roughness	The numerical representation of the hydraulic roughness of a conduit, flow path or channel as used in the Manning's formula.
North-bank problem	The erosive effects of the extra shading that occurs on northern creek banks (in the Southern hemisphere).
Overbank	Relating to not being located between the top of the banks of a channel.
Overbank vegetation	The vegetation that exists over the land that extends from the 'top of bank' to the edge of the floodplain. However, this term is more commonly associated only with the vegetation held within the riparian zone.
Rational Method	A formula for estimating peak discharge of runoff from a given catchment area.
Reach	A segment of stream length that is arbitrarily bounded for purposes of study.
Retard (retarder structure)	A permeable or impermeable linear structure extending from the bank, which is intended to reduce flow velocity, induce deposition, or deflect flow from the bank.
Riffle	A shallow area of a river where water flows rapidly and often turbulently over stones or gravel.
Right bank	The creek bank on the right-hand side when looking downstream.
Riparian vegetation	The vegetation that occurs from normal water level to the edge of the floodplain, and has a direct association with the watercourse.
Riparian zone	The area of land between the edge of the normal water level to the open floodplain; however, the 'minimum width requirement' for riparian zones is often measured from the top of bank.
Riparian zone width	Riparian zone width is the minimum width of riparian forest required for ongoing bank stability. It is measured from the bank crest away from the channel. The minimum width of the riparian zone varies with bank height and bank erosion rate.
River training	Engineering works with or without the construction of embankment, built along a stream or reach of stream to direct or to lead the flow into a prescribed channel. Also, any structure configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a stream bank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.

Rock mattress	A flat wire cage or basket filled with stone or other suitable material and placed as protection against erosion.
Rock-based watercourse	Bed material is made-up of exposed rock outcrops separated by sections of clay, sand or gravel-based channels. Bank stability is governed either by bank vegetation or exposed rock walls. These are fixed-bed ‘spilling’ waterways usually containing riffles and waterfalls followed by deep pools.
Runoff (run-off)	That part of precipitation which appears in surface streams of either perennial or intermittent form.
Sand slug	A body of loose bed material, typically a mix of sand and gravel, that slowly migrates down a waterway as a result of flooding.
Sand-based watercourse	Waterways in which deep, loose sand dominates the make-up of the stream bed. The depth of the sand typically exceeds the depth of the root systems of some bed and lower bank vegetation. These are ‘alluvial’ waterways that experience significant sediment (sand) flow during both minor and major stream flows. The bed material can be highly mobile during floods, thus bed vegetation is normally dominated by quick-response species.
Shield’s-based rock-sizing formula	This includes any of the rock-sizing formulas that have been developed from the Shield’s equation for sediment transport, which assumes the bed sediment (or rocks) rest on a relatively flat bed.
Slaking soil	The process of natural collapse of a soil aggregate in water where its mechanical strength is insufficient to withstand the swelling of clay and the expulsion of air from pore spaces. It does not include the effects of soil dispersion. Slaking aggregates readily break down when immersed in water, but do not disperse. Clouding of the water, if any, is limited to just around individual aggregates. Slaking soils are highly erodible and structurally unstable, but readily settle in water.
Slump	An earth slide where the material in motion is not greatly deformed but has rotated backward on a more or less horizontal axis, i.e. displacement is primarily along a concave surface of separation. Ordinarily slumping results from the removal or death of specific vegetation, such as deep-rooted plants, or a rapid lowering of water level adjacent to the earth slope, e.g. at the end of some flood events.
Slumping	The process of slump erosion occurring within an earth bank or slope, or soil erosion in the form of a slump.
Snag	Woody flood debris that becomes temporarily trapped within a waterway channel.
Soil-cement	A designed mixture of soil and Portland cement compacted at a proper water content to form a blanket or structure that can resist erosion.
SOWN	A community-based creek rehabilitation group known under the title: Save Our Waterways Now.
Stream order	Stream order is a system for ranking the individual reaches of a waterway. There are a number of these ranking systems. In the Horton system a first-order stream has no contributing branches based on a specified mapping scale (the choice of map scale is critical). A second-order stream has at least two contributing first-order branches. A third-order stream has at least two contributing second-order branches, etc.

Stream power	Stream power is a measure of a waterway's capacity or energy to perform geomorphic work within the channel. It is a measure of the energy available to move bed sediment, or reshape a channel during a flood.
Subcritical flow	A free-surface flow condition which has a Froude number less than unity (1), a depth greater than the critical depth, and a velocity less than the critical velocity. During subcritical flow, flow conditions at a given location are primarily controlled by the flow conditions immediately downstream of that location.
Supercritical flow	A free-surface flow condition which has a Froude number greater than unity (1), a depth less than the critical depth, and a velocity greater than the critical velocity.
Threshold flow velocity	The flow velocity that just begins to cause soil scour or the movement of bed material.
Toe of bank	That portion of a stream cross-section where the lower bank terminates and the channel bottom or the opposite lower bank begins.
Top of bank	The top elevation of a given creek bank.
Tractive force	The drag or shear on a streambed or bank caused by passing water which tends to move soil particles along with the stream flow.
Undercutting	Bank erosion that causes the upper bank to cantilever over the lower bank.
Understorey	Vegetation that exists at an elevation below the tree canopy.
Uniform flow conditions	A flow condition in which hydraulic conditions, such as depth and velocity, are the same at all locations along the flow field at a given instant.
V : H	Meaning: The vertical (V) to horizontal (H) gradient.
Void spacing	The potential volume of air that could exist between clean rocks.
Watercourse	Any natural or constructed drainage channel with well-defined bed and banks, including constructed drainage channels of a natural appearance, creeks and rivers, but not grass-lined or hard-surface constructed drainage channels void of ecological values. Within this document, the term can be interchanged with 'waterway'.
Waterway	Any natural or constructed drainage line, watercourse with well-defined bed and banks, including creeks and rivers, and any water body including lakes, wetlands, estuaries, bays and oceans. Within this document, the term can be interchanged with 'watercourse'.