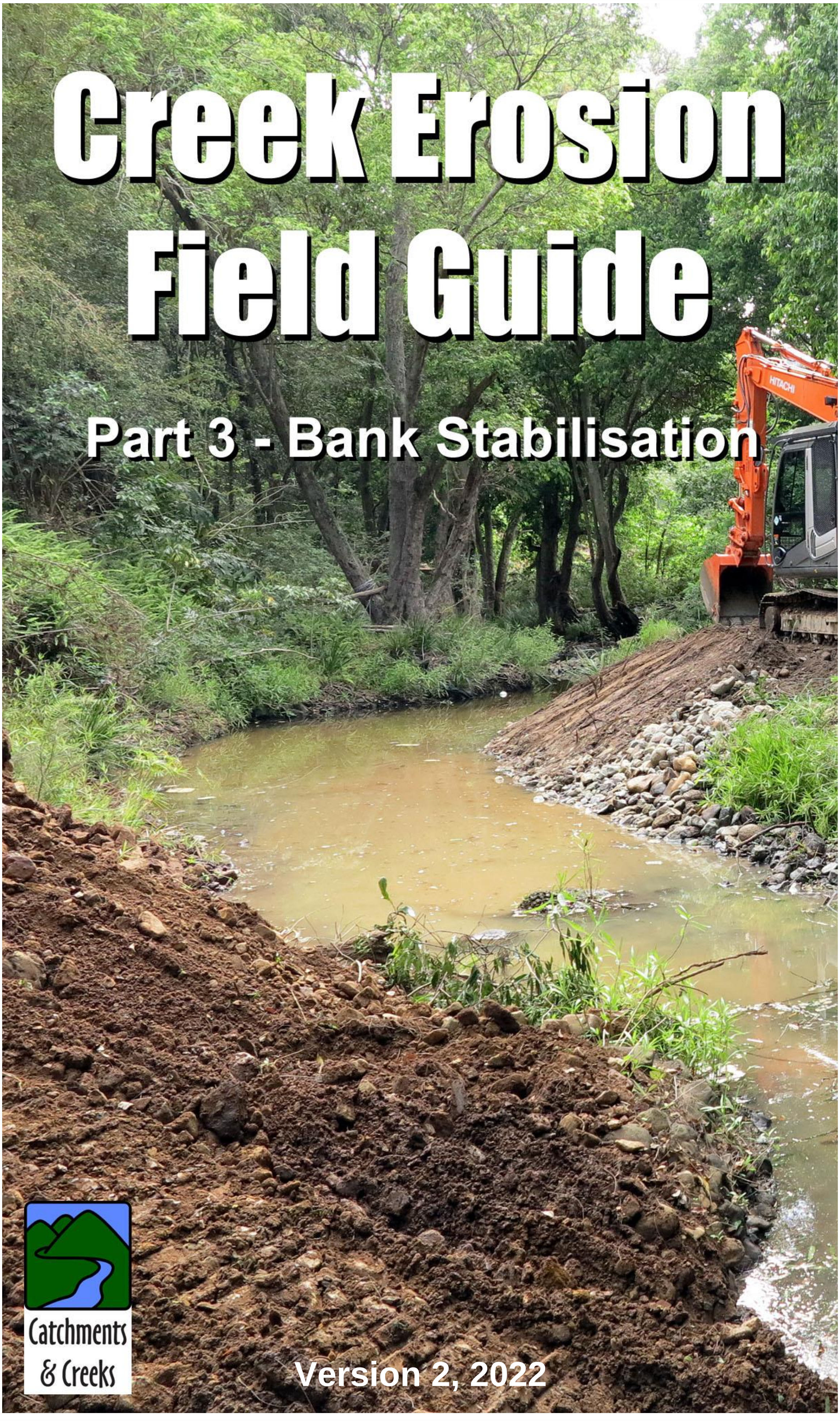
Creek Erosion Field Guide

Part 3 - Bank Stabilisation



Catchments & Creeks

Version 2, 2022

Creek Erosion Field Guide

Part 3 – Bank Stabilisation

Version 2, February 2022

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This document should be referenced as:

Witheridge 2021, *Creek Erosion Field Guide Part 3 – Bank Stabilisation*. Catchments & Creeks Pty Ltd., Bargara, Qld.

Key words: creek erosion, waterway erosion, bank erosion, bed erosion, soil erosion, gully erosion, waterway management.

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Cover image: Cedar Creek at Closeburn, Queensland, 2015

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 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.

No warranty or guarantee, express, implied, or statutory is made as to the accuracy, reliability, suitability, or results of the methods or recommendations.

Further to the above, the adoption of the recommendations and procedures presented within this field guide will not guarantee:

(i) compliance with any statutory obligations

(ii) permanent control of erosion issues

(iii) avoidance of environmental harm or nuisance.

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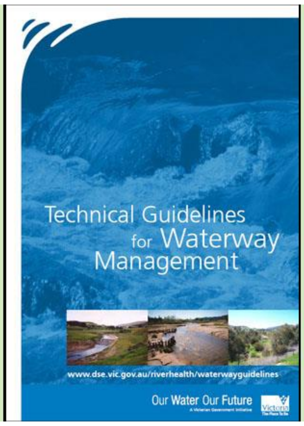
Useful reference documents



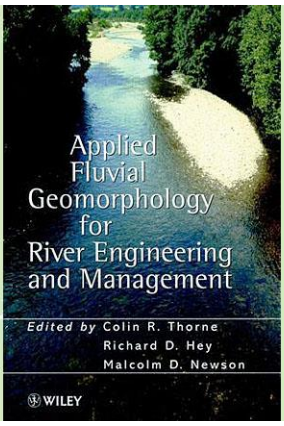
Victoria DSE (2007)

Technical Guidelines for Waterway Management

Department of Sustainability and Environment, Technical Guidelines for Waterway Management, Department of Sustainability and Environment, Victoria.

Published by the Victorian Government Department of Sustainability and Environment, Melbourne, July 2007

ISBN 978 1 74152 794 0



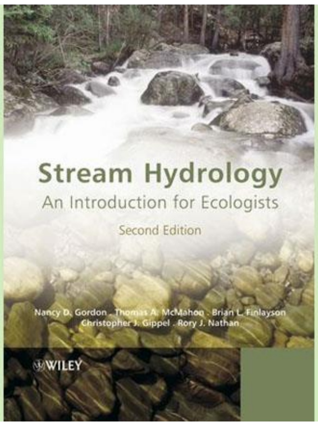
Thorne, Hey & Newson (2003)

Applied Fluvial Geomorphology for River Engineering and Management

Colin Thorne, Richard Hey and Malcolm Newson

John Wiley & Sons, Chichester, England, 1997, Reprinted 2000, 2001, 2003

ISBN 0 471 96968 0 (paperback)



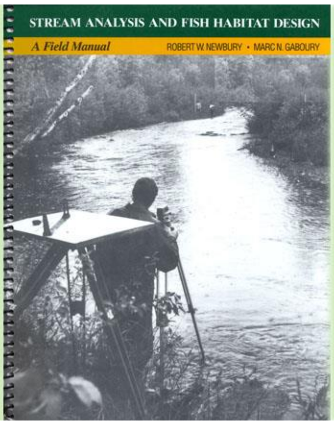
Gordon, McMahon, Finlayson, et al. (2004)

Stream Hydrology – An Introduction for Ecologists

Nancy Gordon, Thomas McMahon, Brian Finlayson, Christopher Gippel and Rory Nathan

John Wiley & Sons, Chichester, England, 1992 (1st edition), 2004 (2nd edition)

ISBN 9780 4708 43581



Newbury & Gaboury (1993)

Stream Analysis and Fish Habitat Design

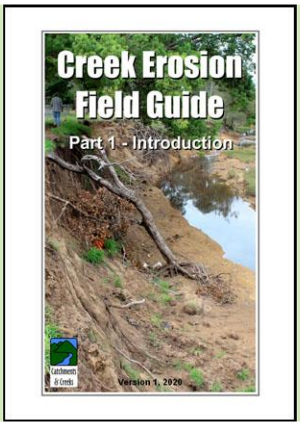
Robert Newbury and Marc Gaboury

Published by Newbury Hydraulics Ltd. and The Manitoba Habitat Heritage Corporation, Manitoba Fisheries Branch, Gibsons, British Columbia, Canada, 1993

ISBN 0 969 6891 0 1

Contents

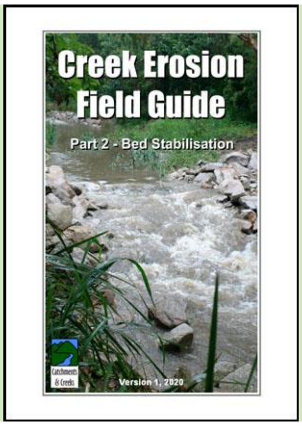
Layout of this four-part field guide



Creek Erosion Field Guide – Part 1

Part 1 – Types of waterways and causes of waterway erosion

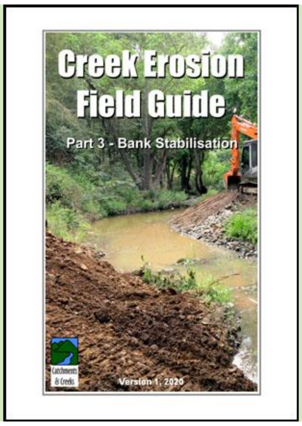
- Designing the appropriate treatment measures for creek erosion depends on knowing:
  - the type of watercourse
  - the type of erosion, and
  - the likely causes of the erosion.
- Part 1 discusses each of these issues, as well as presenting an introduction to creek engineering and fluid mechanics.



Creek Erosion Field Guide – Part 2

Part 2 – Bed stabilisation

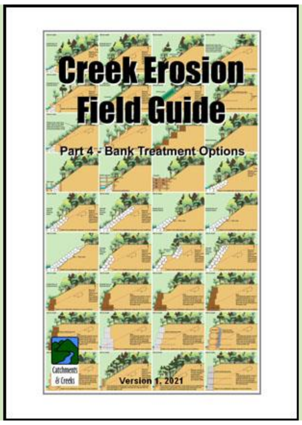
- Prior to presenting detailed information on bed stabilisation techniques, discussion is presented on the following topics:
  - fish-friendly waterways
  - common properties of rock
  - hydraulics of bed structures.
- Information on the treatment of <u>bed</u> erosion is then grouped into two chapters: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



Creek Erosion Field Guide – Part 3

Part 3 – Bank stabilisation

- The treatment of <u>bank</u> 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

Though it would be tempting to prepare a creek erosion guideline that simply stated that all treatment measures should consist of just three elements: soil, rock and plants; the reality is that such a statement could not be justified. The site conditions faced by creek engineers on a regular basis are so varied that it is necessary to use a much wider range of erosion control materials and techniques.

What I can say is that most creek erosion can, and should, be repaired with just five elements: soil, rock, plants, jute and coir. Noting that the 'plant' element includes brushwood, logs and snags.

To be a good waterway manager you must have good people skills because of the importance of good communication, good planning, good team building, the ability to find the necessary resources (including funding), and the ability to win over government regulators.

To be a good creek engineer you must have a good understanding of how water moves in three-dimensions, be able to read the land and the waterway, and have a very good understanding of how to use plants to produce desirable flow conditions, and to control soil erosion. A creek engineer does not need to know the botanical name of plants, but good creek engineers must know how to optimise the use of plants.

An overview of Chapter 8 – Planning your response to creek erosion

Project meeting

A tree's response to severe bank erosion

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.

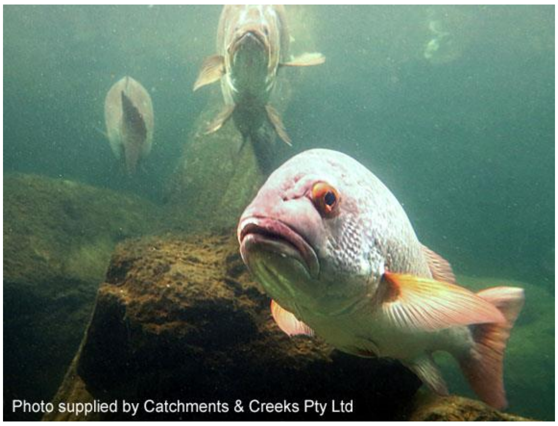
Step 15 – Recontact interested parties

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

Step 16 – Obtain approvals and permits

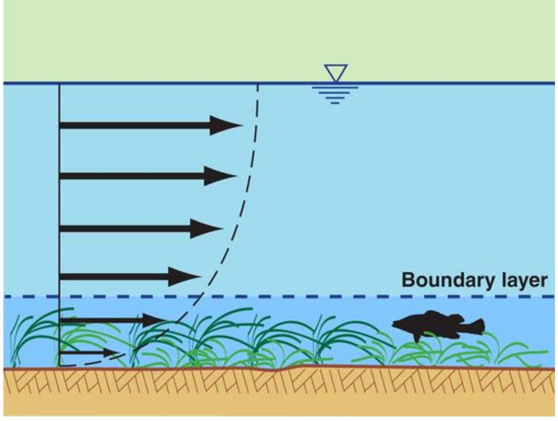
- Get all necessary approvals for your proposed works.

An overview of Chapter 9 – Fish-friendly waterway design (from Part 2)



Aquatic habitat (Qld)

Pygmy perch (NSW Fisheries)



Boundary layer flow conditions

Gravel-based creek with boulders (Qld)

The importance of maintaining fish-friendly waterway conditions

- Consideration of fish habitat and fish passage issues is important for the following reasons:
  - maintaining healthy aquatic life helps to control mosquito numbers
  - conservation of wildlife diversity
  - conservation of fish breeding habitats
  - benefits to recreational and commercial fishing
  - benefits to aquatic–terrestrial linkages.

The swimming ability of fish

- The swimming ability of fish varies with each species, and the size of the fish.
- For any given fish (size and species) its swimming speed can be classified into three levels:
  - *Burst speed*, which is able to be maintained for short periods (seconds)
  - *Sustained speed*, a medium speed able to be maintained for minutes
  - *Cruising speed*, which allows fish to maintain continuous movement.

Variation in flow velocities adjacent to creek banks

- Fish are aided in their movement by the fact that flow velocities are not uniform across the width and depth of most channels.
- Friction and turbulence alter the local flow velocity, with velocities being reduced close to the bed and banks of creeks as a result of friction.
- This region of lower velocity water is commonly referred to as the boundary layer.

Small backwaters and shadow zones

- A key to good aquatic habitat and fish passage conditions is a diversity in type of bed conditions.
- The existence of a uniform channel cross-section means flow conditions across the channel will either be ‘all good’ or ‘all bad’.
- Bed irregularities, such as exposed boulders, can provide fish with areas to rest and rebuild their energy prior to continuing their migration, or their search for food.

Fish-friendly creek bank stabilisation measures (from Part 2)

Gravel-based creek (Qld)

Desirable creek bank features

- Within fish habitats, erosion control measures should aim to provide the following features:
  - bed and bank roughness that simulates the natural creek roughness
  - a diversity of surface conditions that produce a diversity of flow conditions
  - shading of the water's edge and permanent pools to provide shelter, and to control water temperatures
  - a suitable source of food.

Hard engineering scour control

Avoiding hard engineering solutions

- Most 'hard engineering' erosion control measures do not provide desirable fish habitat or fish passage conditions.
- Adding to the problem is the uniform, and possibly smooth, surface conditions that do not provide:
  - good boundary layer conditions
  - good habitat values
  - appropriate shelter.

Undesirable erosion control outcome

Avoiding non-vegetated solutions

- Vegetation is the channel feature that best provides the boundary layer conditions necessary for fish passage.
- Non-vegetated surfaces typically do not provide desirable fish habitat, or fish passage, conditions.
- If gabion and rock mattress surfaces must be provided, then wherever practical, these surfaces should be appropriately vegetated during their installation.

Non-native, mat-forming grasses

Avoiding the use of mat-forming grasses

- In hydraulic terms, there are two types of ground covers, those that fold flat in high-velocity flow (e.g. mat-forming grasses), and those that are more resistant to these hydraulic pressures (e.g. clumping, or stiff grasses).
- Most of the introduced grasses (i.e. weeds) fold flat during flood events, which means that they may not generate the boundary layer conditions considered desirable for fish passage.

Fish-friendly creek bank stabilisation measures (from Part 2)

A native stiff-grass; *Lomandra* (Qld)

Use of stiff grasses

- The first objective should be to use only locally endemic (native) plants.
- The desire to optimise fish habitat values within a waterway should not be used as an excuse to use non-native species, or native plants not common to the area.
- However, in severely modified waterways it may be desirable to make greater-than-normal use of stiff grasses, such as *Lomandra*, in order to achieve desirable boundary layer conditions.

Vegetated rock stabilisation (Qld)

Vegetated rock work

- Placed rock is a very useful means of stabilising stressed or eroded creek banks.
- Establishing native vegetation over such rock work can provide the following benefits:
  - improved fish passage conditions
  - improved shading of the water's edge
  - improved stability of the creek bank
  - improved aesthetics.

Overbank riparian vegetation (Qld)

Overbank riparian vegetation

- The existence of a riparian zone can be critical for good fish passage.
- The upstream movement of fish during flood events is critical for some species, which means fish-friendly features usually need to extend across the riparian zone and into the floodplain.
- Flow velocities are normally much lower in these overbank regions (compared to the channel), so different plants can be used to generate desirable fish passage conditions.

Shading of the water's edge (NSW)

Shading of the water

- It is of course important to focus your attention on the section of creek bank that is currently being repaired; however, while carrying out any rehabilitation program, appropriate attention should also be given to:
  - general weed removal
  - ensuring a suitable balance exists between upper (canopy), middle and lower storey plants
  - ensuring suitable vegetation exists that can shade the water.

An overview of Chapter 10 – Common properties of rock (from Part 2)

Bank stabilisation with rock (Qld)

Introduction

- Rock is one of the most common materials used in the repair of creeks.
- Rock is successful because it works well with the dynamics of most waterways.
- Chapter 10 (in Part 2) presents much of the design information on rock selection and rock placement.

Sizing rock for use in straight channels

$$d_{50} = 40\ V^2$$

where:

d_{50} = mean rock size (mm)

V = average flow velocity (m/s)

Note: this equation gives d_{50} in millimetres

Specifying a required rock size

- The good thing about rock-sizing equations is that they can be programmed into design spreadsheets.
- The bad thing about rock-sizing equations is that they can produce 'answers' to the nearest millimetre, which is simply unrealistic.
- There is little point in determining rock size to the nearest millimetre, or even centimetre, given the high variation in flow conditions at a given cross-section.

Large fractured rock (Qld)

Quarry face or selected rock sizing

- Some quarries only sell a limited range of rock sizes, such as:
  - quarry face (or first blast), which often includes rock sizes from 300 mm to over 1000 mm
  - selected rocks larger than 1000 mm
  - rocks of around 600 mm
  - rocks of around 450 mm
  - graded rocks (50, 100, 200 & 300 mm) of a near uniform size that have passed through a sieving process.

Individual placement of rocks (Qld)

Gradient of rock-stabilised creek banks

- Recommended maximum gradients are:
  - 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 revegetation activities
  - 1 in 2 for dumped rock on the outside of channel bends
  - 1 in 3 for dumped rock on the inside of channel bends.

Use of filter layers and filter cloth (from Part 2)

Filter cloth (Qld)

Conditions where filter cloth should be used

- Filter cloth is typically incorporated into the following structures:
  - some batter chutes
  - some drainage channels
  - non-vegetated bank stabilisation
  - energy dissipaters & outlet structures.
- The filter cloth must have sufficient strength (minimum 'bidim A24'), and must be suitably overlapped to withstand any disturbance during rock placement.

Voids filled with soil prior to planting

Conditions where filter cloth should <u>not</u> be used

- The 'old rule' was that rocks must always be placed over a filter layer made up of either smaller rocks, or filter cloth.
- However, an underlying filter layer is usually not required **IF** the voids are filled with soil and pocket planted (which is the preferred outcome).
- Therefore, fully vegetated, rock-lined banks usually do not require filter cloth to be placed under the rock.

Rock filter layer (blue) under surface rock

The use of aggregate filters

- An alternative to the use of filter cloth is the use of an aggregate filter.
- Two or more layers of aggregate may be required depending on the size of the primary armour rock.
- Recommended rock size grading is:

$$d_{15c}/d_{85f} < 5 < d_{15c}/d_{15f} < 40$$

where:

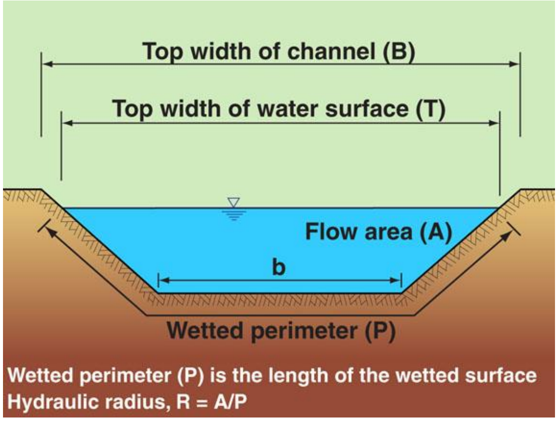
- 'c' and 'f' refer to the coarse layer and fine rock underlay respectively.

Erosion under rocks on a dispersive soil

Filter cloth cannot be placed directly on a dispersive soil

- Dispersive soils contain highly mobile clay particles.
- Clay particles are so small in size that they readily pass through **<u>all</u>** forms of construction-grade filter cloth.
- Dispersive soils **<u>must</u>** be sealed by a layer of non-dispersive soil prior to placement of a filter cloth, or aggregate filter layer.

Manning's roughness of rock (from Part 2)



Channel geometry and flow conditions

Gravel-based alluvial waterway (Tas)

Deep water flow conditions (Qld)

Shallow water flow conditions (Qld)

Manning's equation

- The **average** channel flow velocity may be calculated using Manning's equation:

$$V = (1/n) \cdot R^{2/3} \cdot S^{1/2} \qquad (10.1)$$

where:

- V = average flow velocity (m/s)
- n = Manning's roughness coefficient
- R = hydraulic radius (m) = A/P
- A = effective flow area of channel (m^2)
- P = wetted perimeter of flow (m)
- S = channel slope (m/m)

Factors affecting the hydraulic roughness of rock-lined surfaces

- The Manning's roughness of rock-lined surfaces depends on:
  - the average rock size (d_{50})
  - the distribution of rock sizes, defined in this case by the ratio: d_{50}/d_{90}
  - the depth of water flow, usually defined by the hydraulic radius of flow (R)
  - the existence of vegetation
  - the occurrence of aerated water (e.g. whitewater flowing down rapids).

Manning's roughness in deep water

- The Strickler formula for deep water may be presented as:

$$n = ((d_{50})^{1/6})/21.1 \qquad (10.2)$$

- An alternative equation was developed by Meyer-Peter & Muller:

$$n = ((d_{90})^{1/6})/26.0 \qquad (10.3)$$

where:

- d_{50} = rock size for which 50% of rocks are smaller [m]
- d_{90} = rock size for which 90% of rocks are smaller [m]

Manning's roughness in shallow water

- The Manning's roughness (n) of rock-lined surfaces in both shallow water and deep water flow conditions is provided by:

$$n = \frac{d_{90}^{\ 1/6}}{26(1 - 0.3593^{m})} \qquad (10.4)$$

  - $m = [(R/d_{90})(d_{50}/d_{90})]^{0.7}$
  - R = hydraulic radius of flow [m]

- The relative roughness (d_{50}/d_{90}) of rock extracted from streambeds is typically in the range 0.2 to 0.5; while quarried rock is commonly in the range 0.5 to 0.8.

Manning's roughness of rock (from Part 2)

The Manning's (n) roughness for rock-lined surfaces can be determined from Table 10.1 or Equation 10.4.

Table 10.1 – Manning's (n) roughness of rock-lined surfaces

	d_{50}/d_{90} = 0.5				d_{50}/d_{90} = 0.8			
d_{50} =	**200mm**	**300mm**	**400mm**	**500mm**	**200mm**	**300mm**	**400mm**	**500mm**
R (m)	Manning's roughness (n)				Manning's roughness (n)			
0.2	0.10	0.14	0.17	0.21	0.06	0.08	0.09	0.11
0.3	0.08	0.11	0.14	0.16	0.05	0.06	0.08	0.09
0.4	0.07	0.09	0.12	0.14	0.04	0.05	0.07	0.08
0.5	0.06	0.08	0.10	0.12	0.04	0.05	0.06	0.07
0.6	0.06	0.08	0.09	0.11	0.04	0.05	0.05	0.06
0.8	0.05	0.07	0.08	0.09	0.04	0.04	0.05	0.06
1.0	0.04	0.06	0.07	0.08	0.03	0.04	0.05	0.05

Equation 10.4 is considered to produce significantly better estimates of the Manning's roughness of rock-lined surfaces in shallow water flow compared to the use of traditional deep water equations of Strickler, Meyer-Peter & Muller and Limerinos.

Given the high variability of Manning's n, and the wide range of variables that are believed to influence the hydraulic roughness of a rock-lined channel, Equation 10.4 is considered well within the limits of accuracy expected for Manning's n selection.

Data analysis during the development of Equation 10.4 indicated that the Meyer-Peter & Muller equation (Eqn 10.3) produced more reliable estimates of the deep water Manning's roughness values than the Strickler equation (Eqn 10.2). Possibly the choice between the two equations would come down to how reliable the determination of the d_{50} and d_{90} values are. If the estimate of d_{90} is not reliable, then it would be more appropriate to rely on the Strickler equation for the determination of the deep water Manning's n value, and vice versa.

Table 10.2 provides the range of data values used in the development of Equation 10.4. This table also contains the data range for the selected variables for which the calculated Manning's n value using Equation 10.4 fall within +/-10% of the observed Manning's n.

Table 10.2 – Data range used in determination of Equation 10.4

	d_{50} (mm)	**d_{90} (mm)**	**R/d_{50}**	**R/d_{90}**	**n_o/n**	**d_{50}/d_{90}**
Min (+/-10%)	16	90	2.31	0.73	0.284	0.080
Max (+/-10%)	112	350	55.6	12.0	1.080	0.661
Min (All data)	16	90	1.17	0.31	0.097	0.080
Max (All data)	397	1080	66.9	12.9	1.120	0.661

Bank gradient

The recommended maximum side slope of a large rock-lined chute is 1:2 (V:H); however, side slopes as steep as 1:1.5 can be stable if the rock is individually placed rather than dumped. Typical angles of repose for dumped rock are provided in Table 10.3.

Table 10.3 – Typical angle of repose for dumped rock

Rock shape	**Angle of repose (degrees)**	
	Rock size > 100 mm	**Rock size > 500 mm**
Very angular rock	41^o	42^o
Slightly angular rock	40^o	41^o
Moderately rounded rock	39^o	40^o

Typical properties of rock (from Part 2)

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more 'natural' appearance. A 36% increase in rock size is recommended if rounded rock is used (i.e. K_1 = 1.36, which is a coefficient used in several rock-sizing equations).

The rock should be durable and resistant to weathering, and should be proportioned so that neither the breadth nor the thickness of a single rock is less than one-third of its length.

Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size, but in some cases a maximum rock size of 1.5 times the average rock size may be specified.

Typical rock densities (s_r) are presented in Table 10.4.

Table 10.4 – Relative density (specific gravity) of rock

Rock type	Relative density (s_r)
Sandstone	2.1 to 2.4
Granite	2.5 to 3.1 (commonly 2.6)
Limestone	2.6
Basalt	2.7 to 3.2

Table 10.5 provides a suggested distribution of rock sizes for waterway chutes. The distribution of rock size can also be described by the coefficient of uniformity, $C_u = d_{60}/d_{10}$, which usually falls in the range 1.1 to 2.7, but typically around 2.1. Witter & Abt (1990) reported that poorly graded rock (C_u = 1.1) has a critical discharge 8% greater than well-graded rock (C_u = 2.2).

Table 10.5 – Typical distribution of rock size for fish friendly structures (guide only)

Rock size ratio	Assumed distribution value
d_{100}/d_{50}	2.0
d_{90}/d_{50}	1.8
d_{75}/d_{50}	1.5
d_{65}/d_{50}	1.3
d_{40}/d_{50}	0.65
d_{33}/d_{50}	0.50
d_{10}/d_{50}	0.20

Effective thickness of a rock layer

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size. It is noted that increasing the thickness of the rock placement will **not** compensate for the use of undersized rock.

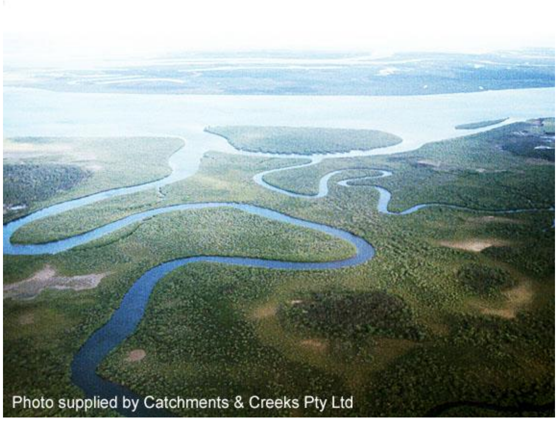
In order to allow at least two layers of rock, the minimum thickness of rock protection (T) can be approximated by the values presented in Table 10.6.

Table 10.6 – Minimum thickness (T) of two layers of rock

Min. thickness (T)	Size distribution (d_{50}/d_{90})	Description
1.4 d_{50}	1.0	Highly uniform rock size
1.6 d_{50}	0.8	Typical upper limit of quarry rock
1.8 d_{50}	0.67	Recommended lower limit of distribution
2.1 d_{50}	0.5	Typical lower limit of quarry rock

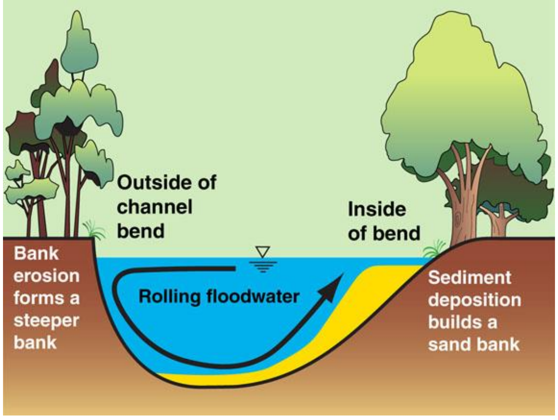
14. Bank Stabilisation Using <u>Soft</u> Engineering Methods

Introduction



Natural erosion processes (Qld)

Bank erosion at a channel bend (Qld)



Typical bank conditions at bends

Benching to provide equipment access

Whether or not to interfere with a creek

- It is important to remember that creeks have been 'fixing' their own erosion problems for millions of years—long before any human interference.
- The concern is, that when creeks are left to find their own response to an erosion problem, the results:
  - may not be acceptable to landholders on both sides of the creek
  - may not have protected public assets
  - may take too long to become stable.

Stabilising or unstable bank erosion

- Some forms of bank erosion can be repaired very effectively just by allowing natural processes to unfold, which means lower costs for the landholder, and no need to bring in heavy machinery.
- However, while there are some forms of bank erosion that can move quickly to a stable outcome, there are also examples of unstable bank erosion where the creek struggles to find a stable condition that is acceptable to the adjacent landowners.

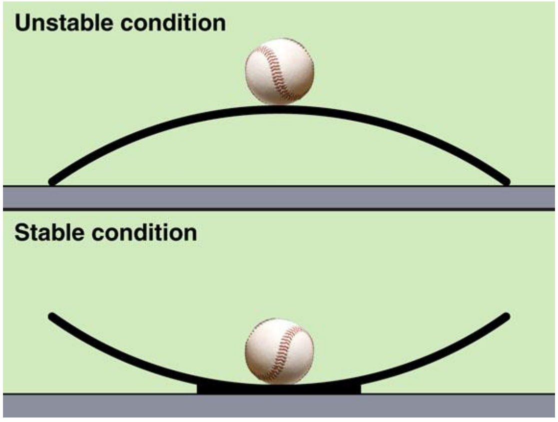
Inside or outside of a channel bend

- The preferred treatment of bank erosion is influenced by several site conditions.
- One of the most important site conditions is whether the bank erosion is on the inside, or outside, of a channel bend.
- Scour forces are usually much higher on the outside of a channel bend, which increases the need for rock protection.
- Also, the slope of the bank on the outside of a bend is usually much steeper than on the inside of the same bend.

Potential damage caused by bringing in heavy machinery

- A critical factor in any response to creek erosion is to consider how much damage could be introduced to the creek simply by bringing in heavy machinery.
- If the creek has critical habitat trees next to the eroded bank, then the only feasible way of bring rock into the creek without damaging these trees is to construct a rock or earth bench in front of the existing bank, but this may (or may not) reduce the flow area of the creek.

Unstable forms of bank erosion



Stable and unstable conditions

Outside of a channel bend (Qld)

Shaded north bank (Qld)

Dispersive soil erosion (NSW)

Introduction

- Examples of 'stable' and 'unstable' conditions can be demonstrated by placing a ball on a concave (stable), or a convex surface (unstable condition).
- When creek erosion exists in a stable form, it can often repair itself (over time).
- When creek erosion exists in an unstable form, the erosion can become an ongoing problem, which means it will likely need human intervention in order to achieve a stable outcome (in the short-term).

Outside bank of a tight channel bend

- It can be very difficult for a creek to stabilise bank erosion 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 places the eroded bank in a shaded condition.

The North bank problem

- The 'north bank problem' is discussed in Part 1 of this field guide.
- The north bank problem (or south bank if located in the northern hemisphere) is a consequence of the increased shading that occurs on eroded creek banks as a result of the sun being positioned in the northern sky.
- This shading can slow vegetation growth, which means this bank can have reduced scour resistance relative to the southern bank.

Dispersive soil erosion

- If a creek or gully exposes a dispersive or slaking subsoil, then it can be very difficult for the creek or gully to stabilise such erosion.
- After a flood event, vegetation can begin to establish over these soils, but during the next storm or flood, excessive amounts of soil can be washed away from the creek banks causing the loss of this vegetation.
- A stable outcome can only be achieved after a new topsoil layer is established.

Technique selection based on the type of bank erosion

Bank scour (Qld)

Bank scour

- The options available for the stabilisation of a creek bank often depend on the type of bank erosion that is occurring.
- The primary cause of bank scour is excessive flow velocities, which means the preferred treatment is:
  - vegetated rock.
- Alternative treatments include:
  - flow diversion techniques
  - vegetated gabions & mattresses.

Bank slumping (Qld)

Bank slumping

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

Bank undercutting (Qld)

Bank undercutting

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

14.1 Battering and Revegetation

Reshaped creek bank (Qld)

Introduction

- The battering and replanting of an eroded creek bank is one of the most common treatment techniques, second only to the placement of rock.
- As simple as this technique sounds, there are a few technical issues, including:
  - the required bank slope
  - the type of toe protection
  - the type and location of plants
  - the possible retention of existing vegetation (e.g. habitat trees).

Bank reshaping and revegetation (Qld)

Battering and revegetation

Some people may question whether simply battering an eroded creek bank is a suitable response to an erosion problem; however, this treatment process is likely to incorporate several additional features, including:

- temporary erosion control blankets (Section 14.4)
- temporary geo logs for mulch and stormwater management (Section 14.5)
- toe protection (Section 14.7)
- dispersive soil stabilisation (Chapter 16)
- management of stormwater inflows (Chapter 17)
- bank revegetation (Chapter 19).

The reason this simple technique of bank battering is important is because it has the potential to be the most natural approach to managing creek erosion, and the technique that is most likely to return the creek back to a 'natural' condition (if not an original condition).

Now, some of you may be correctly pointing out that if the *original creek bank* had recently experienced bank erosion problems, then why should it be considered appropriate to return the creek back to this pre-flood condition?

The answer is: in some (many) cases it will be inappropriate to use this bank repair technique.

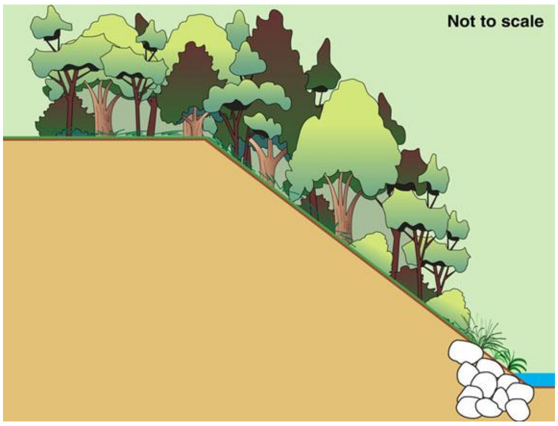
As in all cases, the suitability of this technique needs to be judged on a case-by-case basis. The approach of battering and revegetating an eroded creek bank may be considered appropriate in the following circumstances:

- there is evidence along the creek that the proposed bank conditions have in most cases been stable
- the bank is located on the inside of a channel bend, and high flow velocities are not expected
- the bank repair is part of a larger channel redevelopment project associated with some new infrastructure, such as a new road crossing
- there is evidence that the pre-flood bank condition showed signs of pre-flood bank erosion that had most likely resulted from inappropriate vegetation cover, and the proposed bank battering will remove these old erosion scars, and the proposed bank revegetation will return appropriate erosion-control vegetation to the bank
- the previous bank erosion was caused by the recent deposition of a large sediment slug that had caused stream flows to be diverted into the bank, and the proposed creek works will incorporate the removal, or reshaping, of this sediment slug
- the previous bank erosion was caused by the recent collapse of a large tree that partially blocked the waterway, and this fallen tree was now directed stream flows into the bank causing the bank erosion, and the proposed creek works aim to remove, or reposition this fallen tree
- the previous bank erosion was initiated by lateral bank erosion, which was the result of poor stormwater management practices, and the proposed bank battering will incorporate appropriate changes to how stormwater runoff enters the creek
- the previous bank erosion was partially caused by the exposure of a dispersive subsoil, and the proposed creek works will aim to cover this subsoil with a non-dispersive soil prior to battering and revegetating the bank.

However, the main reason why 'battering and revegetation' remains an appropriate treatment option is because the more you alter the 'condition' of a creek bank, the more you alter the potential 'behaviour' and 'functioning' of the creek bank.

Simple economics suggests that we should not be spending money on elaborate solutions if simple solutions are likely to be sufficient. Also, we should be doing everything possible to avoid engineering solutions, and where possible, maintain the natural processes within our waterways.

Battering and revegetation



Fully vegetated creek bank

Planting a steep creek bank (Qld)

Rock protection of the lower bank (Qld)

Unlawful dumping of earth fill

Bank gradient

- Recommended maximum gradients:
  - 1 in 2 on the outside of channel bends; however, such slopes can be difficult for workers to vegetate, especially on banks higher than 3 metres
  - 1 in 3 on the inside of channel bends.
- Bank slopes steeper than 1 in 2 can be difficult to revegetate.
- Bank slopes of 1 in 4 can encourage recreation vehicles to access the slope, and problems with contract mowing.

Safety concerns for revegetation personnel

- Worker safety issues can exist on steep bank slopes if:
  - the slope is steeper than 1 in 2
  - the bank height is greater than 1.5 m.
- These safety issues can be reduced by:
  - adding 1 m wide safety berms every 1.5 vertical metres up the slope
  - using a harness system during site revegetation.
- Take note of recommendations from revegetation experts.

Toe protection

- Additional toe protection is usually required if a new bank has been created.
- This erosion protection reduces the risk of:
  - damage/undercutting of recently established vegetation
  - undercutting of the new bank.
- Options include:
  - geo logs
  - rock
  - pile field (large projects)

Dumping of loose soil

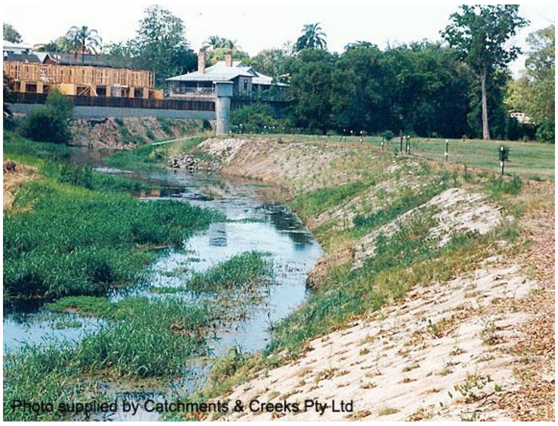
- Creek bank repairs should not consist of loose soil (fill) being left uncompacted on the creek bank.
- In most states there are legislative requirements associated with the placement of earth fill in waterways.
- There are also legislative requirements associated with:
  - the prompt revegetation of disturbed banks
  - the type of plants used.

Case study: Enoggera Creek, Kelvin Grove, Queensland

Looking downstream towards weir

March 1993

- This bank erosion is located on a left-right S-shaped channel bend.
- A stream gauging station (tower) can be seen at the top of the creek bank (background) just upstream of a weir.
- Ongoing bank erosion had caused the formation of an unstable, steep, creek bank that was seen as a safety risk given that a children's play area was established in the adjacent park.



Looking downstream towards weir

December 1993

- In 1993 the creek bank was battered at approximately a 1 in 2 (V:H) gradient.
- The bank was covered with a jute blanket and planted with various native shrubs and groundcovers.

Looking downstream towards weir

December 1996

- By 1996, significant loss of middle storey and upper storey plants had occurred.
- Grasses (weeds) now dominate along the bank (this 'weedy' phase is common in bank revegetation projects).
- Such bank vegetation is likely to reintroduce high flow velocities along the toe of the bank, unless some more woody species can be established.

Looking downstream towards weir

December 2011

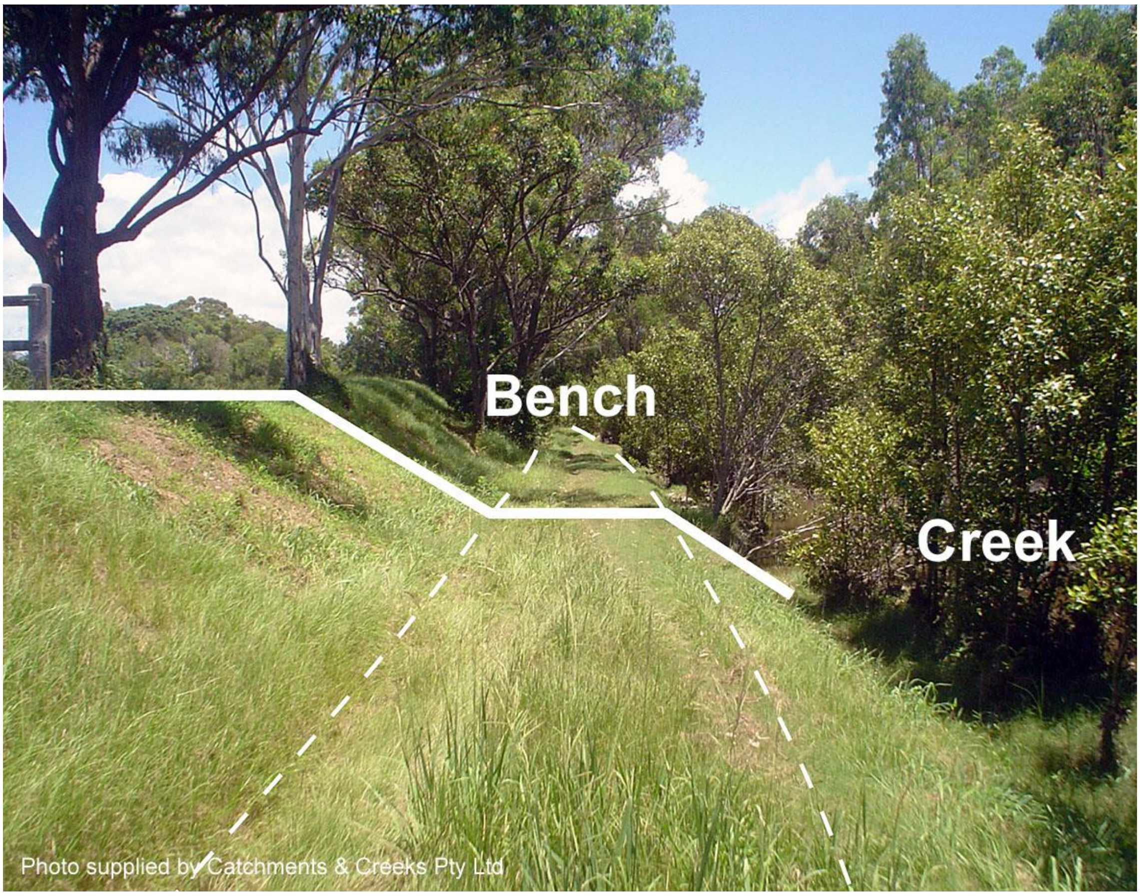
- Native plants have increased in number, but the bank still lacks the required density of woody shrubs that such a creek bank requires to prevent ongoing bank erosion.
- Some significant bank erosion occurred around the base of the old gauging station site (now removed) during the 2010-11 floods (this bank erosion can be seen in the background).
- This bank erosion was later repaired.

14.2 Benching

Benching of a river bank (SA)

Description

- This treatment technique involves reshaping the bank to introduce either:
  - a safety berm to improve safety during bank revegetation and creek maintenance
  - a temporary vehicle access bench to facilitate construction access
  - a maintenance berm to provide permanent maintenance access.
- Benching the bank can also improve safety conditions and bank stability.



Benching of a creek bank to form a maintenance berm (Qld)

Benching

Benching of an urban creek bank (Qld)

Low-level river bench (SA)

Steep, lower bank on outside of a bend

Maintenance berm (Qld)

Width of a bench

- 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.
- Maintenance berms can also be used as public access pathways, and possibly as a bikeway.
- If the waterway acts as an important fauna corridor, then it may not be appropriate to actively encourage public access.

Elevation of a bench

- It is typical for benches to be located at approximately mid-bank height.
- Safety berms are normally located at mid-bank height.
- It is recommended that maintenance berms are located above the 1 in 1 year flood level.
- It is common for bikeways to be located above the 1 in 2 year flood level (refer to local guidelines).

Bank slopes above and below the bench

- If the bank is located on the inside of a channel bend, then it is not unreasonable for the bank below the bench to have a flatter gradient than the upper bank.
- If the bank is located on the outside of a channel bend, then it is not uncommon for the bank below the bench to be steeper than the upper bank, as well as being reinforced with vegetated rock.

Not necessarily suitable on the outside of tight channel bends

- If the bank is located on the outside of a relatively tight channel bend (i.e. a bend radius of approximately three times the channel's top width), then it may not be appropriate to introduce benching.
- Benching on tight channel bends can interfere with the water's preferred 'rolling' action as it passes around the bend.
- The best approach is to mimic the bank conditions at existing stable channel bends.

Case study: Downfall Creek Bushland Centre, Chermside West, Qld

Dispersive soil erosion near the main bank

August 1991

- On this site, sodic subsoils had been exposed to erosion at various locations along the waterway, which resulted in tunnel erosion and vertical rilling known as *fluting*.
- Tunnel erosion had extended deep into the creek bank.

Looking downstream from Rode Road

September 1997

- Significant bank erosion had resulted in the formation of a vertical bank, which can just be seen on the left hand side in this 1997 image.
- In addition to the dispersive soils, significant weed growth has establishment along the bed of the creek, which has increased the erosion stress on the banks.

Looking downstream from Rode Road

September 2001

- The proposal was to stabilise the creek bank (left side) with rock; however, it was also important not to damage the existing riparian (overbank) vegetation.
- The bank was benched in order to provide access for the heavy machinery that was required to place the rock.
- At the same time the bed of the creek was de-silted and cleared of weeds.

Looking downstream from Rode Road

May 2013

- Stable bank conditions have led to thick vegetation establishment along the creek.
- There is a creek, somewhere amongst all those plants!

14.3 Brushing

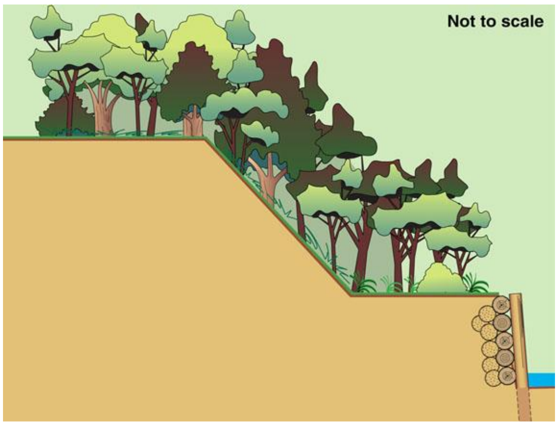
Brushwood bank stabilisation (Qld)

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 and/or wire ties.
- Brushwood can also be integrated into the lower creek bank during the reconstruction of the bank (refer to Chapter 22, Part 4).

Brushwood bank stabilisation (Qld)

Brushwood bank stabilisation



Brushwood toe protection

Use of brushwood as toe protection

- Brushwood can be used to form temporary scour protection for the toe of a creek bank.
- Brushing is typically placed along the outside of channel bends to a height of around 1 metre.
- The anchor posts can be designed to act like a minor pile field, thus requiring the piles to stay in place after brushwood has decayed.

Live staking

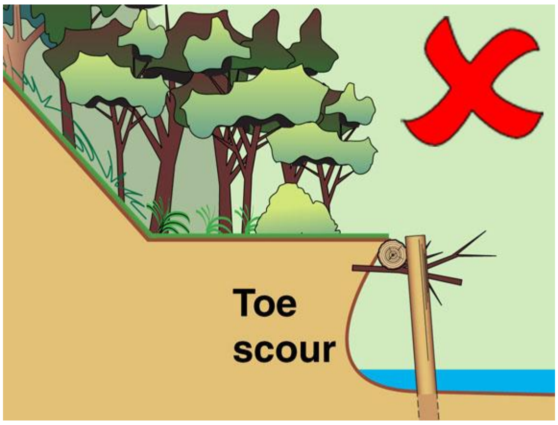
Integration of brushwood into gabions

- Dead and live plant cuttings can be introduced into the construction of some retaining walls (e.g. gabions, crib walls).
- Known as 'bioegineering', live staking, willowing, and various other titles, these techniques are common in countries where native plants can be easily grown from cuttings.
- This technique can be integrated into a variety of bank repair options.

Brushing of overbank area (Qld)

Use of brushing to spread native seed

- Brushing can also be applied to overbank areas with the aim of encouraging native plants to germinate from the brushwood.
- The brushing is also used as a form of 'erosion control blanket' to control raindrop impact erosion during site revegetation.



Potential long-term toe scour

Potential long-term erosion problems

- It is important to remember that brushwood banks are only temporary, and eventually the brushwood will decay.
- If effective toe vegetation has not established along the creek bank, then the eventual failure of the brushwood will likely initiate toe scour and/or bank undercutting.

14.4 Erosion Control Blankets

Jute mesh (Qld)

Description

- Erosion control blankets are a part of the family of *Rolled Erosion Control Products* (RECPs), which are used to temporarily increase the scour resistance of soils.
- On their own, erosion control blankets are not a solution to an erosion problem, instead these products are used in association with site revegetation.
- All blankets are synthetic products; however, the term *'synthetic'* is normally associated only with the plastic reinforced mats.

Bio-degradable 'jute' erosion control blankets prior to planting (Qld)

Erosion control blankets

Jute erosion control blanket (SA)

Jute mesh (Qld)

Hydraulically-applied blanket (Qld)

Plastic-reinforced erosion control mat

Terminology

- The term 'blanket' is typically used to describe rolled erosion control products that have a low shear strength.
- The term 'mat' is typically used to describe rolled erosion control products that have a high shear strength—making them suitable for high velocity drainage channels.
- A 'mesh' is a blanket that has an open weave, usually made from jute or coir.

Bio-degradable products

- Bio-degradable erosion control blankets are typically manufactured from:
  - jute (made from specific 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 use within waterways.
- Meshes are the type of 'blankets' best suited for use on waterway banks.

Hydraulically-applied blankets

- Hydraulically-applied blankets include:
  - hydroseeding
  - hydromulching
  - compost blankets
- Hydraulically-applied blankets:
  - contain a mix of mulch, site-specific seed, and fertiliser
  - can be applied to creek banks that already contain some vegetation
  - can be applied to very steep banks.

Problems associated with plastic-reinforced mats

- Some erosion control mats contain a synthetic (plastic) reinforcing mesh that may, or may not, break down under direct sunlight.
- These synthetic reinforced mats should not be used in bushland and waterway environments because ground dwelling animals, such as lizards, snakes, and seed-eating birds, can become entangled in the mesh.

Erosion control blankets – Anchorage systems

Rock anchors

Rock anchors

- Rocks are a convenient way of anchoring erosion control blankets and meshes.

Metal staples

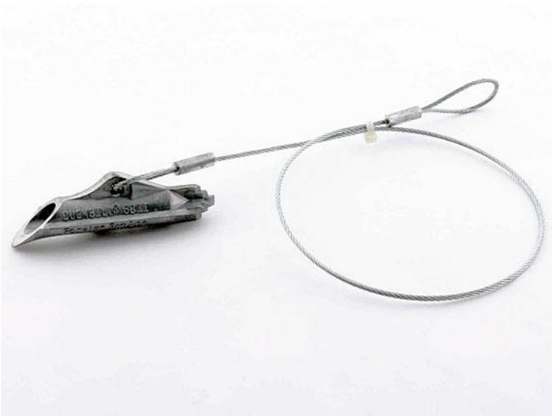
Metal pins or staples

- Metal staples/pins are best used on firm to hard (compacted) clayey soils.
- Anchorage of these pins is partially by friction, and partially through the rusting of the pins; therefore, conditions must exist that will allow the pins to rust.
- Initially (i.e. first few day/weeks) metal pins provide only marginal anchorage, which means the pinned blankets can be displaced by strong winds or stream flows.

Barbed plastic pins

Barbed plastic pins

- Barbed plastic pins are best used in soft to firm clayey soils, but generally not very sandy soils.
- They can be difficult to use if the soil is heavily compacted.
- When used to anchor a mesh, care must be taken to ensure the pin adequately captures or twists around the mesh.



Duck-billed soil anchor

Duck-billed soil anchor

- Duck-billed soils anchors are best used in soft sandy or silty soils, or any soil that has insufficient strength to hold other anchor types.
- These anchors can also be used to anchor logs and fallen trees, which in-turn can be used to anchor erosion control blankets and mats on the banks of **some** waterways.
- Duck-billed soils anchors can also be used to anchor brushwood (Section 14.3).

Case study: Kedron Brook, Ferny Hills, Queensland

Looking upstream, November 2008

Year 2008

- Bank erosion commenced during the 2008 micro-storm that severely damaged the surrounding suburb.
- Following the storm, the top-of-bank was just 1 metre from the base of the tree (visible in top-right of image).

Looking upstream, November 2010

November 2010

- The low-flow channel has now moved to the base of the northern bank.
- The top-of-bank has now moved past the base of the tree.

Looking upstream, September 2014

September 2014

- Rock stabilisation of the bank's toe has now occurred, with the voids filled with soil ready for planting.
- The upper two-thirds of the bank will be stabilised with vegetation.
- As part of the bank revegetation, the upper bank was covered with a jute mesh.

Looking upstream, December 2014

December 2014

- Plants have been placed within the erosion control mesh.
- Prior to this photo, the creek had experienced a near bankfull flow without significant damage being observed.

14.5 Geo Logs

Geo log (NSW)

Description

- Geo logs are a common component of site revegetation.
- These logs can be made from jute or coir (coconut fibre).
- Coir generally has a longer working life.
- Geo logs can be used to:
  - control stormwater movement down creek banks
  - protect recently planted 'toe' vegetation from being disturbed by minor stream flows.

Geo logs (Qld)

Geo logs

Geo log toe protection (Qld)

Use of geo logs for toe protection

- Temporary scour control can be provided to the toe of a creek bank through the use of geo logs anchored (staked) in good contact with the base of the bank.
- Geo logs should be actively planted 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.

Geo log bank protection (Qld)

Use of geo logs to retain mulch and help infiltrate rainwater

- When placed on creek banks, geo logs can be used to:
  - control the movement of stormwater runoff, thus reducing the risk of rilling and lateral bank erosion
  - hold mulch on steep slopes
  - slow and pool stormwater runoff, thus increasing water infiltration into the soil.

Geo log flow diversion bank (Qld)

Use of geo logs to divert stormwater runoff away from newly planted areas

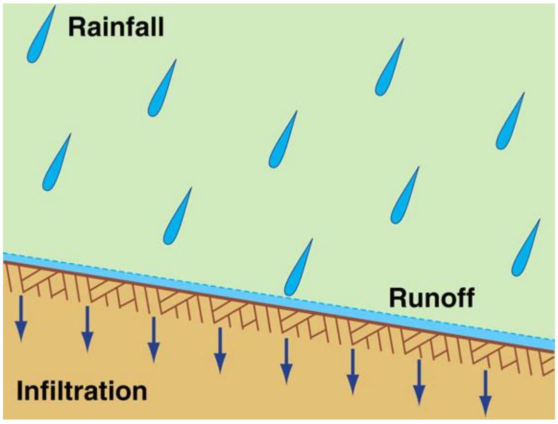
- Geo logs can be used as temporary flow diversion banks to:
  - divert stormwater away from unstable banks during the construction phase
  - direct stormwater runoff into batter chutes (refer to Chapter 17)
  - protect newly planted areas from approaching stormwater runoff.

Geo log bank protection (Qld)

Use of geo logs to control minor flow velocities

- Geo logs can also be used for the following purposes:
  - protect newly established bank and overbank vegetation from minor flood flows
  - as a form of 'retard fencing' to control overbank flow velocities, soil scour, and sedimentation (refer to Section 18.4).

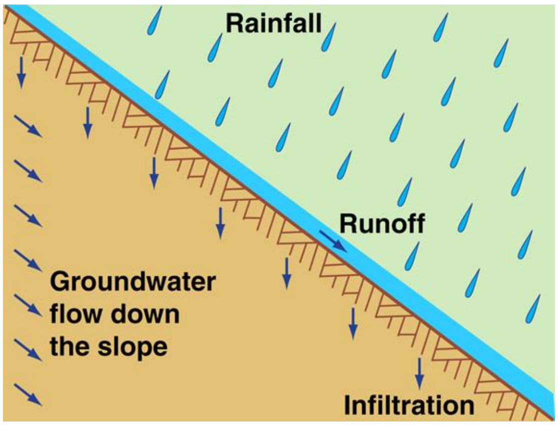
Geo logs – The hydraulic properties of steep slopes



The occurrence of stormwater runoff

The occurrence of stormwater runoff

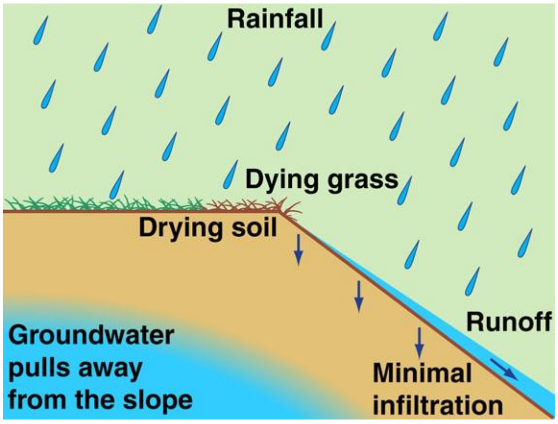
- Some documents claim that stormwater runoff occurs only when the ground has become saturated, but this is not the case.
- Stormwater runoff occurs whenever the rainfall exceeds the infiltration rate of the soil; and this infiltration rate varies according to:
  - the type of groundcover
  - the slope of the soil, and
  - the current degree of soil wetness.



Water movement on steep slopes

Natural supply of water to plants growing on steep slopes

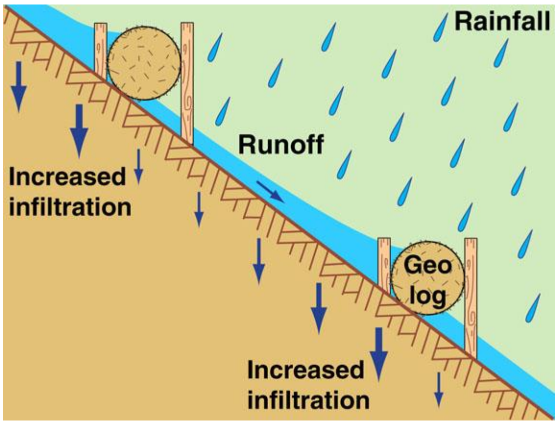
- One of the problems faced by plants that grow on steep slopes is the potential lack of stormwater infiltration into the soil, especially after the slope has been burnt (which can remove the mulch & leaf litter).
- As the land slope increases, it becomes harder for rainwater to infiltrate the soil before it turns into stormwater runoff, which means plants may need to rely on the water supplied through groundwater movement down the slope.



Water movement on creek banks

Water supply problems experienced by plants near the edge of a bank

- Creek banks are different from hill slopes because there is usually only limited groundwater movement down the face of the bank.
- During dry weather, groundwater can become drawn away from the bank edge.
- As the slope of the creek bank increases, it can become harder for new plants to access sufficient rainwater or groundwater.

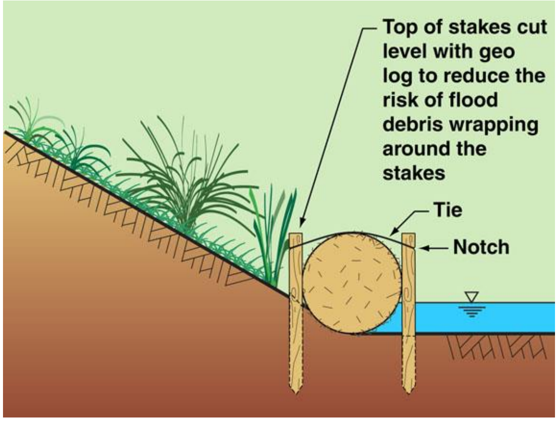


The use of geo logs to slow stormwater

Benefits provided by retaining bush mulch on steep slopes

- During bank revegetation, geo logs can be used to:
  - capture and hold stormwater on the banks, thus allowing time for infiltration
  - hold loose mulch on steep slopes
  - reduce the risk of lateral bank erosion.
- There is always the risk of concentrated stormwater spilling <u>around</u> the ends of geo logs, so their position may need to be adjusted if bank erosion begins to occur.

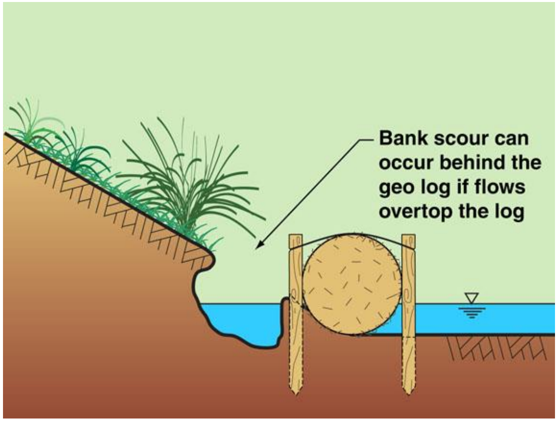
Geo logs – Potential scour problems when used for toe protection



Typical placement along toe of bank

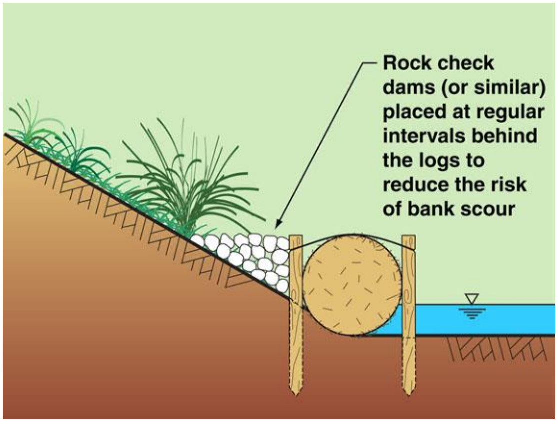
Toe stabilisation

- If geo logs are not properly integrated into the creek bank, then there is the risk that soil scour can occur behind the logs during minor floods.
- It is worth noting that this bank scour may occur even without the geo logs being installed (i.e. the geo logs may not have directly caused the erosion).
- This is not a common erosion problem, and the risks should be assessed on a case-by-case basis.



Potential bank scour problem

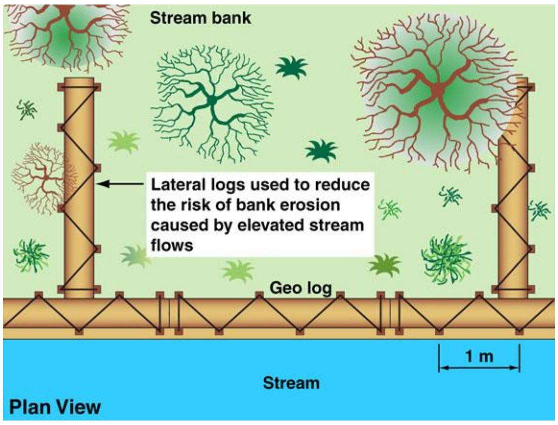
Note the soil scour behind geo logs



Use of rock check dams to control scour

Controlling soil scour through the use of rock check dams

- The risk of such bank scour can be reduced by installing 'rock check dams' at regular intervals (say 2 m) behind the geo logs (as shown left).
- Rock check dams are one of the drainage controls used in the *Erosion and Sediment Control* (ESC) profession—refer to the various ESC Field Guides.



Use of lateral logs (plan view)

Controlling soil scour through the use of lateral geo logs

- The risk of bank scour can also be reduced by installing additional geo logs up the creek bank (laterally extending from the toe logs).
- Again, it is noted that this is not a common erosion problem, and the risks should be assessed on a case-by-case basis.

14.6 Management of Riparian Zones

Riparian zone adjacent a floodway (Qld)

Description

- This practice involves managing specific aspects of the riparian zone in order to minimise the risk of creek erosion.
- Management practices include:
  - fencing to control stock and human access to the waterway
  - restoration and/or widening of the riparian corridor
  - stock management
  - stormwater management
  - snag management
  - weed management.

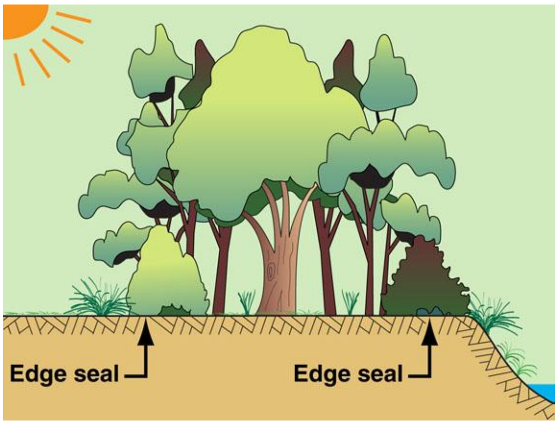
Newly established riparian zone adjacent an urban waterway (Qld)

Riparian management

Riparian vegetation (Qld)

Riparian zone adjacent a park (Qld)

Flood-induced bank scour (Qld)



Controlling the edge effects

Introduction

- Riparian vegetation provides many benefits to creeks, including:
  - fauna habitat
  - a source of food for local fauna
  - connectivity of movement corridors
  - stability of creek banks
  - reducing flow velocities
  - shading of the water
  - filtering of some stormwater inflows.

Design issues

- Critical issues include:
  - choice of plant species
  - shading of the water's edge
  - controlling the movement of floodwater between the creek and its floodways
  - controlling the access of stock and humans to the creek
  - controlling weeds using natural processes (e.g. shading)
  - control of lateral sunlight intrusion through the use of edge planting.

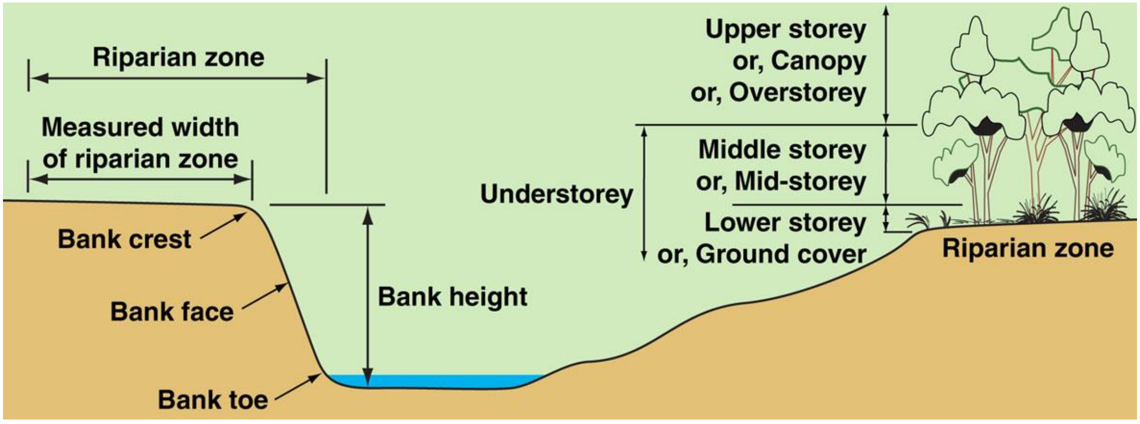
Controlling bank scour

- Removing woody vegetation from riparian zones may be seen as a solution to:
  - flooding issues
  - maximising the area of workable land.
- **However**, using only grasses to stabilise creek banks can:
  - allow very high velocity water to come close to the bed and banks, and
  - can contribute to bank scour during major flood events.

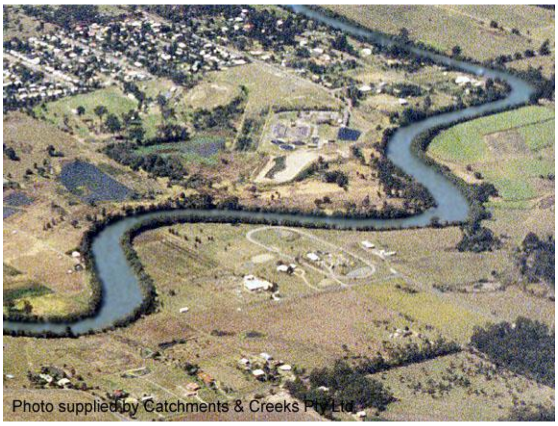
Controlling 'edge effects'

- The width of the riparian zone affects the degree of light that enters this zone (known as the *edge effects*).
- Middle storey plants and robust ground covers (e.g. stiff grasses) can be used to reduce the degree of diffuse light penetrating into riparian zones.
- Appropriate edge planting can also improve the aesthetics of parks by providing a visual barrier between the high-maintenance open parkland, and the low-maintenance riparian zone.

Riparian management – Desirable width of riparian zones



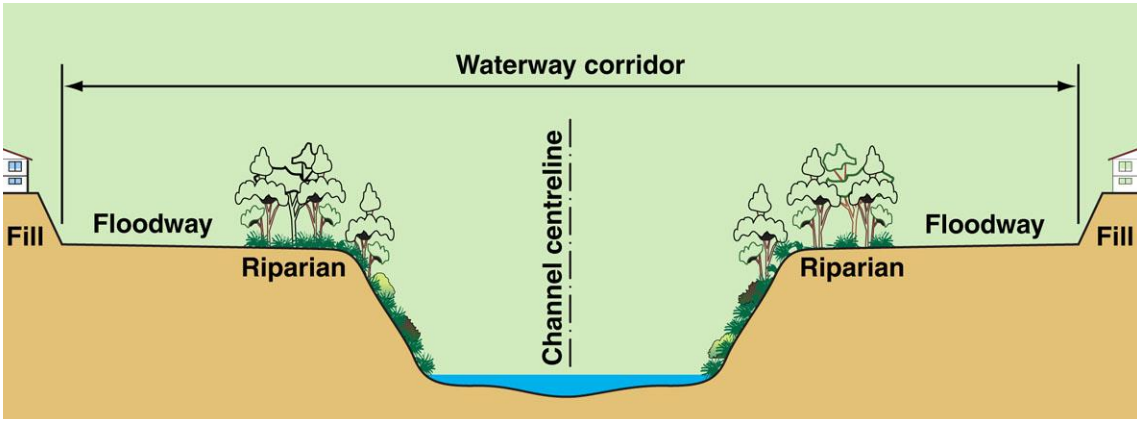
Defining the riparian zone and riparian 'width'



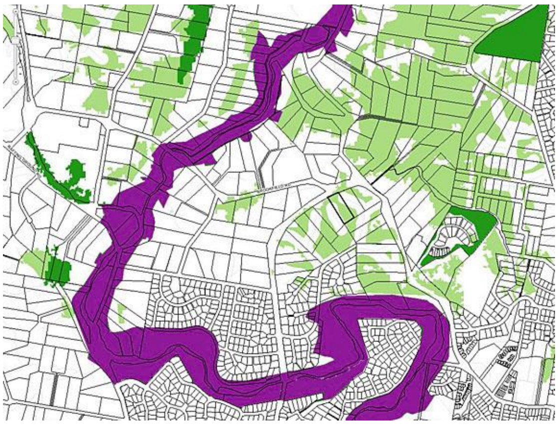
Narrow riparian corridor

The required width of riparian zones

- Most states have guidelines that specify the minimum required width of riparian zones.
- Most authorities also recommend that the wider the riparian zone the better.
- The requirements placed on riparian zones usually varies from creeks to rivers, and in the case of large rivers, the issues affecting the management of riparian zones can be very complex—expert advice is always recommended.



Waterway corridor



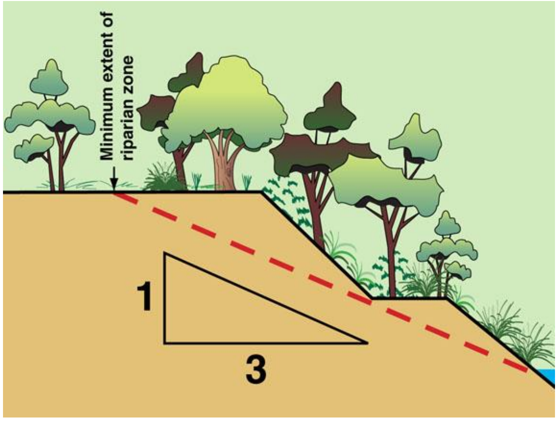
Corridor mapping

Corridor mapping

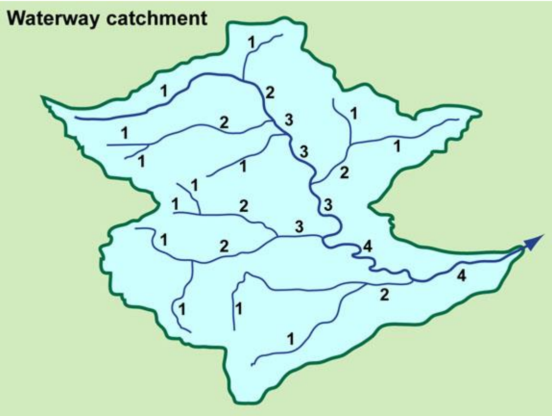
- Some authorities prepare *Waterway Corridor Maps* that identify which land must be excluded from development.
- The nominated corridor width is often measured from the centre of the creek (but may be a different distance each side of the creek)—suggested widths are:
  - 1st order streams = 15 m (each side)
  - 2nd order streams = 30 m (each side)
  - larger waterways = 60 m (thus the full width would be 2 x 60 = 120 m)

Riparian management – Desirable width of riparian zones

Riparian zone and grassed floodway (Qld)



Minimum width based on bank stability



Horton's stream order system

Bank revegetation (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).

Riparian width based on bank stability recommendations

- The minimum width of the riparian zone depends on numerous local factors, including bank stability.
- 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.

Width based on waterway classification

- Some guidelines nominate a minimum riparian width based on the stream order (based on 1:25,000 mapping):
  - 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).

Additional allowance based on the time required to establish new vegetation

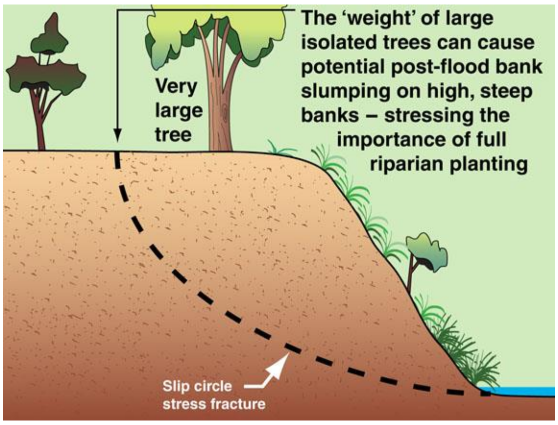
- If the land near the top of the bank is largely absent of riparian vegetation, and new plantings are being proposed, then the minimum width of the riparian zone should take account of the expected movement (erosion) of the creek bank during the establishment period of this new vegetation.
- Depending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

Riparian management – Design issues

Tree planting (Qld)

***Lomandra* planting on outside of a bend**

***Lomandra* planted around a shrub (Qld)**



Slip circle bank failure

Planting density

- 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.
- The spacing of plants 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.

Planting on the outside of channel bends

- Flow velocities and erosion forces are normally greatest on the outside of channel bends.
- Banks are usually steeper on the outside of a bend (compared to the inside of the same bend).
- Plants that typically work best on the outside of bends are:
  - stiff grasses (e.g. *Lomandra*)
  - shrubs with flexible branches (e.g. *Callistemons*).

Tree planting in floodways and other high-velocity areas

- In flood control zones, trees often need to be planted further apart in order to reduce their impact on flood levels.
- As trees become more isolated, high-velocity floodwater can cause localised erosion around the base of the trees.
- To avoid such erosion problems, isolated trees can be surrounded with stiff grasses (e.g. *Lomandra*) to form a streamlined 'island' of plants.

Tree planting on steep, high banks

- Large trees can add significant weight to a creek bank.
- Even though the tree's root system can provide significant anchorage, if the tree is isolated from other trees, then in the days following a large flood, the weight of the tree can help trigger a bank slump.
- The risk of such bank slumping is low, and should <u>not</u> dominate the design of riparian zones; instead, this should be considered just one of many issues that need to be given appropriate consideration.

Riparian management – Stock management

Dairy cows returning home for milking

Introduction

- For some people, the only acceptable outcome is to permanently exclude all livestock from entering waterways.
- However, this idea of permanent exclusion is not practical in many situations.
- Livestock need access to waterways:
  - to access the water
  - to cross the stream if the property extends on both sides of the stream.

Bank erosion at stock access point (Qld)

Bank erosion issues

- The rutting of creek banks as a result of livestock entering waterways can either turn into a major erosion problem, or a complete non-issue that needs no further treatment.
- There are two factors that can turn such erosion into a major problem:
  - whether or not the rutting exposes a dispersive subsoil
  - whether or not stormwater runoff from the adjacent floodplain is allowed to flow down these ruts.

Stabilised stock access ramp (Qld)

Stabilised access points

- Livestock access points can be stabilised using one or more of the following steps:
  - stormwater runoff is diverted away from the access point, either by cutting a diversion drain, or by forming a compacted earth mound across the top of the access ramp
  - covering any dispersive subsoil with a thick layer of non-dispersive soil
  - covering the ramp with a soil-gravel mix, and then grassing the surface.

Livestock underpass (NSW)

Livestock friendly culvert underpasses

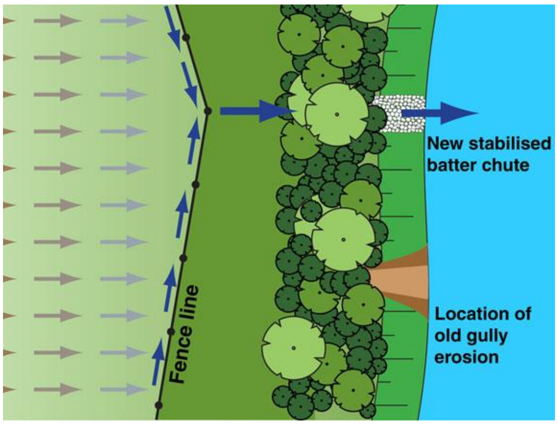
- In circumstances where livestock need to regularly pass through a culvert, road authorities should work with the landowner to convert one or more of the cells into terrestrial corridors (also known as 'dry cells').
- Stabilised access ramps (formed from a vegetated mix of soil and rocks) can be used to direct livestock down the creek banks and through the culvert.

Riparian management – Fencing

Fencing of riparian zone (SA)

Fencing of riparian zone (Qld)

Gully erosion along a fence line (Qld)



Managing stormwater runoff

Introduction

- Many guidelines call for the fencing of rural waterways in order to control livestock movement and overgrazing.
- However, such recommendations are not without the risk of potential problems, including:
  - the undesirable redirection of stormwater runoff along fence lines
  - gully erosion along fence lines
  - increased cost of fence replacement following wild fires.

The redirection of stormwater runoff

- When riparian zones are fenced, it is typical for the density of the grasses on the creek side of the fence to be greater than on the paddock side of the fence.
- This change in hydraulic roughness can cause stormwater runoff to be redirected along the fence, which causes the storm water to now move as 'concentrated flow'.
- However, this redirection of runoff does not always occur, and if it does, it usually occurs only during major storms.

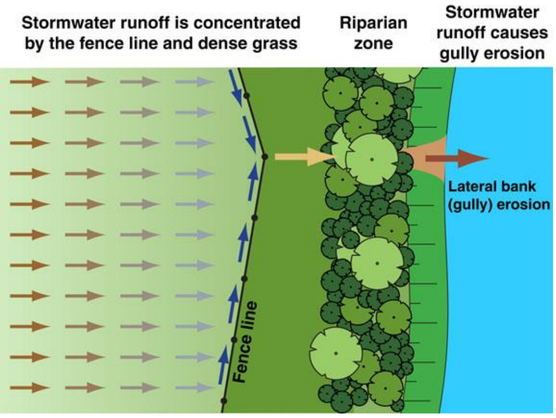
Gully erosion along fence lines

- If high-velocity, concentrated flows travel along a fence line, then soil erosion can occur around the base of each post:
  - which can cause a localised loss of grass cover
  - which can expose the soil resulting in the formation of a gully
  - which, if it exposes a dispersive subsoil, can quickly form a major gully erosion problem that will be expensive and difficult to repair (photo left).

Designing fence lines adjacent to creeks

- If a property has a history of stormwater runoff being diverted along its fence lines, then the fencing of riparian zones should aim to:
  - zigzag the fence such that regular low points are formed along the fence that will force the stormwater to be released from the fence line at as many 'safe' locations as is possible, and
  - ensure that stormwater is only released at locations where lateral bank erosion is unlikely to occur.

Riparian management – Stormwater management



Potential cause of lateral bank erosion

Stormwater-induced lateral bank erosion

Tunnel erosion adjacent a creek (Qld)

Pedestrian access to a creek (Qld)

Introduction

- Stormwater runoff can contribute to creek erosion problems in three ways:
  - initiating and/or aggravating lateral bank erosion
  - initiating and/or aggravating tunnel erosion problems
  - aggravating soil erosion along pedestrian or livestock access tracks.
- Note: this field guide addresses only erosion problems, and does not address stormwater quality issues.

Controlling lateral bank erosion

- The potential for lateral bank erosion can be reduced by:
  - controlling the locations where stormwater runoff enters the creek
  - constructing stabilised batter chutes to carry stormwater safely down the face of creek banks.
- Batter chutes can be stabilised with grass, rock, rock mattress, and stiff grass chutes (refer to Chapter 17).

Controlling tunnel erosion

- The potential for tunnel erosion can be reduced by:
  - diverting stormwater away from existing tunnel erosion
  - constructing stabilised batter chutes that are capped with a 300 mm thick layer of non-dispersive soil prior to revegetation.
- The management of tunnel erosion is discussed in more detail in Chapter 17.

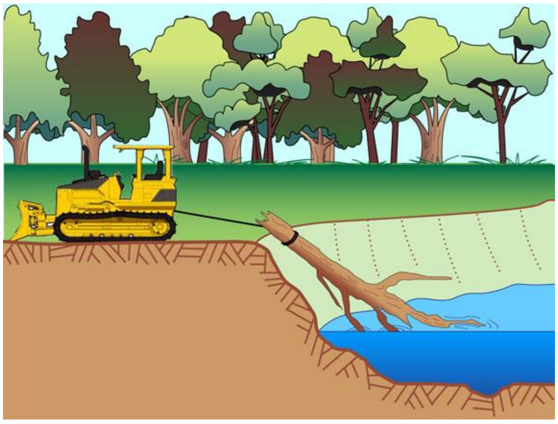
Controlling stormwater movement along access tracks

- The potential for soil scour along access tracks can be reduced by:
  - diverting stormwater away from these tracks
  - establishing well-drained ‘low points’ along these tracks to force stormwater to exit the track at regular intervals
  - stabilising livestock access tracks with a rock-soil-grass surface to increase the wear resistance of the track.

Riparian management – Snag management

Eastern Water Dragon basking on a log

Severe snag blockage (Qld)


Snag removal

Log jam (Qld)

Introduction

- Snags provide several benefits to waterways, including:
  - places for fauna to bask in the sun
  - aquatic habitat
  - wetted surface acting as a potential food source
  - helping to reduce the average channel velocity
  - increasing the potential for terrestrial fauna to cross (bridge) the waterway.

Potential problems resulting from snags and fallen trees

- Fallen or trapped woody debris can cause the following problems:
  - reducing the average channel velocity, which can increase the flood risk
  - diverting flood flows towards creek banks causing bank erosion
  - diverting the low-flow channel towards a creek bank causing a bank slip or bank undercut
  - blockage of culverts.

Snag management

- There are no universal guidelines on the management of snags—each waterway must be assessed on an individual basis.
- The best long-term outcomes are achieved when the rules applying to the management of snags are included within the waterway's Management Plan.
- The snags that present the greatest risk are those that can capture large quantities of debris during floods, resulting in:
  - raised flood levels
  - localised bank erosion.

Increasing instream timber content

- If flood control practices result in the excessive removal of snags from a waterway, then the potential benefits of these snags (as listed above) can be reintroduced to a waterway through the installation of:
  - log jams (Section 18.2)
  - toe protection pile fields (sections 14.7 and 18.3)
  - bed stabilisation pile fields (Section 12.8 in Part 2).

Riparian management – Weed control practices

The connection between weed control and erosion control may not at first appear obvious, but there can be strong links between these two activities. Weeds are 'plants', and as pointed out several times in this field guide, plants play an important role in the stabilisation of minor waterways, such as creeks.

I am sure there are many that will argue that weeds should play no role in the functioning of our waterways. However, many of our urban waterways would not survive in their current size or condition without the contribution made by weeds, especially many of the introduced grasses. The real key is knowing how to replace weeds with more appropriate plants, and how to do this in a manner that does not cause undesirable consequences for the creek.

In order to practise weed control in a responsible manner, the following rules must be followed:

- Never remove a weed before first understanding the functions that the weed is currently performing within the waterway. These functions may include:
  - fauna habitat, shelter, and benefits to fauna movement
  - a source of food for local fauna
  - shading of the water
  - control of soil scour
  - bank stabilisation through its root system
  - adding organic matter to the soil
  - assisting in the development of flow conditions that facilitate fish passage during flood events.
- Ensure that the weed is replaced with a native plant, or community of plants, that are able to perform these same functions (assuming that each of these functions remain desirable).
- If large scale weed removal is required, then this activity should not be carried out in a manner that significantly reduces the vegetative roughness (hydraulic roughness) of the waterway to the extent where flow velocities will increase to the point of causing unacceptable bed or bank erosion. Such problems can be avoided by staging the weed removal in a manner that avoids forming long sections of partly denuded channel.
- If weed trees are to be removed, then investigate whether or not their root systems can be retained to provide an extended period of bank stabilisation. It is noted that a tree's root system can continue to provide bank reinforcing for some years after being poisoned.

'Timing' can be a critical component of weed removal; timing when to remove the weeds; timing how quickly the area can be replanted; timing when each sector of a waterway can be treated. As much time should be spent planning how and when to remove the weeds, as is spent planning the revegetation of the area.

Local working groups are an effective way of achieving rapid weed removal from urban waterways, but such activities must be appropriately managed by people that understand what potential hydraulic and erosion impacts can result from weed control practices.

If a weed survey identifies that most of the middle storey plants are weeds, then full weed removal will significantly reduce the hydraulic roughness of the riparian zone, which could result in a significant increase in flow velocities, plus scour around the base of the remaining trees.

If the weed removal is expected to result in a short-term increase in the risk of soil erosion, then consider the option of *'using a weed to control a weed'*. This technique involves the following steps:

(i) seek expert advice before you start

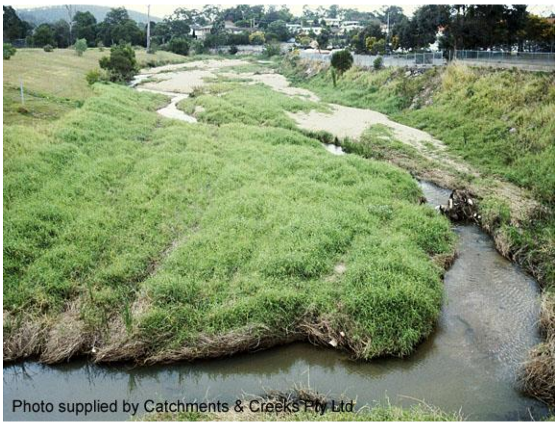
(ii) remove the target weeds

(iii) temporarily stabilise the area with a fast-growing, non-aggressive weed that is known to be easy to control (such as certain grasses)

(iv) progressively establish the chosen natives within the temporary grass (this may involve removing or poisoning small areas of the grass)

(v) once the natives are established, remove all remaining elements of the temporary weed.

Riparian management – How weeds can contribute to creek erosion



Bed sediment stabilised with grasses

Stabilisation of sediment slugs

- ‘Sand slugs’ and ‘sediment slugs’ are terms used to describe the mounds of loose bed sediment that slowly migrate down many of our creeks and rivers.
- In certain conditions, these sediment slugs can become overgrown with weeds, which can prevent the slugs from migrating down the waterway during flood events.
- Excessive weed growth can cause the low-flow channel to be diverted around the sediment, possibly causing erosion along the base of the adjacent creek bank.

Blockage of a creek with wetland plants

Blockage of narrow channels by reeds and other stiff grasses

- If the sediment is rich in nutrients, and the creek has an open canopy, then reeds and/or tall grasses can establish over the sediment, which can:
  - cause the low-flow channel to move into the small space between the bank and the reeds, which . . .
  - can start bank erosion, which . . .
  - can ultimately cause the complete relocation of the waterway channel.

Vine growth over native trees (Qld)

Suppression of native plants

- Some aggressive weeds can cause the loss of native species, which can remove the erosion control benefits that these plants were providing for the creek.
- Erosion problems can occur if the introduced weeds do not provide the same erosion control benefits as the original native species.

Bank erosion following weed removal

Increased erosion risk during weed removal

- A weed problem often results in the need for a ‘weed control program’, which can:
  - temporarily denude the creek bank, which . . .
  - can increase the risk of bank erosion, which . . .
  - can increase the opportunities for more weed growth (because weeds are often a fast-response plant that quickly establishes over an eroded bank).

14.7 Sediment Management

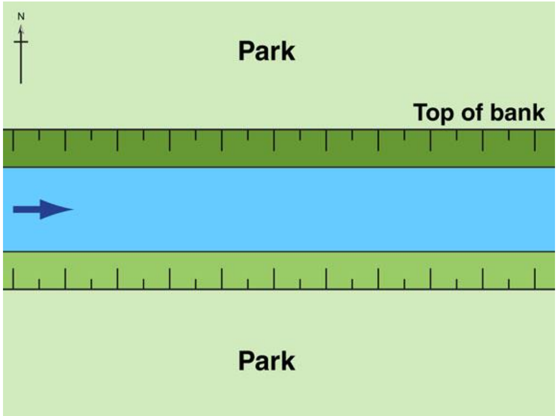
Bank erosion (left), sediment (right)

Description

- Waterways are naturally active areas for soil erosion and sediment deposition.
- In alluvial waterways (i.e. sand or gravel-based waterways) it is common for large deposits of natural bed sediment (known as sediment slugs) to slowly migrate down the waterway.
- Sediment management can consist of removing, or re-positioning, this sediment if it begins to cause bank erosion, or the weeding of the sediment to allow its natural migration down the channel.

Bank erosion caused by stream flows passing around a well-grassed sediment slug

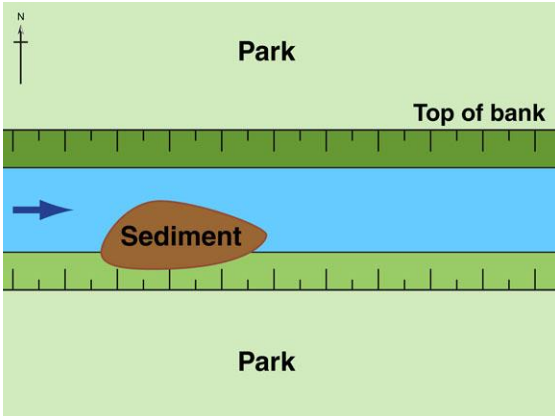
Sediment management – The triggering of a channel meander



Straight waterway channel

Introduction

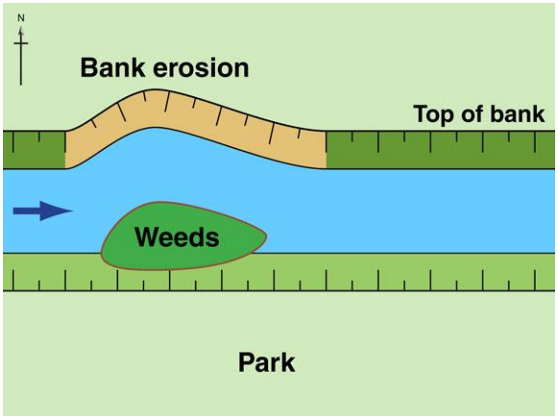
- In order to understand the potential impacts of sediment slugs on waterway behaviour, please consider the following scenario.
- Imagine a relatively straight channel, possibly a creek passing through an urban park in the northern suburbs of the capital city of a state north of NSW.
- It could be assumed that this creek had at some stage been straightened in order to maximise public usage of the urban park.



Deposition of a sediment slug

Creation of a sediment slug

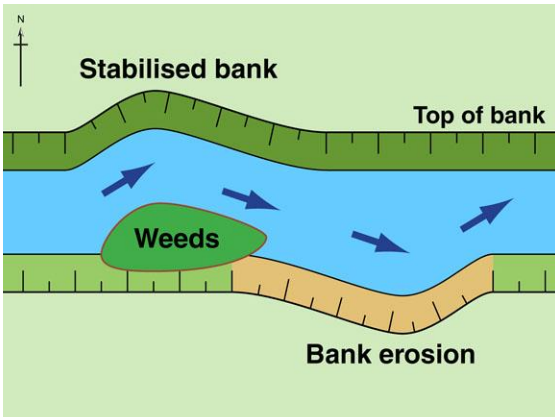
- Now consider the situation where sediment began to collect on the bed of the creek just downstream of a footbridge (i.e. where stream flows expand and slow after passing under the footbridge).
- Add to this situation an extended drought during which time the only in-channel vegetation to remain in a healthy condition are the reeds that were beginning to establish within the sediment slug.



Initial bank erosion

Resulting bank erosion

- When the drought finally breaks, it breaks with the occurrence of a local flood, which confronted the vegetated sediment slug head-on.
- Channel flows are now deflected around the weed-covered sediment.
- In order to pass around the sediment, the channel flow cut into the 'northern' bank, which initiates the beginnings of a channel meander.



Formation of a channel meander

Channel meander

- After passing around the sediment, the channel flow now moves towards the opposite bank, and begins to cut into this bank.
- Over time, the flow would have (if it had not been stopped) formed a series of channel meanders through the remainder of the park, and into the downstream property.

Sediment management

Bank erosion (left), sediment (right)

Sediment runoff from an urban area

Erosion (left), grassed sediment (right)

Desilting using a long-reach excavator

Introduction

- As previously discussed, the likelihood of bank erosion increases if the sediment slug (which should be a temporary feature) becomes stabilised with vegetation.
- The question is whether or not waterway managers should:
  - interfere with the natural processes associated with these sediment slugs
  - weed and/or vegetate these sediment slugs.

Natural vs unnatural sediment deposition

- Alluvial waterways regularly experience the natural movement of their loose bed material during floods.
- However, in their natural condition, small clay-based creeks typically have very little natural sediment movement.
- Unfortunately, all waterways, especially urban waterways, can experience the effects of unnatural sediment inflows, which originate from farming practices and urban construction.

Circumstances where a sediment slug should be removed from the channel

- In most circumstances, natural sediment slugs in alluvial waterways should be allowed to migrate down the waterway with minimal interference.
- The circumstances where interference could possibly be justified include:
  - the sediment is causing unacceptable bank erosion
  - the sediment is becoming stabilised with unnatural weed cover
  - the sediment is considered ‘unnatural’.

The management of unnatural sediment deposition

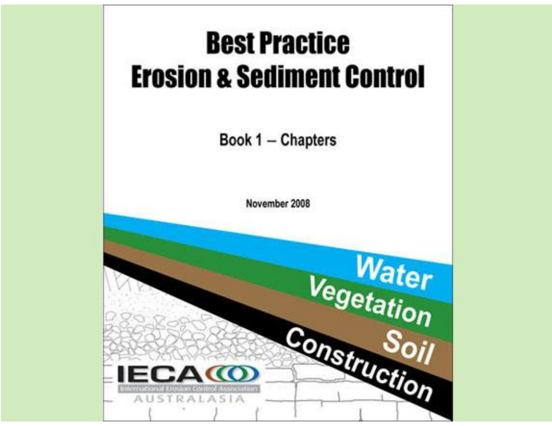
- If the sediment is likely to have resulted from unnatural sediment inflows (e.g. urban or farm runoff), then the options are:
  - remove the sediment (e.g. de-silt)
  - allow the sediment to migrate downstream (e.g. weed removal).
- Rarely will it be appropriate for the sediment to be actively vegetated, but exceptions do exist (always seek expert advice).

Sediment management

Rock groynes (left), sediment on right

Use of bank stabilisation techniques to help control the effects of sediment slugs

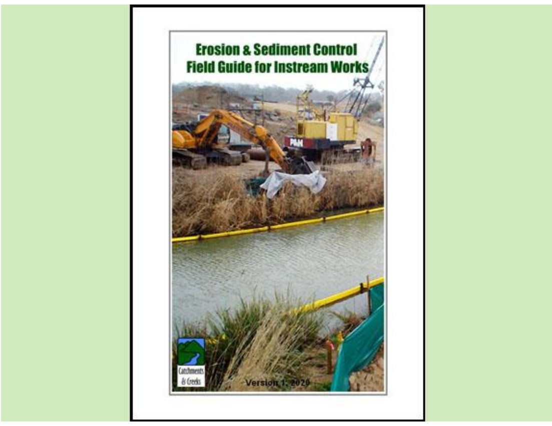
- If sediment extraction is not viable, or desirable, then steps must be taken to ensure that the sediment can continue to migrate down the waterway, including:
  - removal of any vegetation from the sediment
  - rock stabilisation of any vulnerable creek banks in order to maintain hydraulic stress on the sediment
  - installing groynes to protect vulnerable banks.



IECA Australasia (2008)

Building site sediment control programs

- In urban areas, *erosion and sediment control* (ESC) practices can be applied to building and construction activities.
- Guidelines for such ESC practices are well established and documented.
- In rural areas, the desire to control sediment runoff, particularly to the Great Barrier Reef, is increasing year by year.



Field Guide for Instream Work Activities

De-silting creeks

- Unnatural sediment can be removed from waterways via:
  - long-reach excavators working from the banks
  - standard excavators working on the creek bed, but inside an isolation bund.
- A separate field guide has been produced outlining the procedures for conducting work activities within waterways:
  - *Erosion and Sediment Control Field Guide for Instream Works* (2020).

Permanent sediment extraction ponds

Permanent sediment extraction points

- If unnatural sediment deposits need to be extracted from an urban waterway on a regular basis, then consideration should be given to the establishment of permanent sediment extraction ponds.
- If maintenance vehicles need to access these ponds, then permanent access ramps need to be constructed (refer to Section 15.1 for discussion on the use of flexible concrete ramps).

14.8 Toe Stabilisation

Pile field toe protection (Qld)

Description

- Toe stabilisation involves the addition of temporary or permanent scour protection, and/or slope stability, to the toe of a creek bank for the purpose of:
  - reducing the risk of soil scour
  - reducing the risk of damage to plants along the water's edge during the establishment phase of these plants
  - provide the bank with additional stability in the event of the mass movement of the adjacent bed material during a flood.

Toe stabilisation using rock (Qld)

Toe stabilisation

Rock toe protection (Qld)

Timber log toe protection (Qld)

Geo log toe protection (Qld)

Pile field toe protection (NSW)

Use of rock

- Rock can provide permanent toe protection within clay-based creeks.
- However, rock may not be suitable for sand-based creeks because the rocks may 'sink' into the sand during a flood.
- The rock size (metres) is based on:

$$d_{50} = 0.04\, V^2 \qquad (14.1)$$

- If rock is also being placed above the toe, then use the same rock as determined for the rest of the bank.

Use of timber logs

- Timber logs and fallen limbs have been used as toe protection on sites where:
  - access is limited to bring in large rock
  - funding is not available to purchase and install rock.
- It is essential that the logs are well anchored (tied down).
- 'Jute bagging' can be placed between the logs and the bank to help establish plants along the water's edge (for discussion on jute bagging, refer to Chapter 19).

Alternative toe stabilisation measures

- Geo logs can be used as an alternative to rock stabilisation of the toe.
- Geo logs typically provide only temporary (less than 2-years) protection for the toe.
- These temporary protection measures are only successful if suitable vegetation is incorporated into, or around, the logs.
- It is important to ensure that bank erosion does not occur behind the logs during overtopping stream flows (refer to discussion in Section 14.5).

Use of pile fields

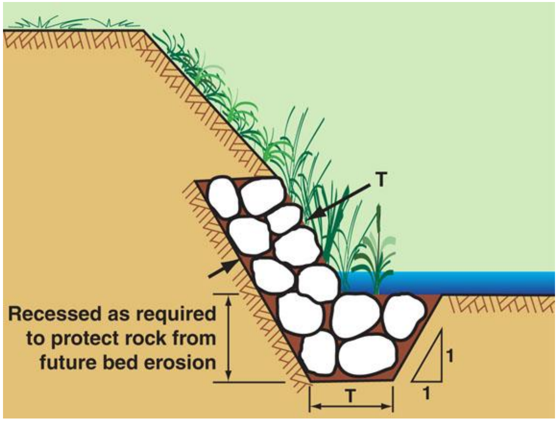
- Pile-field toe protection typically consists of one or two rows of timber piles placed along the toe of the bank.
- Pile fields are most commonly used on alluvial (sand or gravel-based) creeks.
- The required depth of the piles depends on the expected depth of bed movement during floods.
- Pile fields can also improve bank stability (at least for a few years), by reducing the risk of a bank slip.

Toe stabilisation – Estimating the depth of toe protection

Undermining of toe rock

Introduction

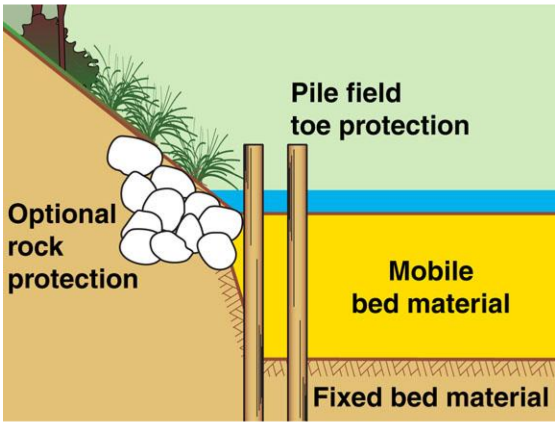
- If the toe protection is expected to provide long-term benefits, then it must be able to withstand the erosive effects of floods.
- Floods can disturb the toe protection in three ways:
  - direct scour
  - undermining of the toe protection, or mass movement of the adjacent creek bed
  - liquefaction of the sandy bed causing the loss (sinking) of the toe protection.



Depth of protection in a clay-based creek

Clay-based waterways

- In clay-based creeks, there should not be a significant amount of bed sediment, and the bed should not be mobile during a flood.
- This means that the 'depth' of the toe protection is usually not critical (exceptions do exist).
- However, if the creek bed is slowly lowering, then the toe protection should extend below the predicted long-term bed level.



Pile field installation in a sandy creek

Sand and gravel-based waterways

- In sand-based creeks, rock protection can sink into the bed sand during floods, making it ineffective.
- In gravel-based creeks, the whole bed could move (migrate) during a major flood, which can dislodge any toe rock.
- If toe rock is to be used, then ideally, the rock should extend below the depth of the bed sand.
- The depth of the toe protection should not be an issue in cobble and boulder creeks.

Scour around a bridge pier (Qld)

Local bed scour issues

- If the toe protection is located downstream of a bridge or culvert, then an estimate will need to be made of the depth and shape of any associated scour holes.
- The scour depth may be estimated using appropriate design guides, such as:
  - *Supplement to Austroads Guide to Bridge Technology, Part 8, Chapter 5: Bridge Scour (2018)* The State of Queensland (Department of Transport and Main Roads), January 2019.

14.9 Vegetated Gabions & Mattresses

Vegetated rock mattress (Qld)

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 established.
- Actively encouraging vegetation provides the following benefits:
  - long-term bank stability following the eventual failure of the wire baskets
  - the benefits commonly associated with vegetated rock.

Vegetated rock mattress-lined channel (Qld)

Vegetated gabions and rock mattresses

Gabion filled with soil and rock (Qld)

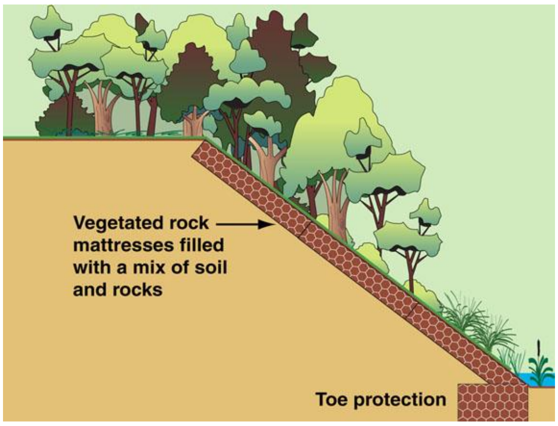
Filling gabions with a rock soil mixture

- To encourage the establishment of native plants over the gabions, the baskets should be filled with a rock-soil mixture that eliminates the existence of open voids.
- Typical void spacing (for estimation of the required soil percentage) is usually around 30–40% (the more uniform the rock size, the larger the void spacing).

Live staking

Use of brushwood

- Brushwood, straw or living plant cuttings can be incorporated into the gabions during their assembly.
- Expert advice is required on the right plant selection and placement.
- This design option will not be practical in all regions due to limited plant species suitable for live staking.



Vegetated rock mattress bank protection

Use of vegetated rock mattresses

- Rock mattresses can be vegetated the same as gabions.
- Rock mattresses have been applied to bank slopes in high velocity drainage channels.
- Potential conflicts can occur with desirable fauna habitat issues (as is the case for vegetated rock).

Mulch covered rock mattress (Qld)

Assessing the risk of soil loss

- The integration of soil into the rock fill can result in some soil being exposed to stream flows during plant establishment.
- However, this installation procedure is still considered appropriate because:
  - the boundary layer that forms over the gabions reduces the shear stress
  - the risk of soil loss can be reduced by covering the soil-rock mix with a light cover of straw
  - there are long-term benefits gained from establishing a vegetative cover.

Vegetated gabions and rock mattresses

Gabions:

- Typical dimensions of 500 mm or 1000 mm thickness, 1 m width, and 2 or 3 m length.
- Heavily galvanised, PVC coated cages should be used for all hydraulic structures.

Rock mattresses:

- Typically available in thicknesses of 170, 230 and 300 mm, a length of 6 m, and width of 2 or 3 m.
- Heavily galvanised, PVC coated cages should be used within waterways.
- Mattresses should be laid over filter fabric, or a properly designed gravel filter layer.

Rock-fill:

- Rock-fill should be angular and block-shaped.
- Nominal rock size as specified in Table 14.1 (below).
- Minimum rock size around 1/3 the basket depth.
- Maximum rock size around 2/3 the basket depth.
- The rock should be uniformly graded with 80% by number greater than 100 mm in size.
- Nominal rock size should be 200–300 mm when used within the splash zone of weirs and drop structures.

When used as the lining of a batter chute, filter cloth and subsoil drainage should be placed under the mattresses.

When used within the splash zone of weirs and drop structures, at least two layers of minimum 300 mm thick mattresses should be used.

On bank slopes, the mattresses should be laid with the internal diaphragm aligned across the slope (i.e. the long mattress is laid down the bank slope).

On batter chutes and creek beds, the mattress should be laid with the internal diaphragm at right angles to the main direction of water flow.

Table 14.1 – Recommended rock size for rock mattresses and gabions [1]

Type	Thickness (m)	Rock size		Allowable flow velocity (m/s)
		Range (mm)	d_{50} (mm)	
Rock mattress	0.15–0.17	70–100	85	3.5
		70–150	110	4.2
	0.23–0.25	70–100	85	3.6
		70–150	120	4.5
	0.30	70–120	100	4.2
		100–150	125	5.0
Gabion	0.50	100–200	150	5.8
		120–250	190	6.4

[1] Sourced from Maccaferri (1988) *"Flexible gabion and Reno mattress structures in river and stream training works".*

14.10 Vegetated Rock Stabilisation

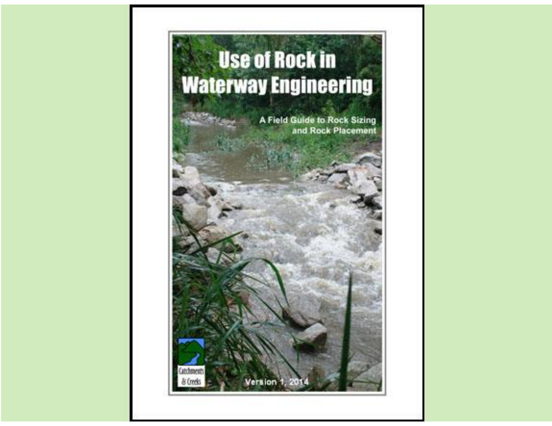
Vegetated rock stabilisation (Qld)

Description

- Vegetated rock stabilisation involves:
  - placement of rock on the creek bank
  - filling all voids with soil during placement of the rock
  - pocket planting into the rock 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.

Vegetated rock stabilisation of a creek bank (Qld)

Vegetated rock stabilisation



Use of Rock in Waterway Engineering

Bankfull flow conditions (Qld)

Vegetated rock protection (Qld)

Waterway maintenance (Qld)

Introduction

- Rock stabilisation has been one of the most widely adopted techniques for the control of bank erosion.
- In the past its application has primarily been in the form of loosely dumped rock with open voids; however, the practice of filling the voids with soil and pocket planting is becoming more common.
- The placement of rock within waterways is discussed in a separate field guide; *'Use of Rock in Waterway Engineering'*.

Factors affecting rock size

- The factors likely to affect rock size and rock selection include:
  - flow velocity (usually based on bankfull flow conditions)
  - degree of flow turbulence
  - bank slope
  - rock shape (round or angular)
  - rock density
  - void condition (open or filled with soil)
  - degree and type of vegetation cover.

Long-term stability of rock-lined banks

- Rock-protected waterway banks generally exhibit good long-term stability, especially if suitable deep-rooted vegetation is established over the rocks.
- In dynamic waterways (i.e. waterways subject to active channel expansion or migration) rock-lined banks can fail over the long-term.
- Large toe rock may be required if long-term bed lowering (bed erosion) is expected, especially on the outside of channel bends.

Waterway maintenance

- Maintenance costs are usually related to the desired aesthetics of the waterway.
- The control of weed growth can be an expensive and labour-intensive exercise.
- Long-term maintenance is best controlled through the development of a canopy cover over the creek banks for the purpose of reducing weed growth.
- Appropriate plant selection is the key to reducing maintenance costs, which means seeking out expert advice.

Vegetated rock stabilisation – Design issues

Partial vegetated bank stabilisation (NSW)

Single layer of rock over filter cloth (black)

Rock placement over filter cloth (Qld)

Vegetated, rock-stabilised bank (Qld)

Rock type and grading

- Fractured rock is generally more stable than natural rounded stone.
- A 36% increase (i.e. $K_1 = 1.36$) in rock size is recommended for rounded rock.
- All rock should be durable and resistant to weathering.
- Neither the breadth nor the thickness of a given rock should be less than one-third its length.
- Rock placed in creeks is normally in the size range of 200 mm to 600 mm.

Thickness of rock protection

- The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size (refer to Table 10.6 at the beginning of this field guide).
- The thickness of rock protection must also be sufficient to accommodate the largest rock.
- It is noted that increasing the thickness of the rock placement will **not** compensate for the use of undersized rock.

Backing material or filter layer

- Non-vegetated armour rock must be placed over a layer of suitably-graded filter rock, or geotextile filter cloth.
- Filter cloth must have sufficient strength, and must be suitably overlapped, to withstand the placement of the rock (which can cause movement of the fabric).
- Armour rock that is intended to be vegetated, subsequent to filling all voids with soil and pocket planting, will generally not require the use of a filter layer.

Manning's roughness of vegetated rock

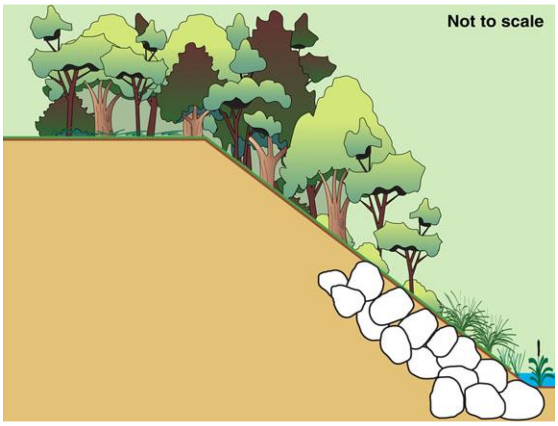
- Once the rock stabilisation is vegetated, the Manning's roughness of the surface becomes dominated by the hydraulic roughness of the vegetation.
- If highly flexible plants are used (e.g. grasses), then the surface can become relatively smooth.
- If woody plants are used, then the Manning's roughness should be based on the vegetation roughness.

Vegetated rock stabilisation – Gradient of rock stabilised banks

Example of 'placed rock' (Qld)

Introduction

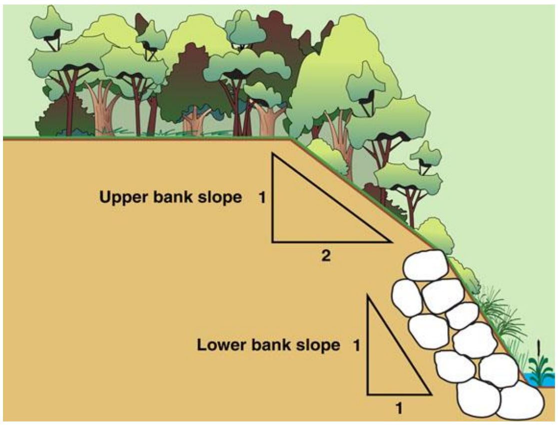
- The maximum gradient of rock-lined surfaces depends on:
  - how the rocks are placed (dumped from the back of a truck, individually placed by a rock grab, or stacked so as to minimise any individual movement)
  - the existing bank slopes upstream and downstream of the proposed rock work.



Dumped rock

Dumped rock

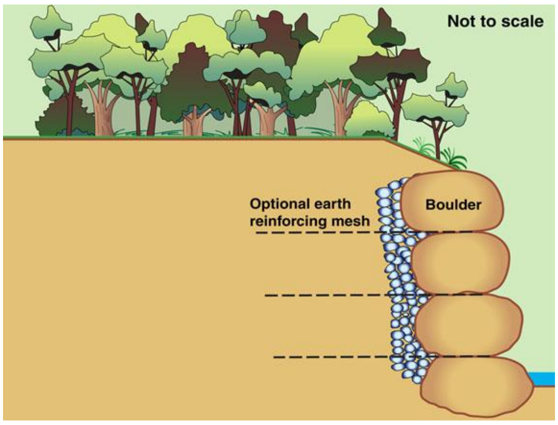
- Typical bank gradients for 'dumped' rock are:
  - 1 in 2 on the outside of channel bends
  - 1 in 3 on the inside of channel bends.
- Wherever practical, bank gradients should blend well with the existing upstream and downstream banks, i.e:
  - avoid sudden changes in bank slope
  - make sure your bank repair fits in with the rest of the creek.



Placed rock on outside of a channel bend

Placed rock

- 'Placed rock' means individual rocks are positioned on the creek bank in a manner that ensures good stability.
- Maximum bank gradient for 'placed' rock is:
  - 1 in 1 on the inside or outside of a channel bend.
- The desirable bank gradient on the inside of a channel bend is:
  - 1 in 2, but probably flatter.

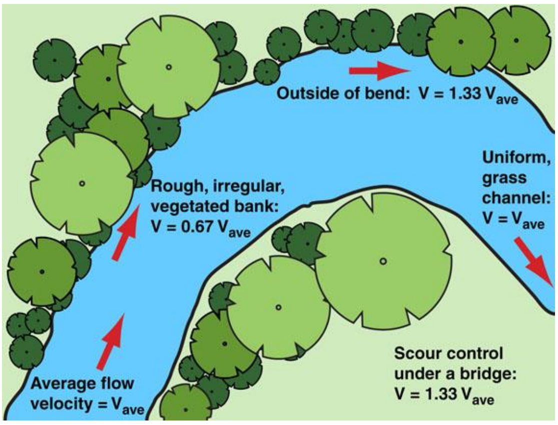


Stacked rock retaining wall

Stacked rock

- Steeper banks can be achieved with the use of stacked rocks (boulders), but the rocks must sit on a stable bed.
- The stability of the boulder wall can be increased by integrating earth reinforcing mesh into the design.
- Warning; steep, high banks can represent a safety hazard to revegetation teams and the public.

Vegetated rock stabilisation – Hydraulic conditions at channel bends



Velocity multipliers at channel bends

Rock placement on a channel bend (Qld)

Design flow velocity

- In channels with a smooth uniform cross-section, adopt a design velocity equal to the calculated average channel velocity. (i.e. $V_{design} = V_{average}$)
- In an irregular, well-vegetated waterway, adopt a design velocity of two-thirds of the average channel velocity. (i.e. $V_{design} = 0.67\ V_{average}$)
- On the outside of a significant channel bend, adopt a design velocity of 133% of the average channel velocity. (i.e. $V_{design} = 1.33\ V_{average}$)

Height of rock placement on banks

- Rock placement usually does not need to extend to the top of the bank.
- In most cases, the upper bank region only needs to be stabilised with suitable vegetation.
- Full height bank protection may be required if the bank height is less than 3 metres.
- Rock placement on the inside of channel bends is usually less than on the outside of the same bend.

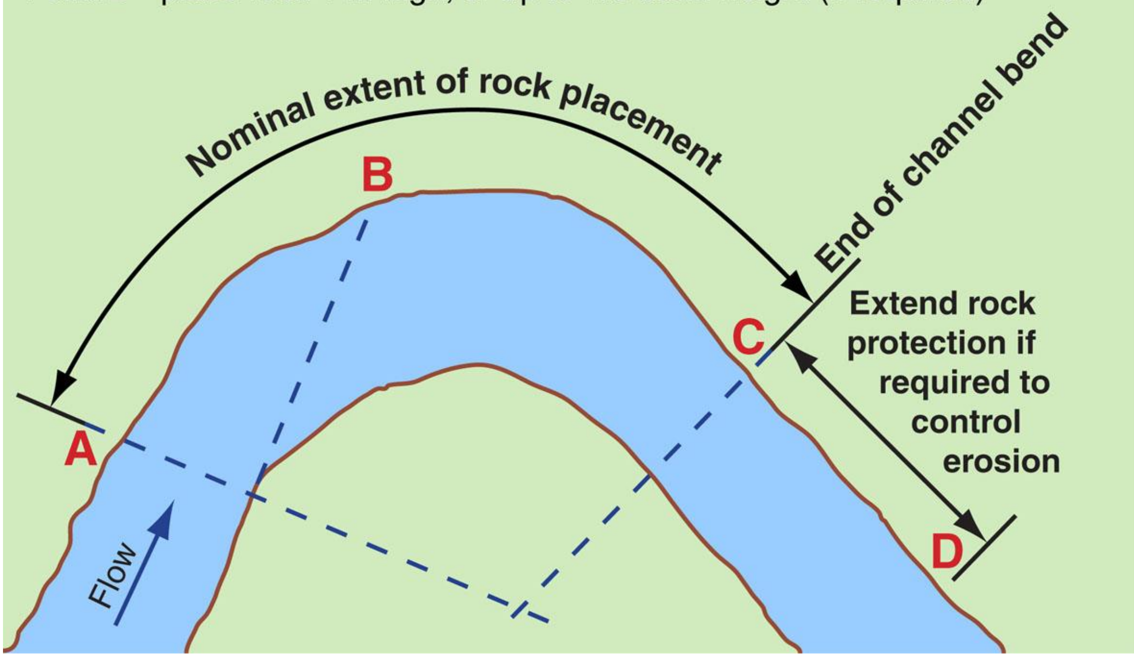
'Typical' extent of rock protection (assess case-by-case)

Point A - place rock to a height of 1 m, or up to 1/3 bank height

Point B - place rock to 2/3 bank height (or full bank height for low banks)

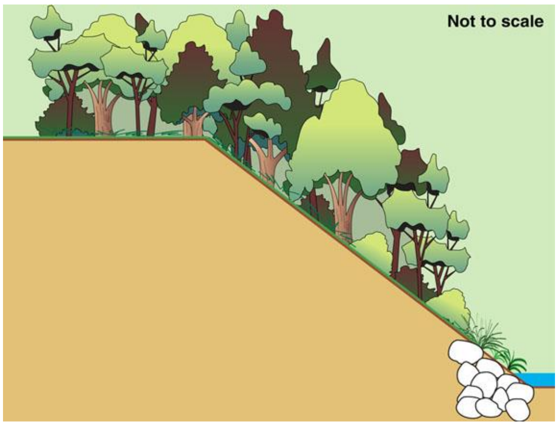
Point C - place rock to a height of 1/2 the bank height

Point D - place rock 1 m high, or up to 1/3 bank height (if required)



Height of rock placement around the bend of a major waterway

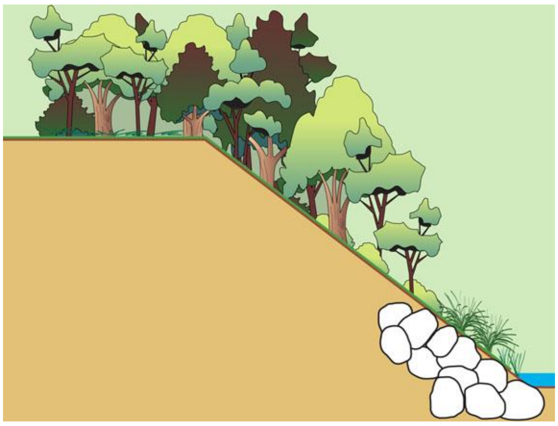
Vegetated rock stabilisation – Height of rock placement



Toe protection

Toe protection

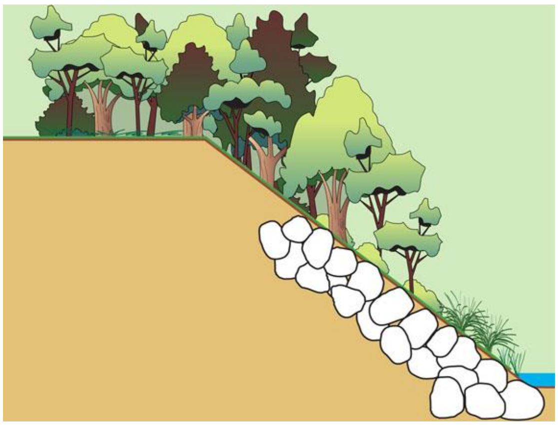
- If flow velocities are low enough to allow a fully vegetated bank, then there may still be the need for additional stabilisation of the toe of the bank in order to protect the bank during plant establishment.
- The height of the toe protection is usually 0.5 to 1.0 m above the bed.
- The rock should not sit on the bank, but should integrate well into the soil and vegetation.



One-third bank height placement

One-third bank protection

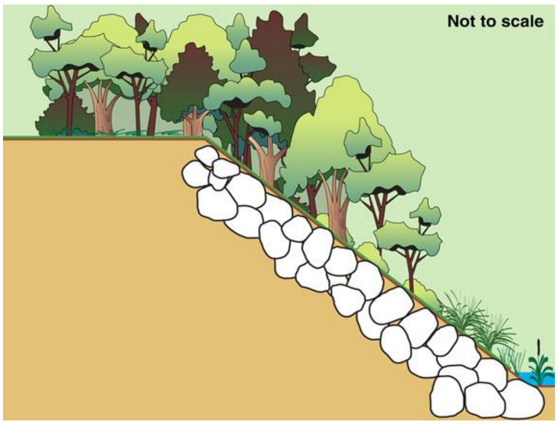
- On the <u>inside</u> of channel bends, the required height of the rock protection is likely to be in the range of 1 m high to one-third of the bank height (depending on the flow velocity).
- If the average channel velocity is less than 2 m/s, then minimal rock protection is likely to be required (unless that bank is very unstable).
- If the bend represents a 'chock', then more rock is likely to be required.



Two-third bank height placement

Two-thirds bank protection

- On the <u>outside</u> of channel bends, the height of the rock protection is likely to be between 1/3 and 2/3 bank height.
- Along straight channel reaches, the height of rock placement is also likely to be between 1/3 and 2/3 bank height, with 1/3 bank height being more common.
- As the average channel velocity increases above 2 m/s, and especially above 3 m/s, the need for rock stabilisation increases.



Full bank height placement

Full-height rock placement

- 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
  - the planned revegetation consists only of non-woody species (e.g. grasses) that are likely to encourage high velocities to exist close to the bank.

Sizing rock for bank stabilisation

Equation 14.2 can be used to size rock placed on the banks of waterway channels provided the bank slope is equal to or less than 1:2 (V:H). A 25% increase in rock size should be applied for bank slopes of 1:1.5.

A 36% increase in rock size is recommended for rounded rock (i.e. $K_1 = 1.36$).

Application of Equation 14.2	Equation 14.2
• Simplified velocity-based equation suitable for uniform and non-uniform flow conditions [1] • Low channel gradients, $S_o < 5\%$	$$d_{50} = \frac{K_1 . V^2}{2.g.K^2 (s_r - 1)} \quad (14.2)$$ K = 1.1 for low-turbulent deep water flow K = 1.0 for low-turbulent shallow water flow K = 0.86 for highly turbulent flow (Table 14.2)

Note: Equation 14.2 represents a modification of the equation originally presented by Isbash (1936).

The 'K' variable takes into account the degree of flow turbulence. Table 14.2 provides the recommended K-values for various uniform channel gradients (i.e. straight, uniform cross-sectioned channels where a constant flow velocity is achieved). In non-uniform flow a K-value of 1.1 should be used for low-turbulent deep water flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow.

Table 14.2 – Suggested values of 'K' for uniform flow conditions

Bed slope (%)	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
K =	1.09	1.01	0.96	0.92	0.89	0.86	0.83	0.80
Flow conditions	Low turbulence ► ► ► ► ► ► ► ► ► Highly turbulent (whitewater)							

Note: Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 10.4 (refer to Part 2, or the beginning of Part 3).

where:

d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]

g = acceleration due to gravity [m/s^2]

K = equation constant based on flow conditions

= 1.1 for low-turbulent deep water flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow (also refer to Table 14.2)

K_1 = correction factor for rock shape

= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)

S_o = channel slope [m/m]

s_r = specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)

V = depth-averaged flow velocity at location of rock [m/s]

Equation 14.2 reduces to the commonly used Equation 14.1 (previously presented in Section 14.8) for angular rock based on a rock specific gravity, $s_r = 2.6$

$$\mathbf{d_{50} = 0.04\, V^2} \quad (14.1)$$

Vegetated rock stabilisation – Establishment of vegetation over rocks

Vegetated rock stabilisation of bank (Qld)

Introduction

- The establishment of vegetation over the rocks provides many benefits including:
  - increased stabilisation of the rocks
  - improved terrestrial habitat
  - improved aquatic habitat
  - improved fish passage conditions during periods of high flow
  - improved aesthetics.

Voids filled with soil ready for planting

Infill soil

- Experience has shown that minimal soil is lost from the rock voids during flood events.
- This image (left) shows a recently planted bank that experienced a bankfull flow just weeks after planting—all plants were lost, but most of the soil remained.
- **Important:** In order to allow proper plant growth, the infill soil needs to be placed progressively as the layers of rock are added to the bank, thus avoiding voids behind the soil.

Planting along the water's edge (Qld)

Planting along the water's edge

- Wherever practical, vegetation should extend to the water's edge to increase the value and linkage of aquatic and terrestrial habitats.
- Plants that reach over the water's edge provide essential shading of the water, which provides pockets of cool water suitable for aquatic life.
- Edge plants also assist aquatic life to shelter from predators (e.g. nosy creek engineers trying to take photos!).

Planted rock covered with jute mesh

Use of erosion control mats

- During plant establishment it may be necessary to mulch around newly placed plants to control soil moisture loss.
- Covering such areas with a jute mesh can help to reduce the loss of mulch by wind and minor flows—but use these mats with caution in these circumstances.
- It is noted that the complete loss of the matting during elevated stream flows can cause damage to, or the total loss of, any plants that protrude from these mats.

Case study: Sheep Station Gully, Algester, Queensland

Soil-filled voids ready for planting (1999)

July 1999

- This project was one of the first examples in Brisbane where the voids between the rocks were filled with soil allowing plants to be introduced into the channel upon completion of the channel works.
- Prior to this, the practice of filling the voids with soil was considered unacceptable due to the risk of the soil being washed from the rocks by stream flows.

Early plant establishment (2000)

May 2000

- Bank vegetation was established at the time of the rock placement.

The 'weedy' phase (2001)

February 2001

- It is common for these creek rehabilitation projects to go through a 'weedy' phase during the first couple of years.
- During this early stage, the weeds provide a benefit to the rehabilitation program by:
  - helping to control soil loss, and
  - the generation of favourable boundary layer conditions.
- I would caution against the mass removal of all weeds at this stage.

Mature plant growth (2004)

July 2004

- Selective weed control can begin once the native plants become established.
- Remember; never remove a weed before first understanding the functions that the weed is currently performing within the waterway, and then ensuring that the weed is replaced with a native plant that is able to perform these same functions.

Case study: Kedron Brook, Ferny Hills, Qld – looking downstream

Bankfull flow (11/10/2010)

Looking downstream

- Extensive bank erosion occurred during 2010 and 2011 floods.
- The creek bank is both the northern and outside bank of a sweeping channel bend.
- The bank was lined with rock, all voids filled with soil, covered with jute mesh, and pocket planted with natives.
- The chosen native plants have low woody branches, which will aid bank roughness.

Post-flood eroded bank looking downstream (28/01/2011)

Planted rock stabilisation (12/06/2011)

Early plant establishment (weedy) phase (29/10/2012)

Case study: Kedron Brook, Ferny Hills, Qld – looking upstream

Looking upstream (11/10/2010)

Looking upstream

- The same processes were applied to the upstream bank.
- In the bottom image, the mature eucalypt tree hasn't been removed—there was so much vegetation density that it prevented me from photographing the creek from my previous observation points.

Post-flood eroded bank looking upstream (28/01/2011)

Planted rock stabilisation (12/06/2011)

Early plant establishment (weedy) phase (29/10/2012)

Case study: Kedron Brook, Dawson Parade, Keperra, Queensland

Eroded bank on left (28/09/12)

Kedron Brook, Keperra, 2012–14

- In 2012, rock stabilisation was placed against the southern bank (left bank, looking upstream).
- The bank repair required the use of imported fill to reconstruct the bank.
- After placement of the rocks, the voids were filled with soil and pocket planted.
- Once again, a jute mesh was used to protect the new plants from elevated stream flows, which occurred between 2012 and 2014.

Establish flow diversion bund (24/10/12)

Placement of fill (31/10/12)

Placement of rock (20/11/12)

Final rock placement (30/11/12)

Placement of jute mesh (13/12/12)

Early plant growth (2014)

15. Bank Stabilisation Using Hard Engineering Methods

Hard engineering bank stabilisation

Concrete-lined stormwater drain (Qld)

Introduction

- Hard channel linings have traditionally been used in the formation of stormwater drains, often replacing the original meandering watercourse.
- Concrete-lined open channels provide good hydraulic efficiency, reduced spatial requirements, and reduced opportunities for mosquito breeding.
- However, open channels like this also have high safety risks, which is becoming of increasing concern for urban communities.

Failure of stone pitching (Qld)

Repairs to old storm drains

- As the age of these drains increases, so too does the need for their ongoing repair.
- One of the most common causes of bank failure is the existence of dispersive soils under the concrete or stone pitching, which can result in tunnel erosion and wall failure (as in this photo).

'Greening' of an old storm drain (Qld)

Rehabilitation of old storm drains

- Significant limitations can exist when attempting to rehabilitate old drainage channels, including:
  - space limitations
  - the need to maintain the channel's existing flow capacity
  - erosion problems associated with dispersive soils under the hard lining.
- Most of the hard engineering options presented in this chapter have been used to reline sections of old storm drains.

Cherry Creek, Denver, USA

Introducing ecological values to drainage channels

- When plans are being prepared for the rehabilitation of old storm drains, it is important to clearly define the project's objectives, such as to:
  - restore ecological values, or
  - enrich human interaction with the waterway.
- Typically these are two conflicting objectives, and the community needs to be clear as to which objective must take priority.

15.1 Flexible Concrete Mats

Porous concrete pavers (ACT)

Description

- The term 'flexible concrete mats' has been used as a collective term for a variety of concrete-based products, including:
  - porous concrete pavers
  - concrete blocks anchored to a flexible mat
  - concrete pavers tied together with metal cables.
- These products have a variety of uses that are mostly associated with drainage channels, not waterways.

Vegetated porous pre-cast concrete pavers (Qld)

Flexible concrete mats

Concrete flex mat (Qld)

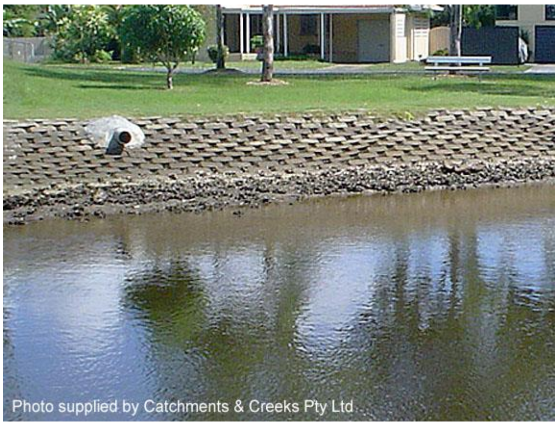
Introduction

- Most of these products can be integrated with vegetation, usually grasses.
- However, this does not make these products an example of 'soft engineering'.
- With respect to their placement on waterway banks, the associated problems include:
  - poor vegetation diversity
  - poor fauna habitat diversity
  - problems for animals that need to burrow into the creek bank.

Concrete flex mat maintenance ramp (Qld)

Maintenance access ramps

- Flexible concrete mats have been used successfully as:
  - boat ramps
  - permanent maintenance access ramps.
- Over time, these mats can become fully covered with vegetation, usually grasses.



Flexible concrete mat bank protection

Flexible concrete mat bank protection

- Flexible concrete mats have in the past been used to stabilise:
  - tidal channels
  - stormwater drains
  - high-velocity floodways
  - the rehabilitation of concrete drainage channels when significant space limitations exist.

Flexible concrete mat bank protection

Vegetated concrete mat bank protection

15.2 Gabions and Rock Mattresses

Gabion-lined channel bend (Qld)

Description

- A 'gabion' is a wire basket filled with rocks.
- A 'rock mattress' is a mattress-like basket that has a thickness of 170 to 300 mm, a length of 6 m, and width of 2 m (alternative sizes do exist).
- Gabions typically have dimensions of 1 m x 1 m, with a length of 2 or 3 m.
- When used in waterways, the wire should be galvanised and plastic coated.
- Discussion on vegetated gabions is provided in Section 14.9.

Gabion creek bank retaining wall (Qld)

Gabions and rock mattresses (non-vegetated)

Construction of a gabion wall (Qld)

Achieving good design outcomes

- The best thing about gabions is their potential for flexible design outcomes.
- The worst thing about gabions is that too many designers fail to appreciate the likely long-term outcomes.
- With care and attention to details, good outcomes can be achieved.
- However, poor outcomes are usually achieved if designers treat gabions as just another form of 'building blocks'.

Rock mattress in a waterway environment

Use of gabions and mattresses in waterways

- When placed away from a waterway, good long-term outcomes can be achieved by non-vegetated gabions.
- When placed within a waterway, good long-term outcomes usually require the gabions to be fully vegetated.
- Unfortunately, galvanising and plastic coating of the wire cannot protect it from the effects of flood debris, or extreme variations in water pH.

Plastic cage gabion (Qld)

Waterway and marine environments

- Gabion baskets can also be formed from earth reinforcing (plastic) mesh.
- Full vegetation cover is still recommended.

Tunnel erosion under rock mattress

Placement of gabions and rock mattresses over dispersive soils

- Non-vegetated gabions or rock mattresses must <u>not</u> be placed directly over a dispersive soil.
- Prior to placement of the gabion, the dispersive soil must be covered with a minimum 200 mm layer of non-dispersive soil.
- The alternative approach is to fill the gabions with a mix of non-dispersive soil and rock, and then to immediately cover the gabion (or mattress) with vegetation.

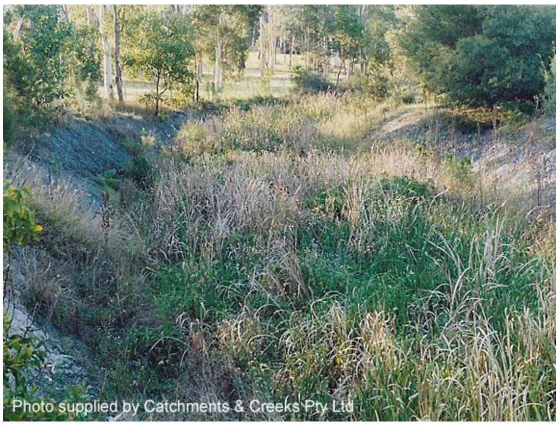
Gabions and rock mattresses – Weed invasion

Gabion wall covered with weeds

Weed invasion of non-vegetated gabions

- One of the many reasons why gabions and rock mattresses should be fully vegetated at the time of their installation is the inevitable invasions of weeds that will occur if gabions are not vegetated.
- Once weeds invade these structures, the removal of the weeds can be both labour-intensive and expensive.
- Similar problems exist for non-vegetated rock stabilisation.

Weeds poisoned in a rock mattress drain



Weed invasion of the same drain (left)

Non-vegetated rock mattress drain

Weed invasion of the same drain (left)

Non-vegetated rock mattress drain

Weed invasion of the same drain (left)

Gabions and rock mattresses – Damage to baskets

Jim Finimore Park drop structure (2008)

Failure of wire baskets

- The wire baskets that enclose gabions and rock mattresses are not permanent features of these structures.
- Ultimately, the baskets must be replaced with the root systems of a vegetative cover.
- If left non-vegetated, any failure of the basket will result in loss of some rocks.
- Failure of the wire baskets is more likely if the flood water is highly turbulent, or it carries coarse sediment or woody debris.

Sandy Creek drop structure (1991)

Alexandra Hills drop structure (1995)

Orphan School Creek (1993)

Torrens River (2014)

Macquarie Park drop structure (2003)

Torrens River (2014)

15.3 Hard Engineering Surfaces

Concrete-lined stormwater drain

Description

- In this context, the term 'hard engineering' is used to describe structural measures that are likely to incorporate solid concrete, and/or non-flexible, non-vegetated surfaces.
- These surfaces are likely to be used for the purpose of achieving:
  - a vertical, or near vertical, retaining wall
  - a wall that is required to have very high scour resistance.

Concrete block river retaining wall

Hard engineering surfaces

Vertical retaining wall

Vertical walls

- Vertical walls are normally used when severe space limitations exist.
- Unfortunately, vertical walls are associated with the following problems:
  - safety risks of a fall
  - safety risks for some fauna
  - high hydraulic shear stress at the base of the wall (if the wall sits adjacent to a natural creek bed).

Concrete-lined stormwater drain

Decorative walls

- Decorative walls are not a substitute for appropriate environmental practice.

Concrete block retaining wall

Hydraulic issues

- Hard engineering channel linings can be relatively ‘smooth’ from a hydraulic perspective:
  - this can attract high-velocity flows close to the side walls of these channels; and
  - if the bed of the channel consists of natural bed material (e.g. soil and gravel), then bed erosion should be expected at the base of the channel’s side walls.

Erosion of a dispersive soil under concrete

Placement of concrete over a dispersive soil

- Tunnel erosion can occur under the concrete if it is placed directly over a dispersive soil.
- Prior to placement of the concrete, any exposed dispersive soil must be covered with a suitable layer of non-dispersive soil.
- Refer to Chapter 16 for further discussion on working with dispersive soils.

15.4 Non-Vegetated Rock Stabilisation

Non-vegetated rock stabilisation (Qld)

Description

- Non-vegetated rock stabilisation involves:
  - trimming and grubbing the creek bank
  - placement of a geotextile, or rock filter layer, over the soil
  - placement of rock over the filter layer.
- The rock should extend only to the height considered necessary, thus allowing the rest of the bank to be vegetated.
- Just because the bank erosion extends to the top of bank, does not mean the rock must extend to the top of bank.

Non-vegetated rock stabilisation (Qld)

Non-vegetated rock stabilisation

Non-vegetated rock stabilisation

Non-vegetated stacked boulder wall

Lizard basking on an exposed rock (NSW)

Fish hiding amongst rocks (Qld)

Aesthetics

- Exposed rock can be unsightly.
- Weed invasion of rock-protected surfaces can also appear unsightly.
- Better aesthetics can be achieved if the rock-lined surface is fully vegetated at the time of placement.
- The use of broken concrete and building rubble for bank protection can be extremely unsightly, and is generally not recommended, especially in publicly accessible areas.

Impact on waterway hydraulics

- Non-vegetated rock stabilisation can significantly reduce the hydraulic resistance of the watercourse, potentially resulting in increased channel velocities and bed scour.
- The hydraulic roughness of rock-lined waterways largely depends on the degree of any vegetation cover (whether intentional, or just weed cover).

Terrestrial habitats

- Rock-lined surfaces can provide the following benefits for terrestrial fauna:
  - areas for basking/roosting
  - protection from predators
  - protection from floods and bushfire.
- However, the desire to provide terrestrial habitat values does not mean that rock-lined surfaces should remain non-vegetated (vegetated surfaces can provide the same habitat values).

Aquatic habitat values

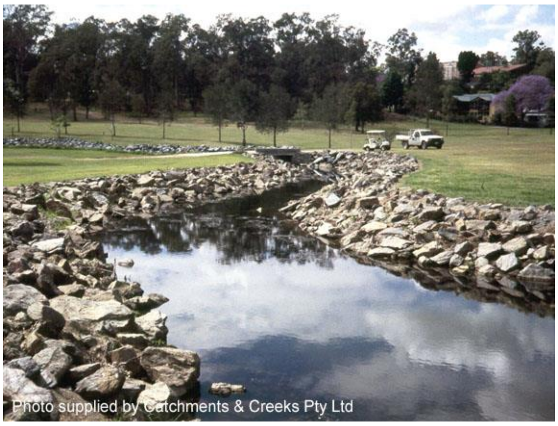
- The battering of eroded banks for the purpose of placing rock may result in the formation of an open-canopy, which may adversely affect water temperatures.
- The establishment of leafy vegetation along the water's edge can reduce water temperatures and benefit aquatic habitat.
- Cavities (voids) between rocks placed **below** the permanent water level can provide desirable aquatic habitat and shelter, especially if rocks smaller than 200 mm are removed from the rock mix.

Non-vegetated rock stabilisation

Bank stabilisation without revegetation

Riparian habitats

- Non-vegetated rock protection creates poor riparian values.
- Non-vegetated rock provides minimal shelter and habitat values for some fauna, while providing enhanced habitat values for other fauna, often non-native.
- Riparian zones that lack middle storey and ground covers have poor aesthetic appeal.
- Open voids **above** the water line can encourage vermin.



Rock-lined channel in a golf course

Maintaining rock-lined surfaces free of weeds

- In the long-term, some form of vegetation, probably weeds, will usually cover the rocks.
- Once weeds invade these surfaces, their removal can be both labour-intensive and expensive.

Individual placement of rocks (Qld)

Design issues

- Recommended maximum gradients are:
  - 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 revegetation activities
  - 1 in 2 for dumped rock on the outside of channel bends
  - 1 in 3 for dumped rock on the inside of channel bends.

Rock placement (Qld)

Construction issues

- Most structural bank failures result from inappropriate placement of the rock, normally as a result of inadequate design detailing, inappropriate rock selection, or poor construction supervision.
- Rock-lined waterway structures are usually most susceptible to failure during the first two years of their operation, that is before sediment and vegetation have begun to stabilise the rocks.

Non-vegetated rock stabilisation – Common problems

Rock placement without planting

Failure to introduce suitable vegetation cover

- The placement of loose rock on waterway banks without incorporating vegetation may initially appear as a cheap scour control option, but weed infestation can lead to ongoing maintenance costs.

Rock placement without planting

Same location (left) after weed infestation

Weak sandy bed structure after a flood

Placement of rock on sandy bed waterways

- Sand-based waterways often contain a deep bed of sand, which can liquefy during floods, and migrate down the waterway like a viscous fluid.
- If heavy rocks are placed on the bed of a sand-based waterway, then these rocks may simply sink into the sand during flood events.
- The risk of the rocks being displaced during floods depends on the depth of sand and how the sand moves during floods.

Rocks sliding down filter cloth

Rocks slipping down smooth filter cloth

- In certain conditions, filter cloth effectively acts as a low-friction surface, which can cause rocks to slowly slide down the face of a slope.
- If rocks need to be placed on steep slopes, then the rocks should be 'keyed' into the bank.
- Keying can be done by 'stair-stepping' the bank prior to placing the filter cloth, or providing suitable toe rock.

Non-vegetated rock stabilisation – Common problems

Bank erosion at d/s end of rock work

Bank erosion at downstream end of rock-lined banks

- In the absence of a vegetative cover, rock-lined surfaces can act as hydraulically-smooth surfaces that can induce high flow velocities to exist adjacent the bank.
- These same high velocities can then pass over the unprotected bank immediately downstream of the rock-lined surface causing soil erosion.
- Erosion along the toe of the bank is also a common problem.

Tunnel erosion under rocks

Rock placed on dispersive or slaking soils

- Rocks should **not** be placed directly onto a dispersive, sodic, or slaking soil.
- Tunnel erosion is a common occurrence when rocks are placed directly over a dispersive soil.

Collapsed dispersive soil bank

Placement of rock over dispersive soils

- If the rock is placed on a dispersive (sodic) soil, then **prior** to placing the filter cloth, the exposed soil **must** first be covered with a layer (typically 300 mm) of non-dispersive soil.
- It is noted that filter cloth, no matter how thick, cannot seal a dispersive soil, and thus should not be relied upon as the sole underlay for rock placed over a dispersive soil.

Poorly placed rocks on creek bank

Rock not integrated into the bank

- Rocks should not be placed on a creek bank in a manner that detracts from the natural aesthetics of the waterway.
- Wherever possible, the rocks should be recessed into the soil, and appropriately vegetated.
- The exception being when the establishment of vegetation would adversely affect local flood levels.

16. Management of Dispersive and Slaking Soils

Introduction

Erosion of a dispersive soil (NSW)

Fluting erosion in a dispersive soil (SA)

Gully erosion within a slaking soil (Qld)

Dry, cracking clay (Qld)

Introduction

- The erosion of dispersive soils is a combination of:
  - electro-magnetic (chemical) erosion
  - raindrop impact erosion
  - soil scour.
- This type of erosion is most commonly associated with sodic soils that have excessive quantities of exchangeable sodium cations in the soil.
- Further discussion on dispersive soils can be found in Section 3.7 in Part 1.

Dispersive soils

- If a soil is dispersive, then it is likely to be highly unstable when wet, resulting in severe, deep rilling (or 'fluting' as shown left), tunnel erosion, and/or gully erosion.
- As a general guide, if an individual 'rill' is significantly deeper than it is wide, then soil chemistry (i.e. exchangeable sodium) is likely to be a significant factor contributing to the soil erosion (although many exceptions to this observation to exist).

Slaking soils

- A slaking soil is a soil that readily breaks down (falls apart) when wet, but lacks the dispersive clays that cause the runoff to become highly turbid.
- In real terms, slaking soils behave in a manner similar to dispersive soils, and as such are commonly treated the same.
- These soils are usually very sandy, low in organic content, and are often found in granite country.
- Scour marks in the soil can be different from those observed in dispersive soils.

Cracking clays

- The term 'clay' can be used to describe the smallest of the soil particles (< 0.002 mm), and it can also be used to describe a soil that has a high clay content (as is the case here).
- Some clayey soils experience significant swelling and shrinkage as the soil's moisture levels change, which causes the soil to crack and crumble if it is allowed to dry excessively.
- The cracked soil can break free of the bank, and then fall to the bed of the creek.

Identifying dispersive and slaking soils

ORGANIC MATTER		
Organic Matter	%	1.7
SALINITY		
Electrical Conductivity	dS/m	0.09
Chloride	mg/kg	28
Sodium	mg/kg	26
EXCHANGEABLE CATIONS		
Exchangeable Sodium	meq/100g	0.11
Exchangeable Potassium	meq/100g	0.37
Exchangeable Calcium	meq/100g	0.40
Exchangeable Magnesium	meq/100g	0.30
Exchangeable Aluminium	meq/100g	Not Applicable
Exchangeable Sodium Percent	**%**	**9.6**
Exchangeable Potassium Percent	%	31.6
Exchangeable Calcium Percent	%	33.4
Exchangeable Magnesium Percent	%	25.4
Exchangeable Aluminium Percent	%	Not Applicable
Cation Exchange	meq/100g	1.18
Calcium/Magnesium Ratio		1.32

Soil analysis

'Fluting' erosion within a dispersive soil

Dispersive soil

Slaking soil

Introduction

- Soil testing is normally required if:
  - the site has an elevation below 5 m AHD, which means the site should be tested for acid sulfate soils
  - the bank erosion has exposed soils that appear to be dispersive.
- The 'exchangeable sodium percentage' or the Emerson aggregate class (see below) can be used to identify dispersive or slaking soils.

Soil testing

- Dispersive soils can be identified through appropriate soil testing:
  - exchangeable sodium percentage > 6%
  - Emerson aggregate classes 1 to 5 (class 1 indicates a highly dispersive soil, while classes 3(2), 3(1) and 5 have a slight risk of dispersive problems).
- A simple field test such as the Aggregate Immersion Test (over page) can be used as an on-site indicator test.

Dispersive (sodic) soils

- Soil dispersion commonly results from high levels of exchangeable sodium within the soil.
- Dispersive soils are often recognised by the occurrence of deep, narrow rilling (fluting) often with the rills spaced only a few centimetres apart.
- Soil surfaces not directly exposed to rainfall often have a textured surface (shown, left), which actually results from raindrop splash that has bounced off an adjacent surface.

Slaking soils

- Slaking soils are commonly associated with granite country.
- These soils often display similar visual signs to dispersive soils, but the lack of dispersive clay particles within the soil means stormwater runoff is generally <u>not</u> highly turbid.
- These soils can be difficult to stabilise, and can release large quantities of clean sand into waterways when they erode.

Aggregate Immersion Test

Slightly dispersive soil

Aggregate Immersion Test

- The ***Aggregate Immersion Test*** can be used as an 'indicator' of dispersive soils.
- This test involves filling a dish with distilled water (generally available at petrol stations and supermarkets) to a depth sufficient to cover the soil samples.
- Several dry, hard clumps of soil are gently placed in the water.
- The water is then observed for colour changes (**after** all the air has escaped).

Non-dispersive, non-slaking soil

Non-dispersive soil

- If the water remains clear and the boundary of the soil clumps remains clearly defined, then the soil is likely to be non-dispersive.
- If the original soil clumps were loose or heavily disturbed, then the soil clumps will likely separate into smaller pieces when first placed into the water—this does not indicate that the soil is dispersive.
- Air escaping from the soil can also cause the clumps to fall apart—this also does not indicate that the soil is dispersive.

Dispersive soil

Dispersive soils

- If the water discolours both horizontally and vertically around the soil clumps, then the soil could be dispersive.
- Highly dispersive clumps of soil will collapse in less than 10 minutes.
- Caution; using tap, tank or groundwater can sometimes mask the dispersive reaction due to minerals and/or chemicals in the water.

Slaking soil

Slaking soils

- Slaking soils are soils that readily collapse in water, but do not necessarily cloud the water.
- If the water remains clear, and the clumps completely collapse and **spread horizontally**, then the soil could be a slaking soil.
- Slaking soils commonly occur within regions containing granite rock.
- These soils can be highly erodible, especially if disturbed by earthworks.

Visual identification of dispersive soils

Textured surface not exposed to rain

Textured surfaces

- Both dispersive and slaking soils can display textured patterns on those surfaces that are not directly exposed to rainfall.
- This textured pattern results from raindrop splash bouncing off adjacent soil surfaces, or it can result from very minor surface flows moving over the soil surface.
- The textured soil can take on the look of a white-ant nest.

Textured surface of eroded soil (Qld)

Textured surface (SA)

Fluting erosion (Qld)

Fluting

- 'Fluting' is a type of rill erosion that results in a series of closely-spaced vertically grooves (flutes).
- In dispersive or sodic soils these rills are normally deep, narrow, and regularly spaced across the slope.
- These rills are usually deeper than they are wide—the rills typically have a deep V-shape, rather than a shallow U-shape.

Fluting erosion (Qld)

Fluting and tunnel erosion (Qld)

Visual identification of dispersive soils

Deep rilling and outlet of tunnels (Qld)

Tunnel erosion

- The existence of tunnel erosion is a common indicator of a dispersive soil.
- The outlets of the tunnel erosion can often appear like normal rilling, but further inspections should reveal a tunnel deep in the soil.
- The inlets of the tunnel are often found close to the top edge of the creek bank; however, some tunnels can extend several metres from the bank.

Entry to a tunnel (Qld)

Tunnel erosion adjacent to a creek (Qld)

Deep rilling (Qld)

Deep rilling with near-vertical sides

- When dispersive soils first erode, the erosion is often (but not always) deeper than it is wide, and the sides of the erosion are often near-vertical.
- However, this form of erosion can also be found in soils with one or more of the following attributes:
  - slaking
  - non-cohesive (sandy)
  - poorly compacted
  - very low in organic matter.

Undercutting of surface soils (Qld)

Deep rilling/gully erosion (SA)

Stabilising creek banks that contain dispersive soils

Placement of topsoil on a bank (NSW)

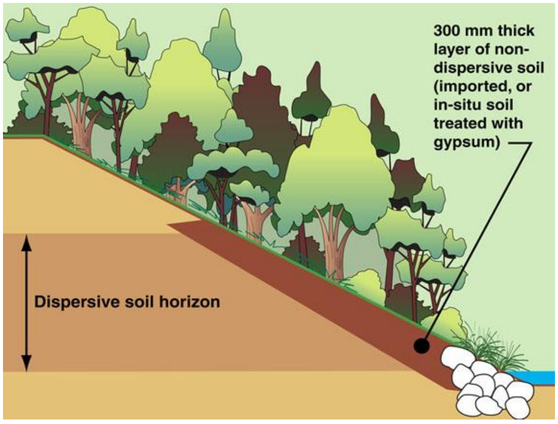
Introduction

- Dispersive soils are 'natural' soils.
- Dispersive soils are subsoils, not topsoils.
- Dispersive soils generate erosion problems because clay particles readily wash from these soils.
- The only way to prevent the removal of these clay particles is to place a 'soil filter' over the dispersive soil (NOT a geotextile filter), which means burying these soils under a layer of non-dispersive soil, then applying vegetation.

Gypsum

Making a non-dispersive soil from in-situ soils

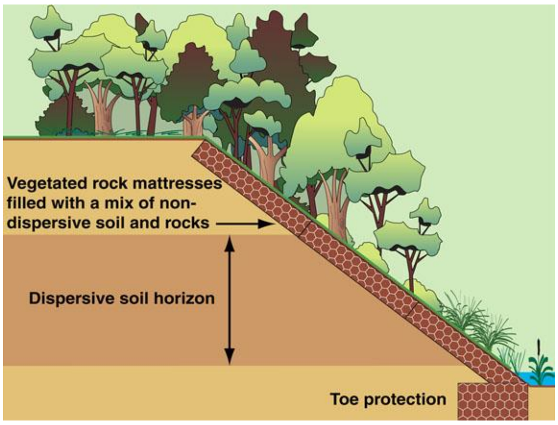
- Non-dispersive soil can be imported onto the work site; BUT, importing soils can create some problems, including:
  - importing weed seed in the soil
  - increased traffic damage to the creek bank.
- Alternatively, a non-dispersive soil can be made from the existing site soil through the addition of gypsum or lime (depending on the soil pH).



Covering a dispersive soil prior to planting

Covering dispersive soils with non-dispersive soil

- One treatment option is to cover any dispersive soil with a layer of non-dispersive soil **prior** to the placement of the surface scour protection.
- The recommended thickness of this cover layer depends on the site conditions:
  - 100 mm for road and some water storage embankments
  - 300 mm for creek banks and farm dams.

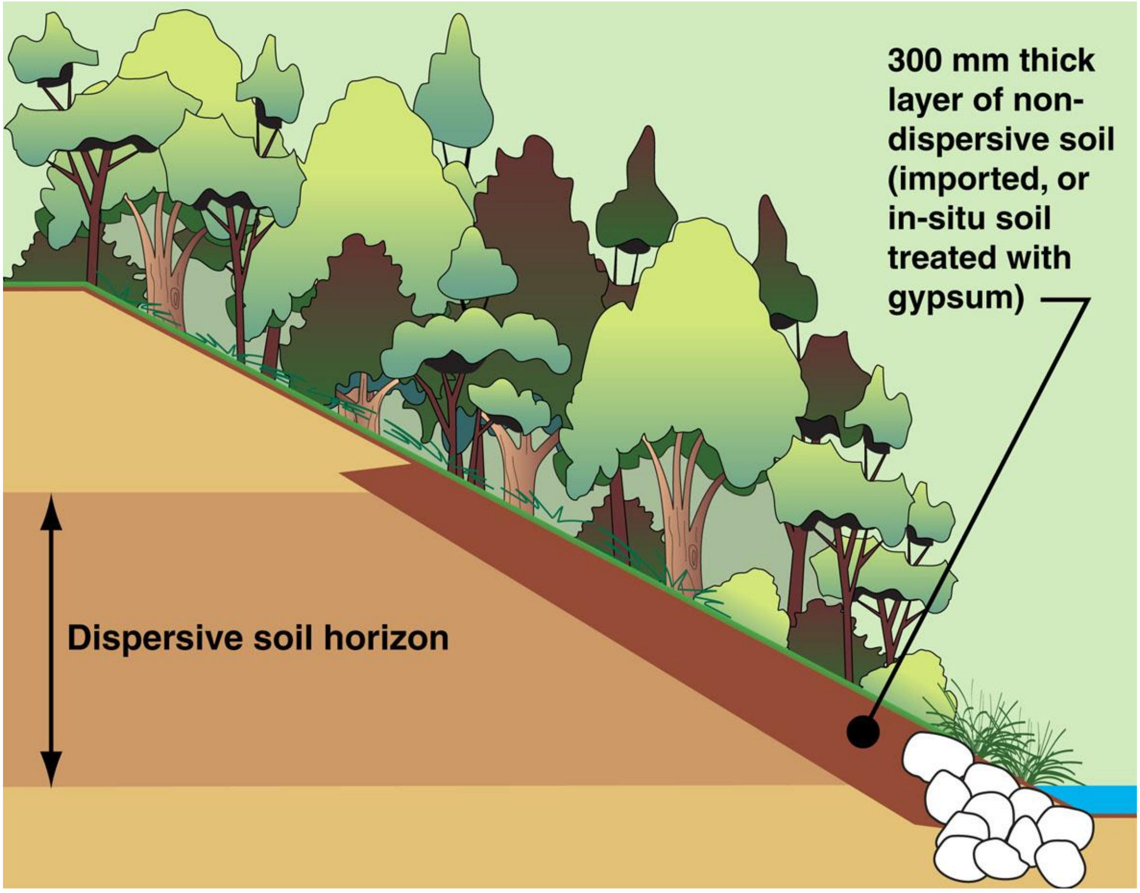


Vegetated rock mattress bank protection

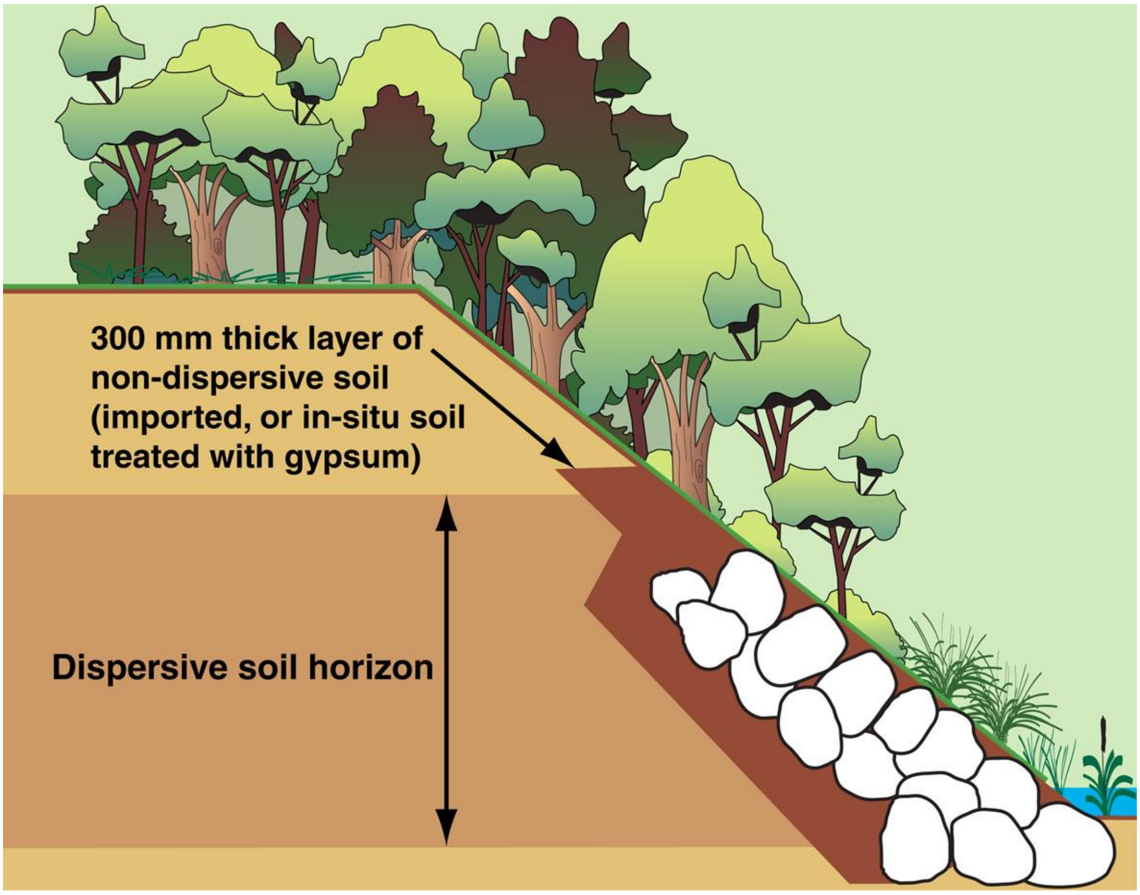
Alternative treatment option

- The alternative treatment option involves using a non-dispersive soil as the soil mix during the placement of the rock or other bank treatment.
- This option can only be used in:
  - vegetated rock stabilisation
  - vegetated gabion or rock mattress protection.
- It is noted that any soil used as a 'topsoil' must be non-dispersive.

Examples of bank stabilisation appropriate for a dispersive soil

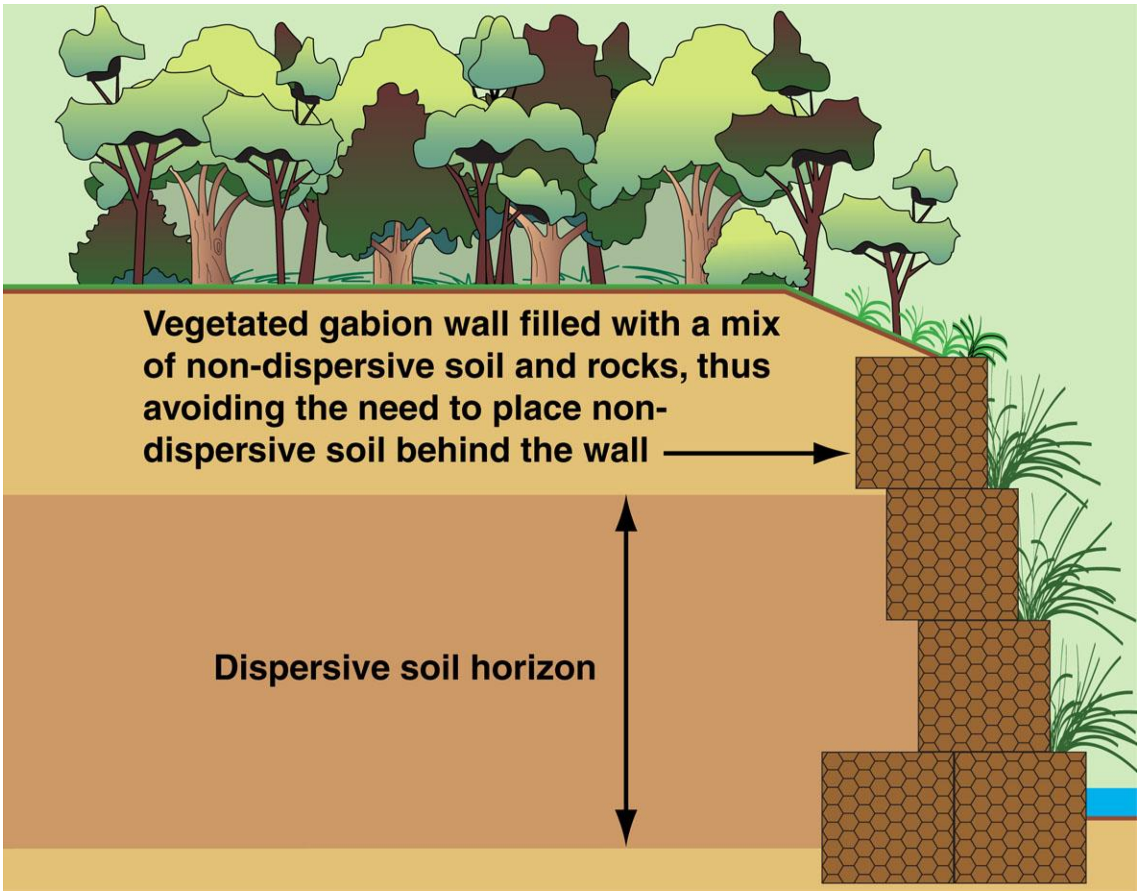


Bank battering and full-height revegetation

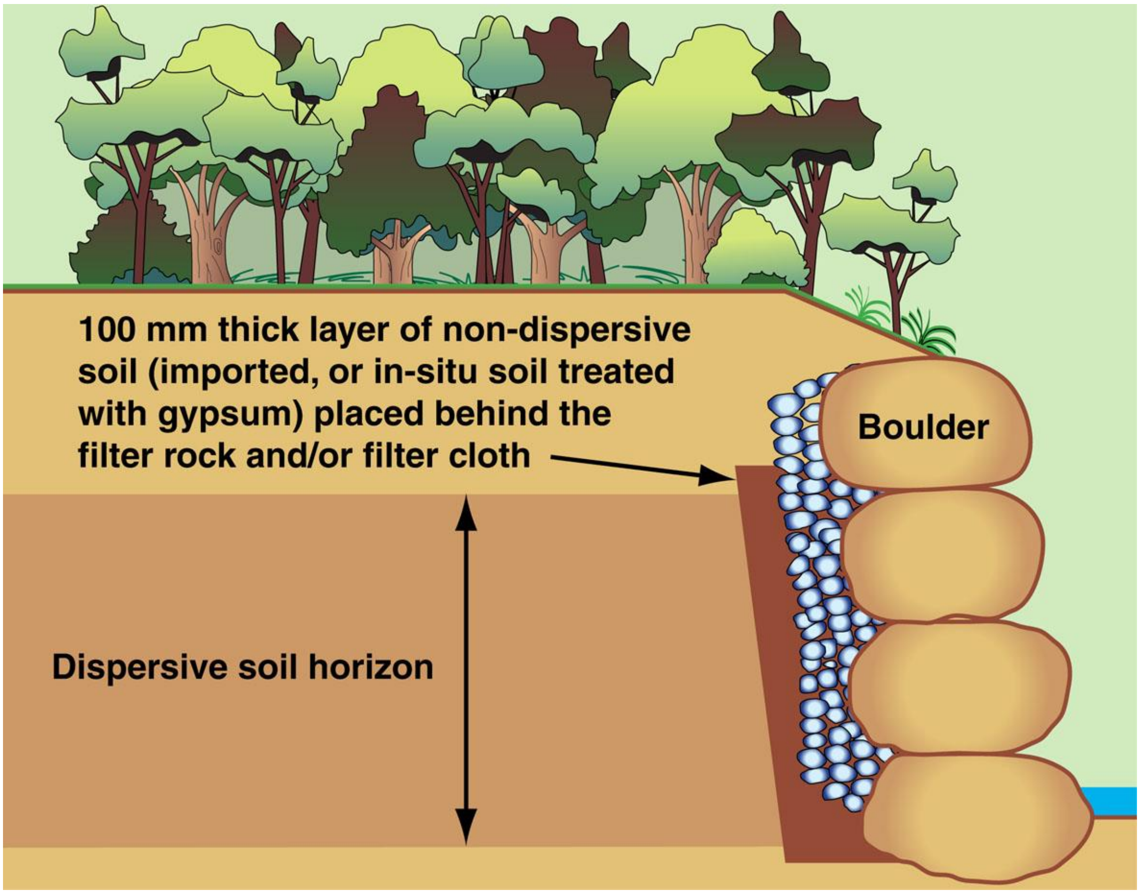


Bank battering with lower bank rock stabilisation

Examples of bank stabilisation appropriate for a dispersive soil



Non-dispersive soil in the vegetated gabion wall helps to retain the dispersive soil



Stacked boulder wall adjacent a dispersive soil horizon

Common problems associated with the stabilisation of dispersive soils

Tunnel erosion under rock stabilisation

Failure of rock protection

- Rock stabilisation is normally used in response to a bank scour, or flow velocity issue.
- However, if the eroding creek bank exposes a dispersive subsoil, then the creek bank is now experiencing two forms of erosion: bank scour and soil dispersion.
- Rock should not be placed directly over such soils, otherwise the result is likely to be tunnelling under the rocks.

Direct seeding of a dispersive soil

Problems associated with the direct seeding of dispersive soils

- Plants, including grasses, can grow in a fertile dispersive soil, but don’t expect the plant’s root system to hold the soil in place, because the clay particles will continue to wash away, leaving behind just a loose, sandy soil.
- It is noted that in their natural state, these soils are always subsoils, not a topsoil.
- Do not directly seed a dispersive soil; bury it, then seed the topsoil.

Tunnel erosion under a rock mattress

Problems associated with the stabilisation of dispersive soils using rock mattresses

- Gabions and rock mattresses should not be placed directly over a dispersive soil.
- Dispersive or slaking soils must first be covered with a non-dispersive soil, before placement of the filter cloth (if required), then construction of the gabion structure.
- The existence of a dispersive soil can cause clay particles to leach from behind the gabion wall resulting in tunnel erosion (this leaching cannot be stopped by the use of filter cloth).

Undermining of bank vegetation

Undermining of bank revegetation

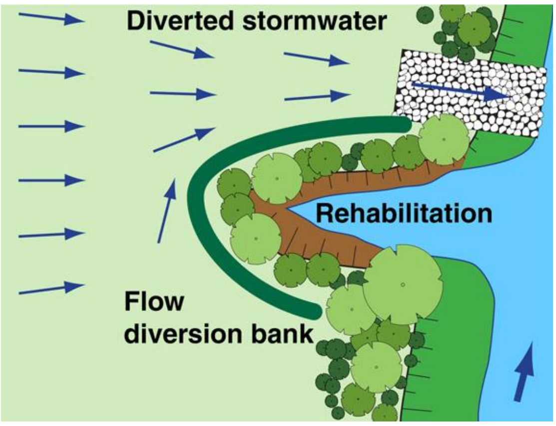
- It is true that a root system can be used to strengthen and stabilise a creek bank, but plant roots cannot ‘bind’ a dispersive soil.
- Dispersive soils effectively turn to a slurry when wet, which allows the clay particles to wash from the soil.
- Once the clay component has been washed from a soil, what is left behind is a sandy soil that most root systems fail to hold in place.

17. Management of Tunnel and Lateral Bank Erosion

Introduction

Lateral bank erosion (SA)

Tunnel erosion (Qld)



Diversion of stormwater runoff

Initial stages of lateral bank erosion (Qld)

Lateral bank erosion

- Lateral bank erosion is a form of bank erosion that usually results from the unnatural concentration of stormwater runoff, and the effects of this runoff spilling down unstable banks.
- Even though it is classified as a form of bank erosion, it displays many of the features commonly associated with bed erosion, such as 'head-cut' erosion.
- The treatment of lateral bank erosion largely depends on how far the erosion has extended into the bank.

Tunnel erosion

- Tunnel erosion is most commonly formed when groundwater begins to weep through a series of connected cracks (voids) within the soil.
- If the soil is dispersive, then the ongoing removal of clay particles by these sub-surface flows can eventually form large tunnels.
- Tunnel erosion is typically an indicator of dispersive soils.

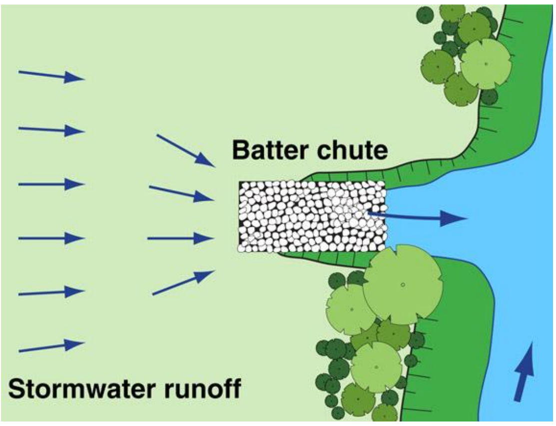
Management of stormwater runoff

- The management of lateral bank erosion needs to be approached in two ways:
  - stabilisation of the gully
  - control of the ongoing movement of stormwater runoff and livestock.
- The management of stormwater runoff is discussed later in this chapter, as well as in Section 14.6.
- The management of livestock movement across riparian zones is also discussed in Section 14.6.

Stabilisation of the gully

- Stabilisation of the gully formed by lateral bank erosion can involve:
  - backfilling of the gully to return the creek bank back to its original condition, followed by the construction of a batter chute to safely carry future stormwater flows, or
  - stabilising the gully in its current (eroded) location, which means constructing a batter chute at the head of the gully, well away from the creek bank.

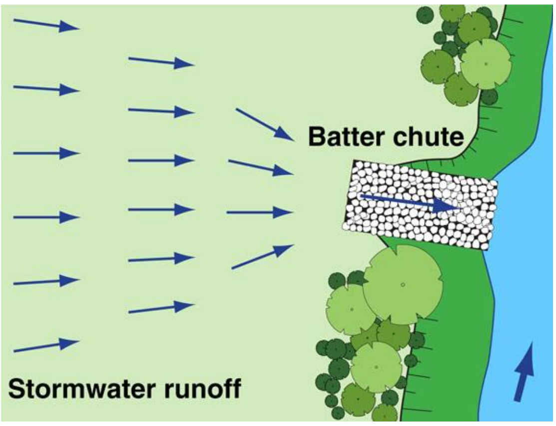
Treatment of lateral bank erosion – Treatment options



Stabilise the gully in its current location

Stabilisation options

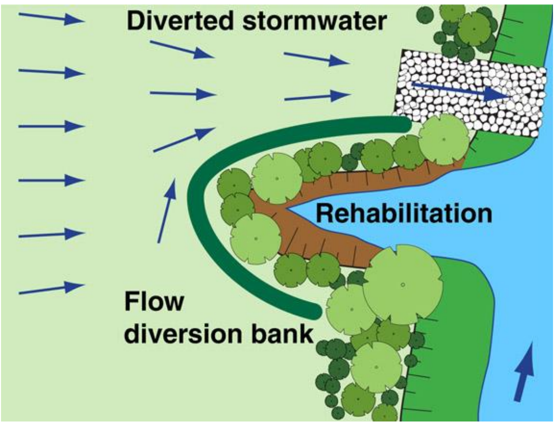
- One option is to construct a stable batter chute at the current location of the gully head.
- This treatment option has the following advantages:
  - reduced cost
  - no need to import fill
  - the batter chute is located away from the creek bank, which means the creek can experience some degree of lateral movement without damaging the chute.



Backfill and stabilise the gully

Advantages and disadvantages of backfilling the gully

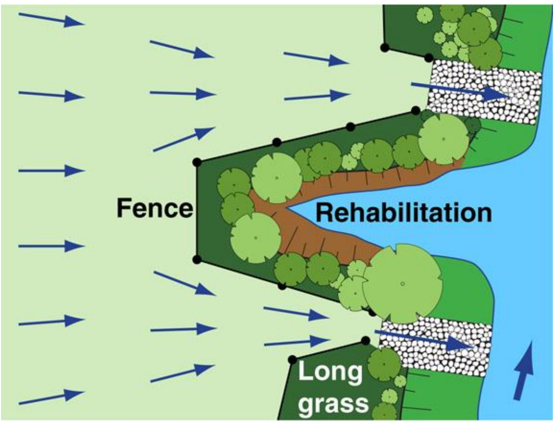
- Another option is to partially backfill the gully, and then construct the batter chute closer to the creek bank.
- This treatment option has the following advantage:
  - reclaiming useable farmland.
- However there is also the following disadvantage:
  - the backfilled gully may be too unstable to allow a batter chute to be built.



Divert stormwater away from the gully

Diversion of stormwater using flow diversion banks

- An alternative approach is to:
  - construct a new batter chute, then . . .
  - vegetate this batter chute, then wait sufficient time for this vegetation to stabilise the batter chute, then . . .
  - divert stormwater runoff away from the existing lateral bank erosion (the gully) and direct it to the new batter chute, then . . .
  - rehabilitate the old gully.

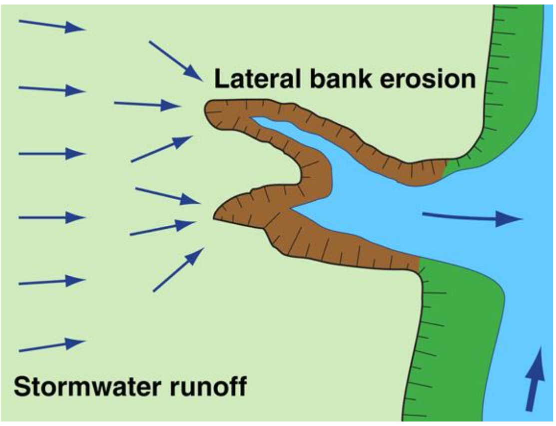


Use of fencing to divert stormwater

The use of fencing to control the movement of stormwater runoff

- This treatment option is based on a *'watch and act'* approach:
  - fencing of the riparian zone to allow the establishment of long grasses that are able to divert stormwater runoff—as per the discussion in Section 14.6
  - if new examples of lateral bank erosion begin to appear along the creek bank, then appropriate actions must be taken to further divert and manage the stormwater runoff.

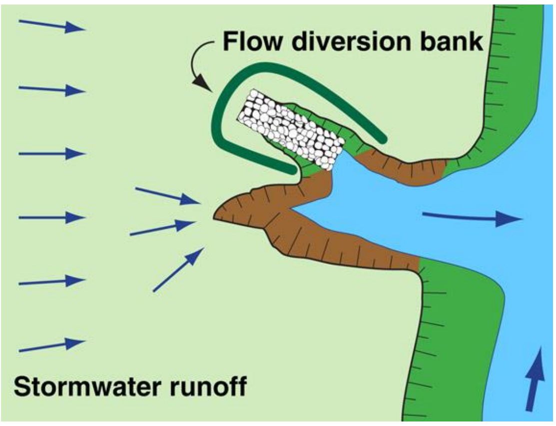
Treatment of lateral bank erosion – Treatment options



Lateral bank erosion

Stabilisation of a gully head that has more than one point of stormwater inflow

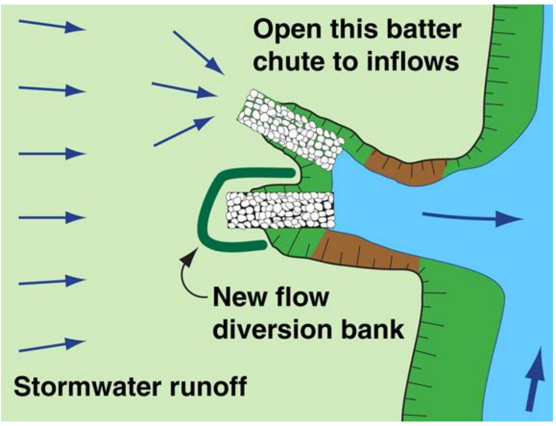
- The treatment of lateral bank erosion shares many common features with the treatment of gully erosion.
- If the lateral bank erosion has more than one ‘branch’ or ‘gully head’, then the treatment of the gully can follow a staged approach, which may better suit the work schedule of the landowner or community working group.



Initial stabilisation of the gully head

Stage 1

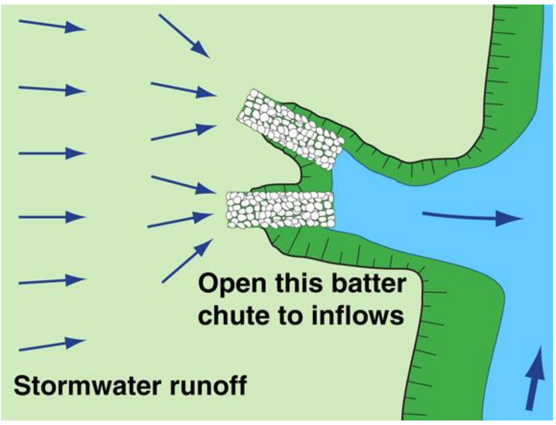
- Batter chutes, particularly vegetated rock chutes, are most vulnerable to flow damage in the first year after being constructed.
- As time passes, the ground becomes more stable, and the vegetation cover begins to anchor the rocks.
- To take advantage of this situation, the first batter chute can be constructed off-line (i.e. with stormwater temporarily being diverted away from this chute).



Continued stabilisation of the gully head

Stage 2

- Once the first batter chute is considered stable, it can be brought on-line, and the next batter chute can be constructed off-line.
- During this process, the banks of the gully can slowly be stabilised with vegetation.



Stabilised gully conditions

Stage 3

- One-by-one the gully heads can be stabilised off-line, then brought on-line.
- If necessary, permanent flow diversion banks can be installed to ensure all stormwater runoff is directed only to these stabilised batter chutes.

Treatment of lateral bank erosion – Batter chutes

Initial stages of lateral bank erosion (Qld)

Batter chute options

- Various types of batter chutes can be constructed, including:
  - flexible concrete mat chutes
  - grassed batter chutes
  - rock mattress batter chutes
  - rock-lined batter chutes
  - stepped batter chutes
  - stiff grass batter chutes
  - batter chutes formed from old car tyres.

Flexible modular concrete mat (Qld)

Flexible concrete mat chutes

- Some manufacturers of concrete products produce flexible, concrete mats that can be used to form:
  - maintenance access ramps
  - boat ramps
  - stormwater drainage chutes (batter chutes).
- Certain types of vegetation, typically grasses, can be integrated into these concrete mats.

Grassed batter chute (Qld)

Grassed batter chutes

- Grassed batted chutes are more commonly used on:
  - small dam spillways
  - stormwater drainage systems located away from riparian areas.
- It can be problematic to introduce a grassed batter chute to a creek because eventually woody trees and shrubs will establish over the grassed surface (however, this may in fact be a desired long-term outcome).

Rock mattress batter chute (Qld)

Rock mattress batter chutes

- Rock mattresses are part of the 'gabion' family.
- These rock-filled cages have dimensions of:
  - length of 6 m
  - width of 2 m
  - depth of 170, 230, 300 or 500 mm.
- A wide variety of vegetation can be introduced across the surface of these batter chutes.

Treatment of lateral bank erosion – Batter chutes

Rock-lined batter chute (Qld)

Rock-lined batter chutes

- Vegetated rock-lined batter chutes are the most common approach to the stabilisation of lateral bank erosion.
- Information on the design of rock chutes is provided in Section 12.3 of Part 2 of this field guide series.
- Information on the sizing of rock used in batter chutes is provided over the page.

Rock-lined batter chute (Qld)

Vegetated rock chute (Qld)

Stepped batter chute (Qld)

Stepped batter chutes

- The steps in a stepped batter chute can be made from:
  - rocks
  - vegetated gabions
  - treated timber (temporary).
- Selective vegetation can be integrated into these batter chutes, but this vegetation must not be allowed to divert the stormwater flow.

Stepped batter chute (Qld)

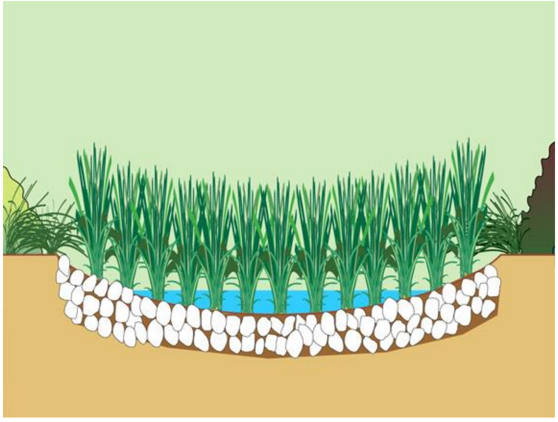
Stepped batter chute (NSW)

Treatment of lateral bank erosion – Batter chutes

Stiff grass chute currently off-line (Qld)

Stiff grass batter chutes

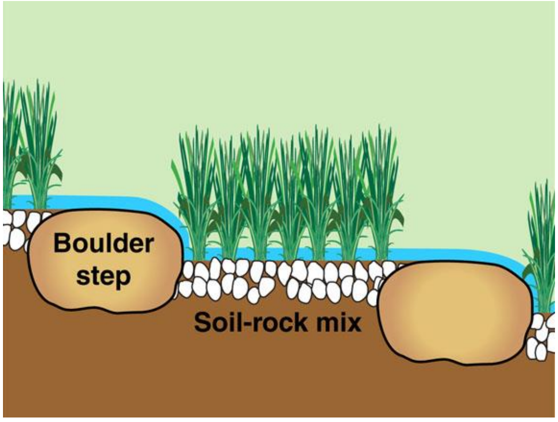
- Stiff grass batter chutes are used to:
  - filter litter and organic matter
  - carry stormwater down a creek bank.
- Stiff grass batter chutes must be formed over a stable surface, either a:
  - rock chute
  - rock mattress chute, or
  - stepped chute with soil-rock base.
- Stiff grass batter chutes must not be formed on a simple earth base.



Cross-sectional profile

Stiff grass batter chutes

- All batter chutes must have a cross-sectional profile that encourages water flow to travel down the centre of the chute, therefore:
  - the sides of the chute must be higher than the centre of the chute
  - any associated vegetation must not block or divert the flow of water.
- A simple earth base cannot be used because flows passing around the individual plants will cause soil scour.



Use of a stepped layout

Stiff grass batter chutes

- As is the case for all batter chutes, the surface of the chute must be erosion-resistant, which (again) means an unprotected earth base should not be used.
- The base of the batter chute is usually made from a soil-rock mixture that can support vegetation.
- In the case of stepped structures, the water also needs to fall onto an erosion-resistant surface.

Rock-filled car tyre batter chute (NT)

Tyre batter chutes

- Tyre chutes are formed from old car and truck tyres, which are chained together and filled with rock, or a soil-rock mix.
- The tyres cannot simply be placed freely within a gully or chute, but must be suitably anchored.
- Best results are achieved when appropriately integrated with vegetation.
- Warning; some design concepts are controlled by copyright conditions.

Sizing rock used in batter chutes

Application of equation	**Equation 17.1**
• Applicable for uniform flow conditions only, $S_e = S_o$ • Batter slopes (S_o) flatter than 50% (1 in 2)	$d_{50} = \frac{127.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$

where:

- d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]
- K_1 = correction factor for rock shape
  = 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)
- K_2 = correction factor for rock grading
  = 0.95 for poorly graded rock ($C_u = d_{60}/d_{10} < 1.5$), 1.05 for well graded rock ($C_u > 2.5$), otherwise $K_2 = 1.0$ ($1.5 < C_u < 2.5$)
- q = flow per unit width down the embankment [m^3/s/m]
- s_r = specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)
- S_e = slope of energy line [m/m]
- S_o = bed slope = tan(θ) [m/m]
- SF = factor of safety (SF = 1.2 recommended)
- y = depth of flow at a given location [m]

Table 17.1 provides mean rock size (rounded up to the next 0.1 m unit) for angular rock, and a safety factor of 1.2. This table is based on Equation 17.1. Use of the ‘unit flow rate’ (q) as the primary design variable is preferred to the use of flow velocity (V) because it avoids errors associated with the selection of Manning’s roughness.

Table 17.2 provides mean rock size for angular rock and a safety factor of 1.2, based on a modification of Equation 17.1, but with flow velocity presented as the primary variable.

Thickness and height of rock layer

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size.

Backing material or filter layer

Rock placed in batter chutes must be placed over a layer of suitably graded filter rock, or geotextile filter cloth (minimum ‘bidim A24’ or the equivalent). The geotextile filter cloth must have sufficient strength and must be suitably overlapped to withstand the placement of the rock.

If the underlying soil is dispersive (e.g. a sodic soil), then prior to placement of filter cloth, the exposed bank **must** first be covered with a layer of non-dispersive soil, typically minimum 300 mm thickness.

Table 17.1 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate (m^3/s/m)	**Bed slope = 1:10**		**Bed slope = 1:15**		**Bed slope = 1:20**		**Bed slope = 1:30**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.10	**0.10**	0.10	**0.10**	0.10	**0.05**	0.11	**0.05**
0.2	0.15	**0.10**	0.16	**0.10**	0.16	**0.10**	0.17	**0.10**
0.3	0.20	**0.20**	0.21	**0.20**	0.21	**0.10**	0.22	**0.10**
0.4	0.25	**0.20**	0.25	**0.20**	0.26	**0.20**	0.27	**0.10**
0.5	0.28	**0.20**	0.29	**0.20**	0.30	**0.20**	0.31	**0.20**
0.6	0.32	**0.30**	0.33	**0.20**	0.34	**0.20**	0.35	**0.20**
0.8	0.39	**0.30**	0.40	**0.30**	0.41	**0.20**	0.43	**0.20**
1.0	0.45	**0.30**	0.47	**0.30**	0.48	**0.30**	0.50	**0.20**
1.2	0.51	**0.40**	0.53	**0.30**	0.54	**0.30**	0.56	**0.20**
1.4	0.56	**0.40**	0.58	**0.30**	0.60	**0.30**	0.62	**0.30**
1.6	0.62	**0.40**	0.64	**0.40**	0.65	**0.30**	0.68	**0.30**
1.8	0.67	**0.50**	0.69	**0.40**	0.71	**0.30**	0.73	**0.30**
2.0	0.72	**0.50**	0.74	**0.40**	0.76	**0.40**	0.79	**0.30**
3.0	0.94	**0.60**	0.97	**0.50**	0.99	**0.50**	1.03	**0.40**
4.0	1.14	**0.80**	1.17	**0.60**	1.20	**0.60**	1.25	**0.50**
5.0	1.32	**0.90**	1.36	**0.70**	1.40	**0.60**	1.45	**0.50**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

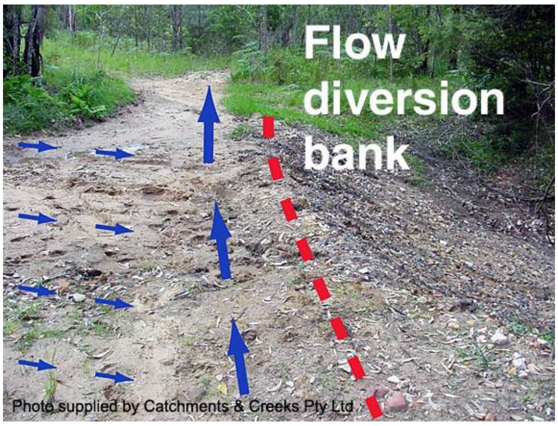
Table 17.2 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05
1.0	0.20	0.10	0.10	0.10	0.10	0.10	0.05	0.05
1.3	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.5	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.8	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
2.0	0.50	0.40	0.40	0.30	0.30	0.30	0.20	0.20
2.3	0.60	0.50	0.50	0.40	0.30	0.30	0.30	0.30
2.5	0.70	0.60	0.60	0.50	0.40	0.40	0.30	0.30
2.8	0.80	0.70	0.70	0.60	0.50	0.40	0.40	0.40
3.0	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
3.5	1.30	1.10	1.00	0.90	0.80	0.70	0.60	0.60
4.0	1.70	1.50	1.30	1.20	1.00	0.90	0.80	0.70
4.5	2.10	1.90	1.70	1.50	1.20	1.10	1.00	0.90
5.0				1.80	1.50	1.30	1.20	1.10
6.0						1.90	1.70	1.60

[1] Based on uniform flow conditions, safety factor = 1.2, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

Treatment of tunnel erosion

Tunnel erosion (Qld)



Diversion of stormwater runoff (NSW)

Entrance to a tunnel near a creek (Qld)

Outlet of a tunnel near a creek (Qld)

Introduction

- The repair of tunnel erosion is a difficult exercise, and the first approach should be:
  - to seek expert advice from a soil scientist.
- Treatment options are generally limited to:
  - excavating the tunnel, then treating the site the same as discussed for lateral bank erosion.
- Some cheaper solutions can be trialed, but long-term success is usually limited with the tunnels often reforming.

Redirection of stormwater runoff

- Possibly the cheapest solution is to collect all stormwater runoff as it moves towards the tunnel erosion, then direct this water towards a stabilised batter chute (thus bypassing the tunnel erosion).
- Stormwater runoff can be collected by using either:
  - excavated catch drain (generally <u>not</u> recommended if the land is prone to tunnel erosion)
  - forming raised flow diversion banks.

Problems associated with filling tunnels with a gypsum slurry

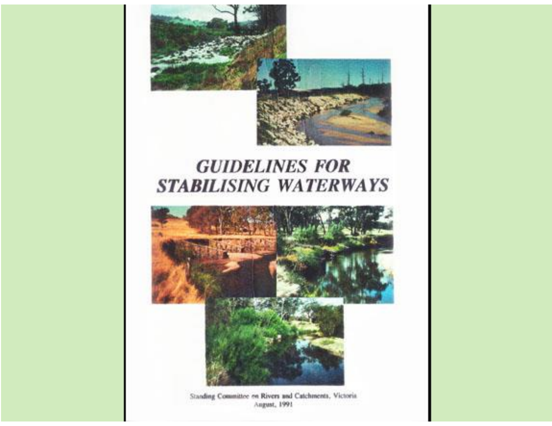
- For minor tunnel erosion, a gypsum-clay slurry can be poured down the tunnel in order to seal the tunnel; however:
  - the gypsum will only treat the soil that comes in direct contact with the slurry
  - which means the tunnel can simply reform in another direction!!!
- If the outlet of the tunnel can be found, then it can be plugged with a mix of gypsum, clay and organic matter.

Problems associated with sealing the entrance or exit of tunnels

- Attempting to 'seal' an existing tunnel is unlikely to be successful in the long-term, so the preferred option is to:
  - direct stormwater away from the tunnel
  - excavate the tunnel and then stabilise.
- If the inlet or outlet of a tunnel is sealed, then groundwater flows are likely to reactivate the tunnel erosion in another location—and the problem continues!

18. Flow Diversion Techniques

Introduction



Guidelines for Stabilising Waterways (Vic)

Log groyne (NSW)

Rock groyne (Qld)

Weed-covered sediment slug (on right)

Terminology

- The techniques discussed in this chapter are often presented in other publications under the headings:
  - Alignment training
  - River training.
- However, this chapter was titled *'Flow diversion techniques'* because these systems are not solely used to stabilise the alignment of a channel, but also to divert stream flows away from unstable banks.

Alignment training systems

- The alignment of stream flows and channels can be altered through the process of either:
  - altering the flow resistance of different parts of the channel (e.g. retard fencing)
  - constructing a flow deflection wall, or barrier (such as a rock or timber groyne)
  - introducing guide vanes of various forms, including a type of pile field.

Use of flow diversion systems

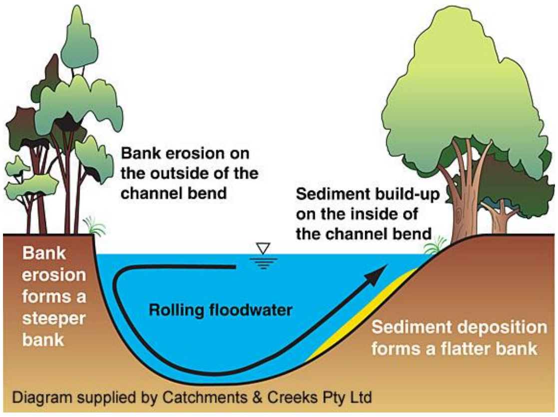
- Flow diversion systems can be used to:
  - divert flows away from an unstable creek bank
  - temporarily divert flows away from a bank revegetation project
  - slow or stop the meandering of a channel at a given location
  - guide stream flows into, or out of, a bridge or culvert opening
  - reduce the degree of sediment accretion within a given channel reach.

Using sediment control practices to control channel behaviour

- Some alignment training practices are linked to the management of bed sediment.
- These practices include:
  - channel de-silting
  - control of vegetation growth (e.g. weeds) on temporary sediment slugs.
- Discussion on the management of channel sediment is provided in Section 14.7.

Controlling water flow – Hydraulic discussion

Installation of a pile field (Qld)



Water flow at a channel bend

Concrete water supply channel (Qld)

Flow monitoring weir (Tas)

Three important lessons

- There are three important lessons that need to be considered at this point:
  1. You can 'help' water to do something it is willing to do.
  2. You can 'force' water to do something it is not willing to do.
  3. But you cannot force water to do something that it is not capable of doing.
- At first these statements may not appear important, but consider the following discussion.

'You can help water to do something it is willing to do'

- Stream flows are usually 'willing' to pass around a gradual channel bend, but the flow will want to 'roll', which means there is a certain cross-section shape that will best accommodate this type of flow.
- If you are happy to accommodate this rolling acting and channel profile, then you will be working with the stream, and you are only likely to require soft engineering measures (i.e. vegetation) in order to guide the flow around the bend.

'You can force water to do something it is unwilling to do'

- If, however, you wish to force the water to pass around a bend while restraining the flow in a rectangular channel, or to force the water to pass around a very tight channel bend, then it is likely that you will require hard engineering measures.
- Hard engineering measures are usually required if we want to restrain the flow in a particular channel shape (cross-section), or our actions are likely to cause significant turbulence within the flow.

'But you cannot force water to do something that it is not capable of doing'

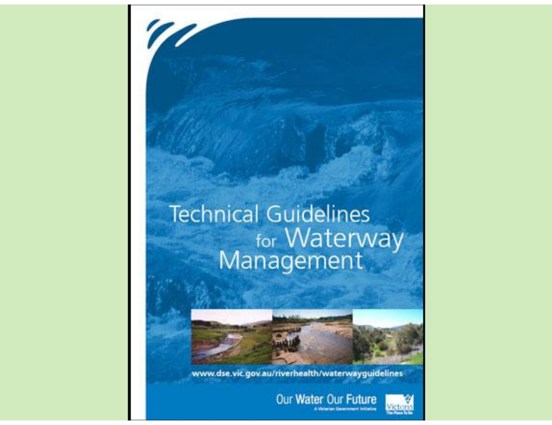
- The movement of fluids can be described by several hydraulic equations.
- These equations demonstrate that water movement is largely governed by changes between potential and kinetic energy.
- If the channel is restricted in its width, then for a given energy level, there is only so much flow that can pass through the restriction (known as a 'hydraulic choke').
- You cannot force the water to go beyond these hydraulic limits.

Acting with due care

Sedimentation around a retard fence (Qld)

Erosion around the base of a pile field

Soil erosion behind a retaining wall



Technical design guidelines (Vic)

Introduction

So what does the previous discussion have to do with the design of flow diversion and alignment training systems?

- Most of the techniques used in alignment training are considered soft engineering systems, which means these techniques should not be used to force water to do something that it does not want to do.
- This means that you really, really need to known what you are doing if you wish to implement a river training program.

River fight-back

- If waterway managers become too ambitious in their use of flow diversion techniques, or:
  - if people try to force a river to do something that it is unwilling to do, and
  - if only soft engineering techniques are used (which is normal practice), then
  - it is likely that the river will ‘fight-back’ during the next flood event, and either undermine, breach, or otherwise damage these structures—Oops!

Controlling large-scale turbulence

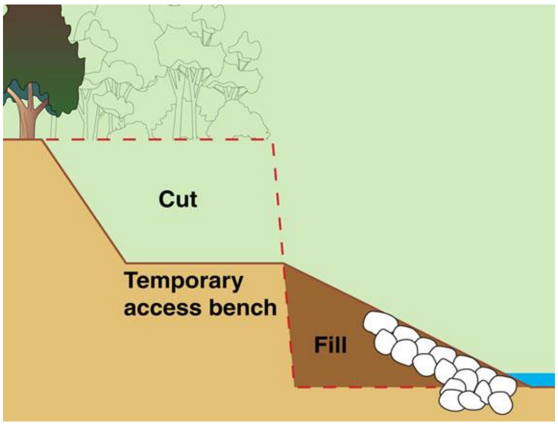
- The most common cause of hydraulic failure is the uncontrolled effects of large-scale turbulence, often generated by the abrupt edges of these flow diversion systems.
- If flow diversion systems are used to guide stream flows around a sharp bend, then there is the risk that these structures will generate large-scale turbulence that can erode the soil from around the edges of the structure—Oops!

Design guidelines

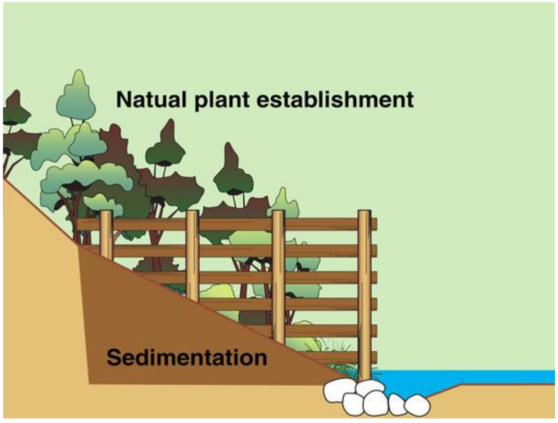
- Various technical guidelines provide details on the design of alignment training systems, including:
  - *Technical Guidelines for Waterway Management*, 2007, Department of Sustainability and Environment, Victoria
  - *Guidelines for Stabilising Waterways*, 1991, Rural Water Commission of Victoria, Published by the Standing Committee on Rivers and Catchments.

The treatment of bank erosion on the outside of channel bends

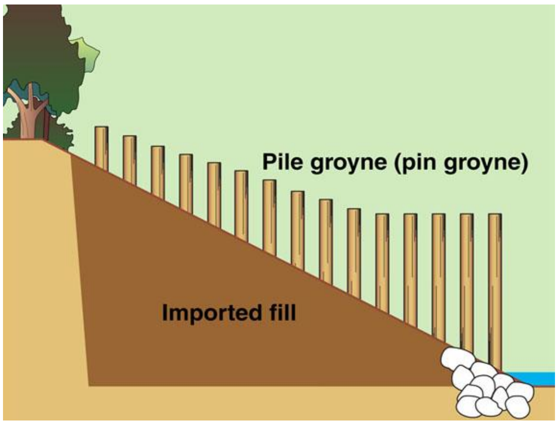
Outside of a channel bend (Qld)



Cut and fill bank stabilisation



Natural sedimentation between groynes



Pile field bank stabilisation

Outside bank of a channel bend

- It can be difficult for a creek to self-repair bank erosion if the bank is located 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 situation 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
  - try to return the bank to its pre-erosion location.
- Stabilising the bank in its current location is usually cheaper, but it can mean:
  - a loss of useable land
  - a loss of essential riparian vegetation (refer to Chapter 22, Part 4).

Stabilising a bank in its new location

- The options for stabilising a bank in its current (eroded) location include:
  - batter and stabilise the bank
  - construct timber groynes to encourage natural sedimentation and vegetation
  - construct a pile field along the bank to encourage sediment and vegetation
  - construct retard fencing to capture bed sediment, or falling bank material (bank slumping), which could ultimately form a vegetated bench.

Returning a bank to its pre-erosion state

- The options for returning a creek bank to its pre-erosion position include:
  - importing fill to extend the bank, and then stabilise with vegetated rock
  - form a new bank using imported fill, then install timber groynes
  - form a new bank using imported fill, then stabilise the toe with a pile field
  - form a new bank using imported fill, then stabilise the toe with log jams.

18.1 Groynes

Rock groyne (Qld)

Description

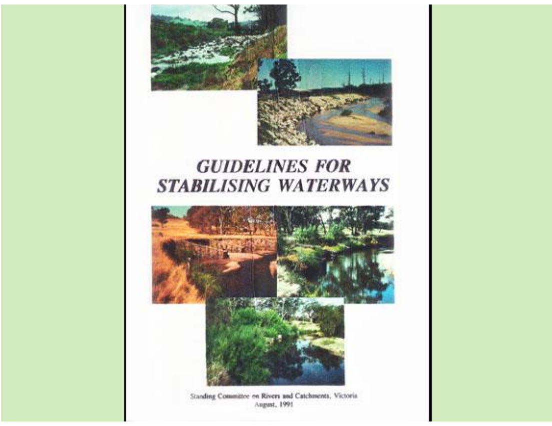
- Groynes are usually tall, finger-like structures that project from a creek bank.
- Groynes differ from 'retard fencing' by their height and purpose; however, some rock and log groynes can be relatively low structures.
- Groynes can be made from:
  - rocks
  - stiff grasses (e.g. vetiver grass)
  - timber fences
  - timber or concrete piles.

Timber groynes (Qld)

Use of rock and timber groynes

Rock groynes (Qld)


Timber 'pin groyne' (Qld)



Technical design guidelines (Vic)

Establishment of vegetation along the bank

Rock groynes

- Rock groynes are effectively impervious flow deflection structures.
- These groynes can be used to:
  - deflect flows away from the toe of an unstable or recently repaired bank
  - reduce the risk of bank erosion along the outside of a channel bend.
- Rock groynes can be left as permanent structures, but within the overall dynamics of a waterway, it is likely that all rock groynes will eventually be undermined.

Permeable timber groynes

- Timber groynes can be permeable fence-like structures, or pile field groynes (pin groynes).
- The benefits gained by allowing flow to pass through the groynes is:
  - the gradual movement of sediment into the spaces between individual groynes
  - reduce turbulence and eddy generation.
- However, over time, flood debris can reduce the permeability of these structures.

Potential erosion problems

- Potential erosion problems include:
  - scour holes at the end of the groynes
  - large-scale eddies shedding from the top of the groyne
  - outflanking of the groynes.
- Design reference material:
  - Dyer, B. 1995, *Retards and Groynes Design Guidelines*, Guidelines for Stabilising Waterways, Victoria.
  - *Guidelines for Stabilising Waterways*, Rural Water Commission of Victoria.

Establishment of vegetation between the groynes

- As with all temporary groynes, the long-term success of this process relies on the capturing of sediment, and the establishment of woody vegetation between the groynes.
- Treated timber should <u>not</u> be used to form the groynes (as these timbers can, over time, release undesirable chemicals into the waterway); instead, the groynes should be allowed to decay naturally.

18.2 Log Jams

Log jam (Qld)

Description

- A log jam is a three-dimensional grouping of logs, as compared to a traditional log groyne.
- Log jams can perform several tasks, including:
  - deflect stream flows away from a bank
  - provide fauna habitat
  - add to the overall hydraulic roughness of the waterway, thus reducing upstream flow velocities, which may increase opportunities to reintroduce woody vegetation to the waterway.

Log jam – looking upstream (Qld)

Use of log jams

A series of log jams (Qld)

A series of log jams (Qld)

Lizard enjoying the Queensland sun

Part of the anchorage system (Qld)

Flow diversion systems

- Hydraulically, log jams are very similar to rock and timber groynes.
- Log jams can be placed at regular intervals around the outside of a channel bend to deflect (push) flood water away from the outer bank.
- When used in this manner, the following outcomes are likely:
  - sedimentation between the log jams
  - increased bed erosion towards the centre of the channel.

Hydraulic influence of log jams

- Like most of the alignment training systems, log jams add to the hydraulic roughness of a waterway, which means if multiple log jams are deployed along a waterway, the outcome should be a general reduction in upstream flow velocities.
- In the right circumstances, this could encourage (over many years) a natural increase in woody riparian vegetation along the waterway due to the improved flow conditions.

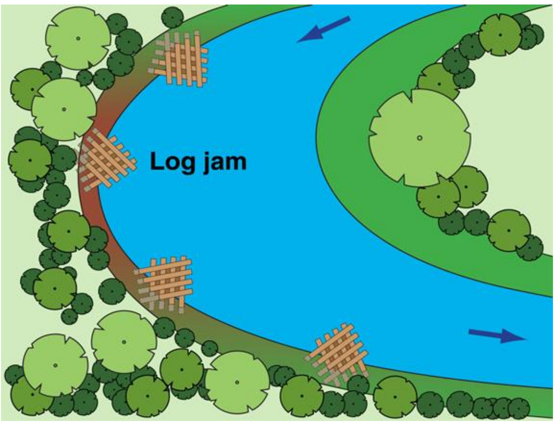
Benefits to fauna habitat

- The more bulky, three-dimensional nature of log jams, means there is an increase in the habitat potential <u>inside</u> the log jams.
- Log jams also:
  - help in the formation of small pools at the ends of the log jams
  - provide basking opportunities for fauna
  - provide an additional food source by increasing the wetted surface area.
- However, these are ‘temporary’ structures.

Anchorage of log jams

- Individual logs are strapped together with strong wire ties, and anchored in place with timber piles.
- The logs are usually locally obtained, which means the felling of the trees may also provide a good source of brushwood, which can be used to:
  - fill the inside of the log jam
  - form brushwood bank protection (brushing) adjacent to the log jams (refer to Section 14.3).

Log jams – Potential hydraulic problems



Typical placement of log jams

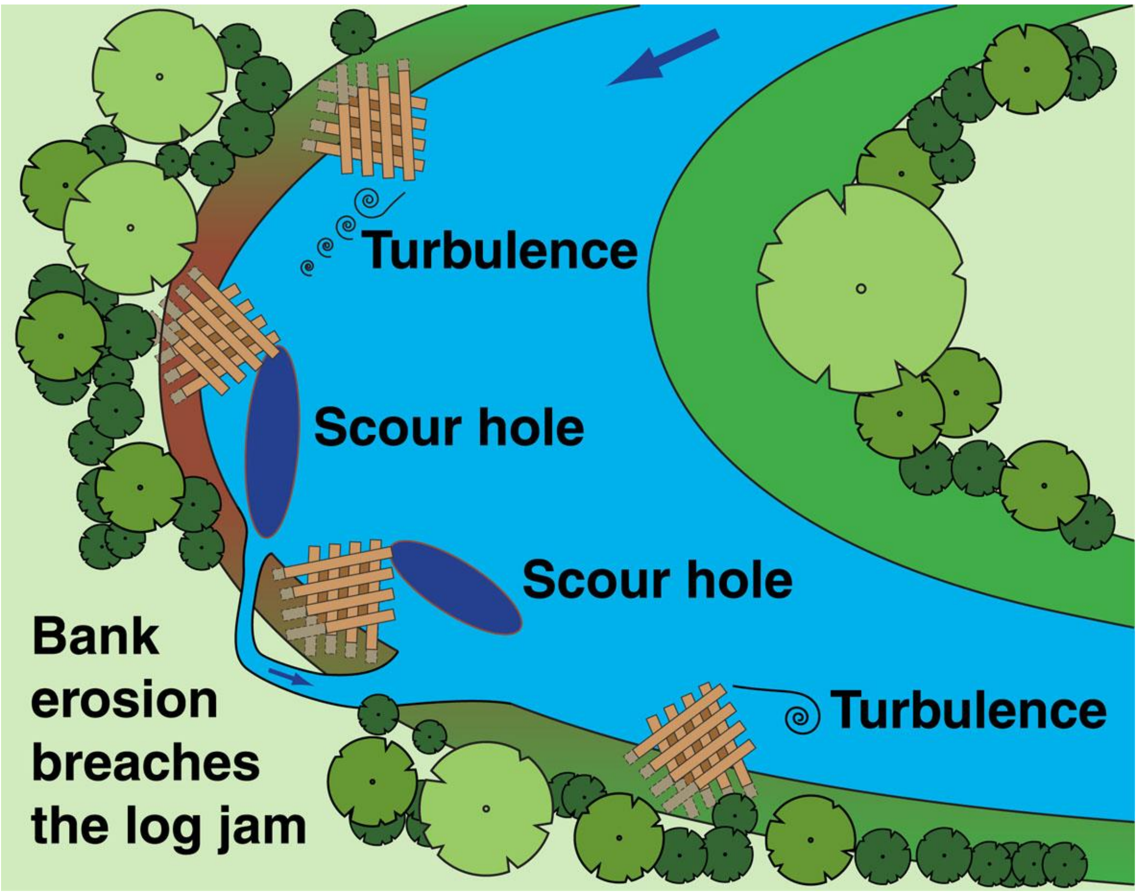
Scour hole downstream of log jam (Qld)

Potential erosion problems

- The placement of log jams around the outside of a channel bend is best determined through the use of:
  - a survey plan
  - aerial photography.
- Potential erosion problems include:
  - scour holes undermining the log jams
  - eddies generated by the log jams, which could move downstream causing bank erosion, which could potentially pass behind (outflank) the log jams.

Localised bed erosion

- The scour holes formed immediately downstream of the log jams are similar to those formed adjacent traditional groynes.
- The size and depth of these scour holes depends on the make-up of the creek bed (i.e. sand or gravel, and the size of gravel).
- These scour holes are not an indication of hydraulic failure, and in fact are usually part of the added habitat benefits provided by the log jams.



Potential bed and bank erosion issues adjacent to log jams placed on channel bends

18.3 Pile Fields

Pile field groyne (NSW)

Description

- A pile field is a collection of piles (usually timber) set out in a two-dimensional grid.
- Some guidelines also use the term to refer to groynes and flow diversion vanes that are formed from piles.
- Pile fields can be used to:
  - control the rate of bed scour
  - stabilise the toe of a bank
  - reduce the risk of channel relocation
  - promote sedimentation in certain areas of a wide channel.

Pile field used to stop flows cutting a new channel through a low bench (Qld)

Use of pile fields

Toe protection (NSW)

Toe protection

- Piles can be used to form toe protection, which is used to reduce the risk of soil scour along the lower regions of a creek bank (refer to Section 14.8).
- Toe protection also helps to keep the low-flow channel away from the bank.
- The use of piles to form toe protection can provide good fauna habitat values.
- Flood debris can collect around the piles, causing the piles to act like a form of retard fencing.

Pile groynes (Vic)

Flow diversion groynes

- Piles can be used to form permeable groynes and roughness units (unlike log jams).
- The benefit gained by allowing water to pass through the groynes is the gradual movement of sediment into the spaces between individual groynes.
- As with all temporary groynes, the process relies on the long-term establishment of woody vegetation between the groynes.
- These are also known as ‘pin groynes’.

Pile field bed control structure (Vic)

Stabilisation of bed scour

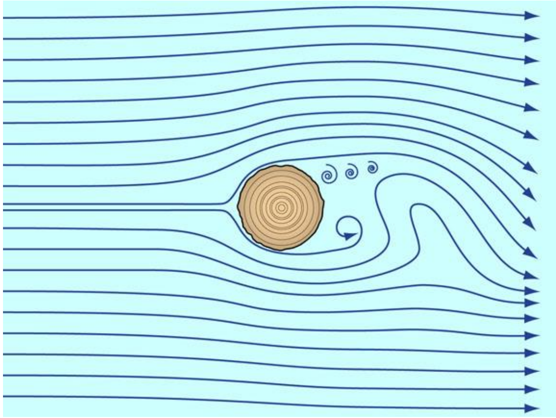
- Pile fields can be used as grade control structures that reduce the rate of creek bed lowering.
- The benefits of a pile field include:
  - allows the ongoing migration of some bed material (sand and gravel)
  - allows fish passage
  - can be used to reduce flood flows cutting through a bench.
- For further discussion, refer to Section 12.8 in Part 2 of this field guide.

Pile field flow control vanes (Qld)

Flow control vanes

- Piles can be used to form flow control vanes that help to direct flood flows:
  - around a sharp bend
  - into, or out of, a bridge or culvert.
- Flow control vanes are different from groynes because they more closely align with the desired direction of flow.
- Treated timber should <u>not</u> be used to form the groynes as these timbers can, over time, release undesirable chemicals into the waterway.

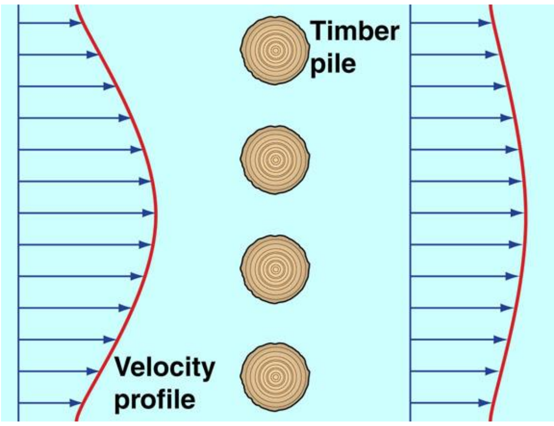
Understanding the hydraulic properties of pile fields



Flow passing an isolated timber pile

The hydraulics of water passing around an isolated object

- Like any 'bluff' body, a pile causes turbulence and energy loss as water passes around the pile.
- These smaller eddies can cause soil loss around the base of the pile.
- There are minor differences between the hydraulics of 'round' timber piles and 'square' concrete piles, but these differences are not important in regards to the overall hydraulic effect.



Flow passing through a row of piles

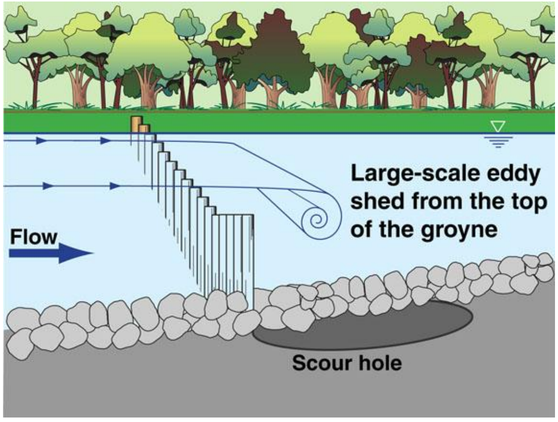
Flow passing through a pile field

- The hydraulic benefits of a porous groyne or pile field include:
  - allows the movement of bed sediments
  - helps to produce more uniform flow velocities downstream of the groyne.
- The higher the velocity of flow approaching an individual pile, the greater the energy loss that occurs around that pile, this means a pile field helps to 'dampen' variations in flow velocity, but only for flow passing through the piles.

Exposed tree roots (Qld)

Nature's pile field

- Hydraulically, pile fields act like:
  - exposed tree roots (which help to protect creek banks), or
  - a floodplain filled with trees.
- Just like a pile field, exposed tree roots can:
  - divert stream flows away from a bank
  - reduce the velocity of flows that pass through the roots
  - capture flood debris.



Generation of a large-scale eddy

The generation of large-scale eddies

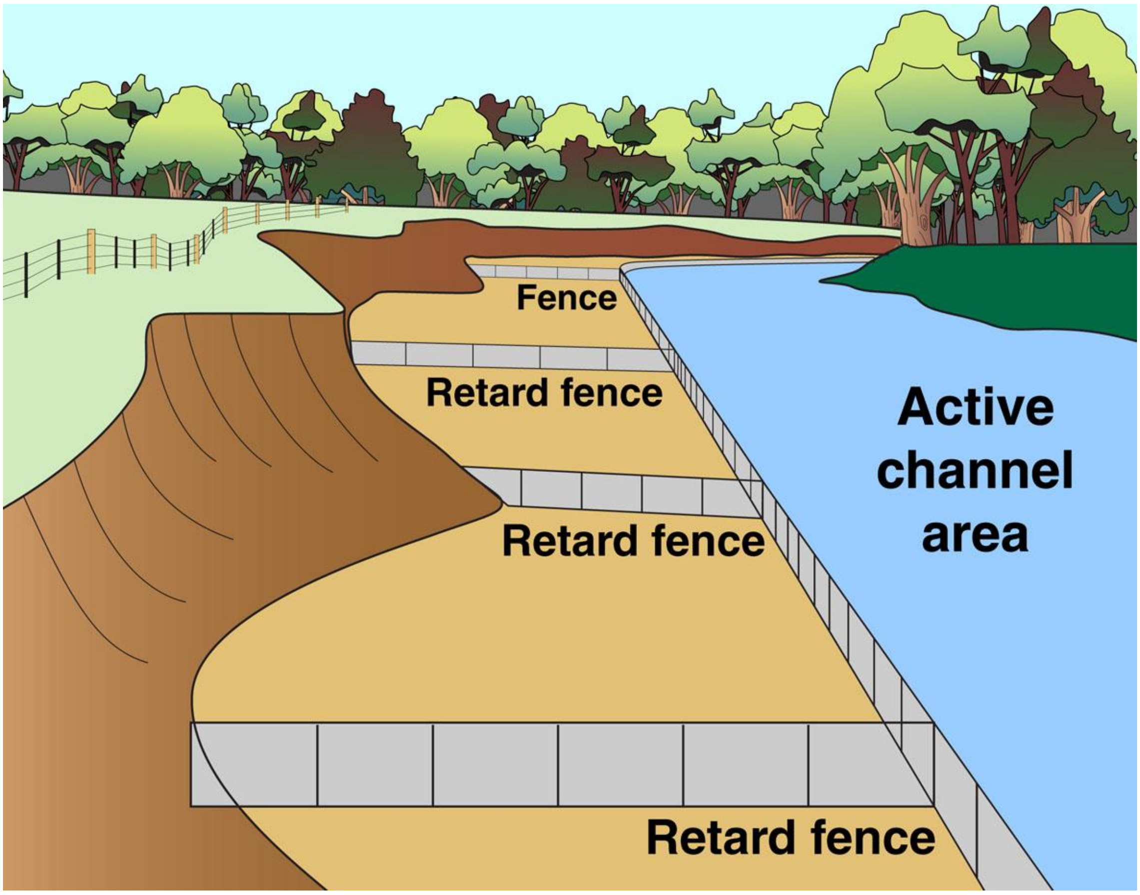
- The use and alignment of pile fields should only be designed by people experienced in 3-dimensional hydraulics.
- Large-scale eddies can form as floodwater passes around the end of a groyne, or over the top edge of a groyne.
- These eddies can migrate downstream of the groynes causing significant bed or bank erosion.
- Similar eddies can be generated from the top edge of rock or timber groynes.

18.4 Retard Fencing

Retard fencing used as toe protection (Qld)

Description

- Retard fencing incorporates a variety of low-height structures that are used to increase flow resistance in certain areas of a channel, or floodplain, for the purpose of:
  - encouraging sedimentation to occur in those locations (possibly to act as toe protection along the outside bank of a channel bend), or
  - reducing flow velocities in order to protect newly established vegetation.



Retard fencing

Use of retard fencing

Retard fencing (Vic)

Traditional use of retard fencing

- Retard fencing has traditionally been used to retard flood flows in wide, sand-based waterways, for the purpose of encouraging sedimentation within the fenced areas.
- This can only occur in waterways that have a significant natural sand-based sediment flow, which means the system is unlikely to work in small creeks, or clay-based waterways.
- These light fences are likely to be severely damaged in gravel-based waterways.

Retard fencing at the base of a bank slump

Toe protection adjacent to active bank erosion

- When installed at the base of an active bank slump, the fencing can be used to help retain slumped earth, forming a bench (refer to Chapter 22 in Part 4).
- Over time, new fences are built on top of old benches, slowly raising and stabilising the toe of the creek bank.
- This process can be adopted on farmland where bank repairs are often conducted in stages over a period of years.

Geo log used to protect new plants (Qld)

Protection of newly established overbank vegetation

- Permeable and non-permeable retard fencing, as well as geo logs, can be used to temporarily slow overbank flow velocities, thus protecting newly established vegetation from flood damage.
- Using a system of permeable fences allows flood debris to be captured by the fences, which means overbank flow velocities will gradually reduce as the flood progresses.

Overbank, timber, retard fence (Qld)

Sediment fence retard fencing (Qld)

19. Using Plants in the Management of Creek Erosion

Introduction

Creek with healthy riparian zone (Qld)

Riparian zone (Qld)

Vegetated gabion wall (Qld)

Creek in an arid environment (NSW)

Creeks and rivers

- The focus of this field guide has been on the management of creek erosion.
- Creeks and rivers share many properties, but what makes creek erosion different from river erosion is the increased importance of plants.
- In general, it is the river hydraulics that dominates over the river vegetation.
- However, with the exception of arid regions, it is the vegetation that usually dominates over the hydraulics of creeks.

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
  - fauna habitat, shelter and food
  - or an association between the plant's life cycle and flood events.

Integrating vegetation into hard engineering treatment options

- The use of hard engineering measures in the treatment of creek erosion 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 helps these areas to achieve many of the essential functions commonly associated with riparian zones.

The types of creeks where riparian vegetation may play less of a role

- The importance of riparian vegetation varies according to the type of waterway.
- In dry, arid, and semi-arid climates, vegetation density along creeks can be significantly reduced, which means a new balance must be achieved between the water, soil, rocks and plants.
- However, this does not mean that arid plants don't play an important role in providing many of the values commonly associated with riparian zones.

How plants control soil erosion

Exposed tree roots (Qld)

A common myth

- It has been written many times that *'tree roots bind the soil together preventing it from being washed away'*, but this is only a half-truth.
- Tree roots are an anchoring system, which helps in the control of bank slumping.
- However, tree roots do not provide much benefit to the control of soil scour, which is an important component of two forms of bank erosion: bank scour and bank undercutting.

Native groundcover (Qld)

Plants that control raindrop impact erosion

- Raindrop impact erosion is important because it can wash clay into waterways, and turn floodwater 'brown'.
- Raindrop impact can be controlled by both living and non-living groundcover, including grasses, leaf litter, organic mulches, and rock mulches.
- Tree foliage can intercept raindrops and reduce their impact energy, but water drops falling from tall trees can still cause significant soil erosion.

Dense upper storey tree cover (NSW)

Plants that control bank slumping

- Deep-rooted plants, such as trees and shrubs, are the best plants for the control of the various forms of mass movement erosion, such as bank slumping.
- The steeper the bank slope, or the higher the creek bank, the greater the need for a continuous, interlocking root system.
- On steep creek banks, middle storey plants can help to cross-link the root systems of the more spatial upper storey plants.

Lomandra in high-velocity flow (Qld)

Plants that control bed and bank scour

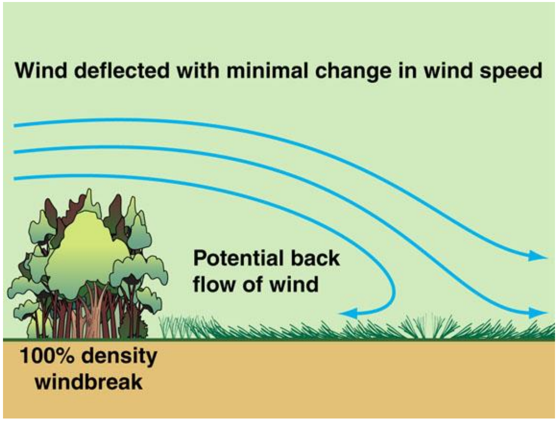
- Soil scour is the type of erosion caused by the direct contact between high-velocity flows and soil surfaces.
- It is the leafy matter above the soil that helps to build a hydraulic boundary layer, which in-turn protects the underlying soil.
- The plants with the greatest ability to control soil scour are flexible, leafy groundcovers, such as most grasses.
- In deep water, certain woody plants can also help to slow flow velocities, and thus help to control soil scour.

Understanding how leafy plants can reduce local flow velocities

The hydraulic effects of flooded *Lomandra*

Introduction

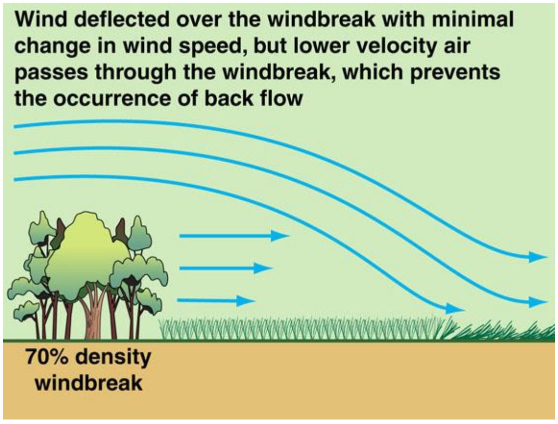
- All plants can help to reduce flow velocities, but different plants achieve this outcome in different ways.
- Woody plants, such as shrubs and trees, provide a resistance to the movement of flood flows, which slows the stream velocity upstream of the plants.
- However, leafy plants, such as stiff grasses, extract energy from the water, which slows the flow velocity at the plant, and immediately downstream of the plant.



Air flow for a 100% windbreak

Using the mechanics of air flow to better understanding water flow

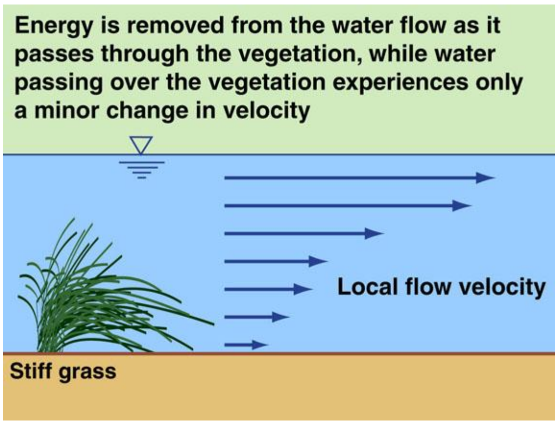
- One way to understand the impact that plants have on water flow is to study how plants interact with air flow (which also behaves like a 'fluid').
- If you were to build a windbreak with densely packed vegetation, then the wind would not pass through the windbreak, but would only pass over it.
- In this case, there will be no real reduction in wind speed, just the 'shadow' effects.



Air flow for a 70% windbreak

Understanding the effects of a porous windbreak

- If the windbreak is slightly porous, then some air flow will pass through the trees.
- Only when air passes through the trees can energy be extracted from the air flow, which results in a reduction in air speed.
- The air that passes through the windbreak fills the air space immediately downwind of the trees, and this air flow also helps to prevent any back flow of high velocity air passing over the windbreak.



Reducion in velocity around stiff grasses

Understanding how stiff grasses can extract energy from flowing water

- In water flow, shrubs have a tendency to act like impervious windbreaks, and as a result they tend to deflect water flow around the individual shrubs, which can cause significant turbulence.
- In deep water, stiff grasses act like porous windbreaks, which means they can extract energy from the water, and thereby reduce local flow velocities.
- However, in shallow water, stiff grasses may simply deflect the passing water flow.

Different plants play different roles in helping to control erosion

Lomandra plant with fibrous root system

Introduction

- Plants help to control creek erosion in two ways:
  - their root system can help to anchor the soil, which is important during floods, and in the days following a flood (thus controlling bank slumping), and
  - the leafy and woody matter above the ground can help to slow flow velocities, which reduces the erosion potential along the waterway (thus controlling soil scour).

Groundcover plants (NSW)

Groundcovers (lower storey plants)

- Groundcovers can consist of living plants and discarded leaf litter.
- It is the groundcovers, such as the various native grasses and vines, that slow flow velocities close to the ground, and help to prevent soil scour during floods.
- What primarily stops soil scour is <u>not</u> the root system, but the leafy matter that stands above the soil.
- This leafy matter also helps to build a hydraulic boundary layer over the ground.

Riparian shrubs (Qld)

Shrubs (middle storey plants)

- Shrubs and other middle storey plants are the undervalued plants of our waterways.
- Shrubs can contribute significant hydraulic roughness to a creek (which can increase flood levels), but this roughness can also be used to push stream flows away from unstable creek banks.
- The species that are best suited to riparian areas are those that have the ability to bend with the flows, and then quickly recover or regenerate after a flood.

Trees without mid-storey plants (SA)

Trees (upper storey or canopy storey)

- Trees are often credited for doing a lot of the erosion control work that is actually performed by shrubs and groundcovers.
- Trees are the main soil anchors, they are the plants that allow our waterways to have steep and high banks.
- The right trees, planted in the right place, at the right density, can be a very powerful force in creek engineering.
- Another important attribute of trees is their shading ability, which benefits weed control and water temperatures.

Different plants play different roles in helping to control erosion

Trees with low branches (SA)

Trees with low branches

- The low branches on trees can behave like shrubs.
- They can benefit erosion control measures by slowing the overall channel velocity **upstream** of the tree.
- The trees that are best suited to riparian areas are those that have lower branches that can bend with the flow (i.e. flexible timber).

Trees with high branches (Qld)

Trees with only high branches

- The following table appears to suggest that trees with high branches do not contribute much to erosion control, BUT this table refers only to the relative importance of the tree's branches.
- All trees can contribute to the control of creek erosion as a result of:
  - their root system
  - the hydraulic roughness generated by their truck (and any low branches).

Erosion type	Ground covers		Shrubs	Trees		
	Mat forming	Stiff grasses		Tree roots	Low branches	High branches
Bank scour	Yes	In deep water	Possible	Rare	Possible	Can help slow overall flow velocities
Outside of bends	Can cause problems	In deep water	Preferred	Rare	Possible	No
Bank slumping	No	No	Assists	Yes	No	No
Bank undercutting	Lower bank	Lower bank	Assists	Some species	Possible	No
Soil dispersion	No	No	No	No	No	No
Fretting (wave action)	Yes	Yes	Some species	Some species	No	No
Bed scour	Aquatic plants	Aquatic plants	No	No	No	No
Lateral bank erosion	Possible	Can cause problems	No	Rare	No	No

The relative importance of different types of plants in controlling creek erosion

The ‘right’ plant in the ‘right’ location

Site revegetation (Qld)

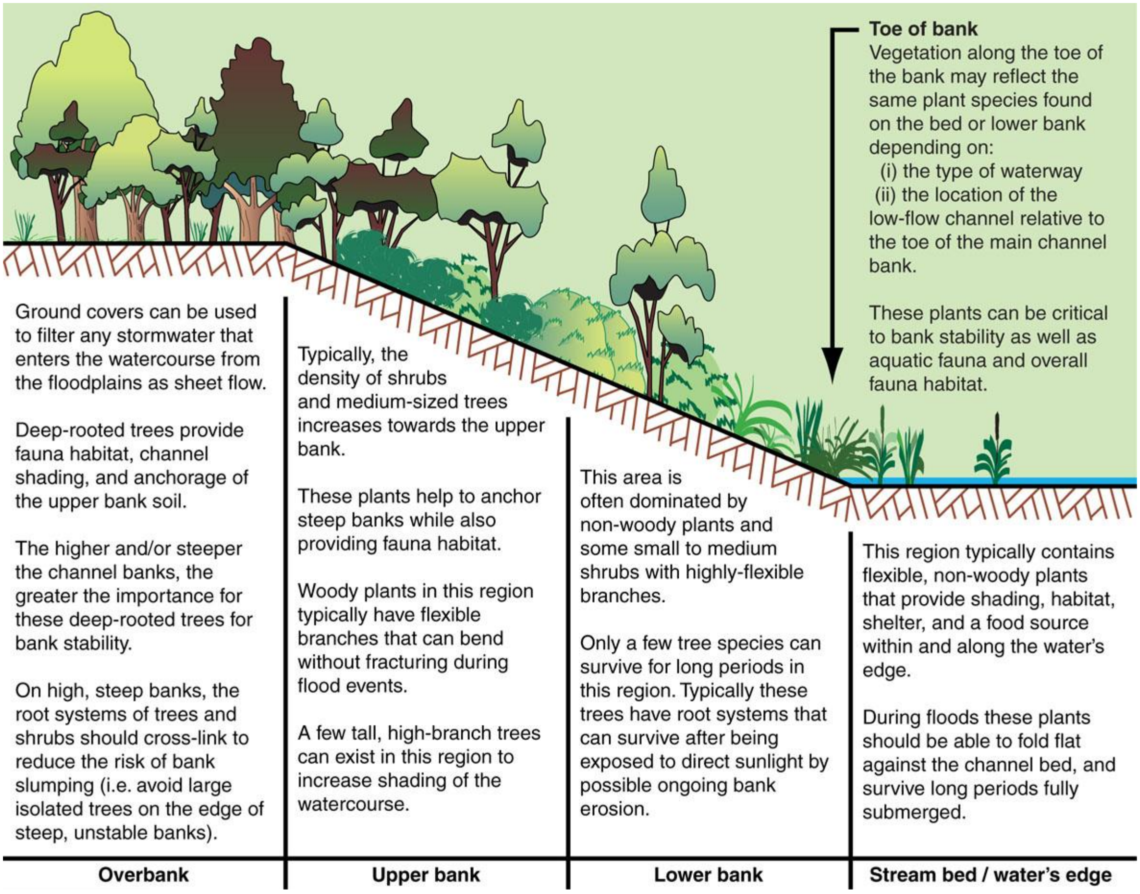
Site revegetation (Qld)

Introduction

- Creek rehabilitation is not a case of simply delivering a truck-load of native plants to a site, then planting them randomly over the disturbed ground.
- Plants play an important role in the stability and everyday functioning of our creeks.
- In order to perform these tasks, the right plant needs to be planted in the right location, which means following a plan, or ensuring that the revegetation is supervised by a suitably trained person.

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 species.
- Plant 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.



Desirable characteristics of riparian vegetation

The ‘right’ plant in the ‘right’ location

Water’s edge (Qld)

***Lomandra* experiencing a minor flood**

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 the bank
  - providing a food source for aquatic fauna
  - providing favourable fish passage conditions during flood events.

Lomandra (mat rush)

- *Lomandra* is possibly the most important erosion control plant in Eastern Australia, but many would suggest it is also one of the most over-used plants.
- *Lomandra* is most effective when flood waters overtop the plant (i.e. when located within the lower bank region)—they are <u>not</u> suited to high-velocity, shallow water conditions, such as dam spillways.

Erosion type	Ground covers		Shrubs	Trees		
	Mat forming	Stiff grasses		Grouped or Multi-trunk	Trees with low branches	Trees with only high branches
Water’s edge	Possible	Yes	Yes	Rare	Rare	Rare
Lower bank	Yes	Yes	Yes	Rare	Rare	Rare
Upper bank	Yes	Yes	Yes	Possible	Possible	Possible
Overbank (riparian)	Yes	Yes	Yes	Yes	Yes	Yes
Outside of bends	Can cause problems	Yes	Preferred	Possible	Possible	Can cause problems
Inside of bends	Yes	Yes	Yes	Yes	Yes	Yes
Flood control areas	Yes	Yes	No	No	Rare	Yes
Floodways (high velocity floodplains)	Yes	No	No	No	No	Rare

The relative importance of plant <u>location</u> on the selection of preferred plant species

The ‘right’ plant in the ‘right’ location

Upper bank region (Qld)

Flood-damaged shrubs (Qld)

The difference between upper bank and lower bank plants

- Any plant can seed and germinate at almost any location, but it is the long-term survival of these plants that determines their suitability.
- The fact that some species are listed for use in the lower bank region does <u>not</u> necessarily mean that such plants should never appear in the upper bank, or overbank regions.
- Planting zones are just an indication of where certain plants will dominate.

Flexible timbers

- For species located within the lower bank areas, you should be able to bend their branches without the branches breaking (within reason).
- A ‘simple’ rule is:
  - *If the branches point to the sky, then put them up high, if the branches point to the water, then put them near the water.*
- A better rule is to simply follow the advice of creek rehabilitation experts!

Overbank	Upper bank	Lower bank	Stream bed
Upper canopy Flooded Gum *Eucalyptus salignus* Large-leaved Grey Gum *Eucalyptus major* Hoop Pine *Araucaria cunninghamii* Pepperberry *Cryptocarya obovatus* Blackbutt *Eucalyptus pilularis* Brisbane Blue Gum *Eucalyptus tereticornis* Three Veined Laurel *Cryptocarya triplinervis*	Spotted Gum *Corymbia citriodora* Tallowwood *Eucalyptus microcorys* Swamp Box *Lophostomen suaveolens* Blue Quandong *Elaeocarpis grandis* Smell-of-the-bush *Mallotus claoxyloides*	Waterhousea *Syzygium floribundum* Black Bean *Castanospermun australe* Cheese tree *Glochidion ferdinandi* River She Oak *casuarina cunninghamiana*	
Middle storey *Alectryon tomentosus* *Drypetes deplanchei* White Bottlebrush *Callistemon salignus* Hairy Lollybush Native Quince *Guioa semiglauca* Soap Tree *Alphitonia exelsa* Red Kamala *Mallotus philippens* Native Olive *Notelaea longifolia* White Tamarind *Elattostachys xylocarpa* Flint Wood *Scolopia braunii*		Creek Bottlebrush *Callistemon viminalis* Chewing-gum Bush *Backhousia myrtifolia* Brown Myrtle *Choricarpia leptopetala* Native Guava *Rhodomyrtus psidioides* Ferns & brackens	
	Sedges and groundcovers	Bolwarra *Eupomatia laurina* Creek Matrush *Lomandra hystrix*	*Carex* *Juncus* *Ghania spp.* *Crinum pedunculatum* *Cyperus exaltatus* *Persicaria spp.*

Example of riparian species for the Brisbane region (extracted from a SOWN guideline)

Vegetation strength

Straight channel with mild bed slope

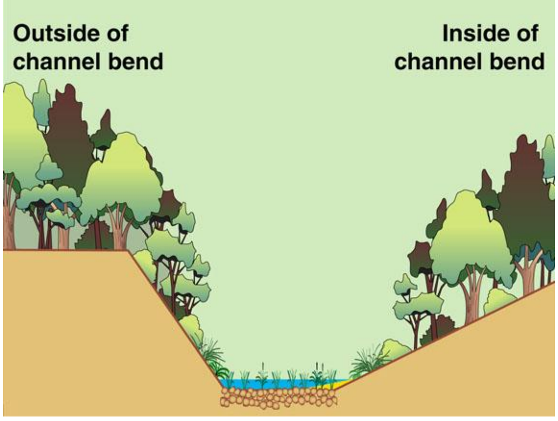
Straight channel with mild bed slope

- In the control of creek erosion, the soil, rock and vegetation that make up the bed and banks, all work together to control the erosive effects of the flowing water.
- As a <u>general</u> guide, along a low gradient, straight channel reach, it is preferable that the overall scour resistance of the banks is greater than the scour resistance of the bed.
- If strong, tough reeds begin to invade the creek bed, then this can initiate bank erosion.

Straight channel with steep bed slope

Straight channel with steep bed slope

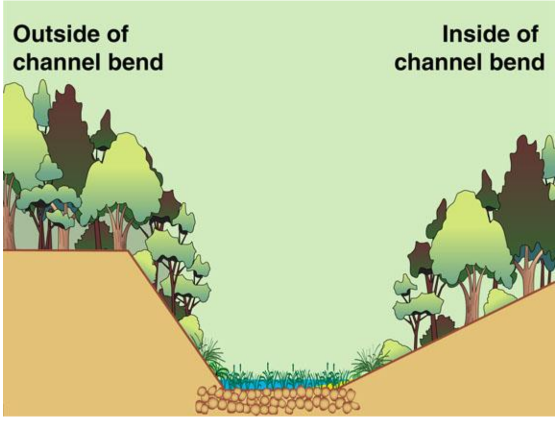
- If, however, the creek is steep, then there is the need for increased shear strength along the bed of the creek.
- Often this increased shear strength is provided by exposed bedrock.
- If significant bedrock is not present, then increasing the vegetation density on the banks (and thus the scour resistance of these banks) can increase the risk of bed erosion—which is a problem!



Channel bend with mild bed slope

Channel bend with mild bed slope

- On channel bends, it is usual for the outside bank to be steeper than the inside bank.
- In <u>some</u> cases, the increased gradient of the outside bank can cause a reduction in vegetation density, which could result in a reduction in its scour resistance.
- In general, the overall scour resistance of the outside bank should be greater than the inside bank, which usually means trying to maintain a higher vegetation density on the outside bank.



Channel bend with steep bed slope

Channel bend with steep bed slope

- Once again, if the channel is steep, then there is the need to maintain good shear strength along the bed of the creek.
- If significant bedrock is not present, then:
  - the overall scour resistance of the bed should be greater than the banks, and
  - the outside bank should be stronger than the inside bank.
- Always consider the potential effect a bank rehabilitation program may have on the bed of the creek.

Planting in response to bank scour

Bank scour (Qld)

Introduction

- Bank scour is the direct result of high-velocity flows damaging bank vegetation and exposing the underlying soil to erosion.
- This type of erosion is common:
  - in the lower levels of creek banks
  - on the outside of channel bends.

Vegetated rock stabilisation (Qld)

Vegetated rock

- The most common treatment of bank scour is the placement of rock along the lower bank.
- If this rock is left without appropriate vegetation cover, then the high velocity flows will once again be attracted to the creek bank, resulting in further bank scour immediately downstream of the rock.
- Wherever possible, rock-lined creek banks should be fully vegetated at the time of rock placement.

Shrubby creek bank (Qld)

Bank scour on the outside of a channel bend

- Rock placement is common on the outside of channel bends, but if flow velocities are not excessive, then a fully vegetated treatment can be applied.
- Two types of vegetated solutions exist:
  - planting with flexible-timber shrubs (which aims to push high-velocity floodwater away from the bank)
  - planting a near-monoculture of stiff grasses (e.g. *Lomandra*) along the lower bank.

Monoculture of *Lomandra* (Qld)

Dense planting of stiff grasses

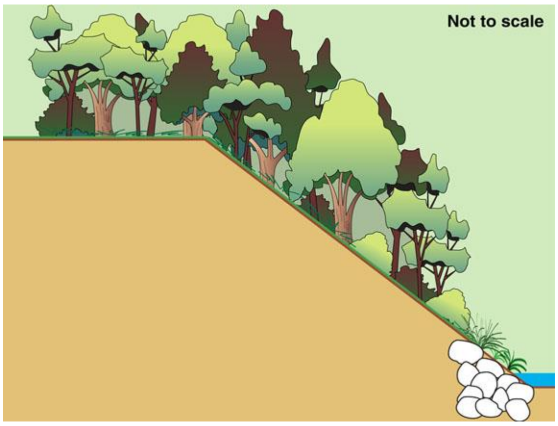
- Normal mat-forming grasses can perform well in high-velocity stormwater channels, but such planting schemes generate very shallow boundary layer conditions, which harms fish passage, and can cause erosion at the base of trees and shrubs.
- Stiff grasses, like *Lomandra*, can be very effective as a monoculture in high-velocity channels.
- Stiff grasses, such as *Vetiver* grass, must be used with extreme caution in creeks as these plants can redirect flows.

Planting in response to bank slumping

Bank slump (Qld)

Introduction

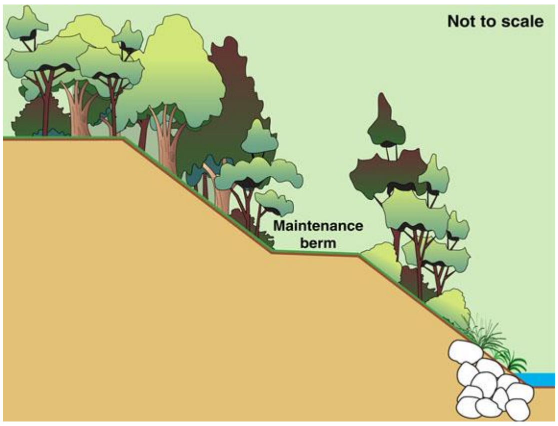
- Bank slumping is a form of 'mass movement', where the creek bank either:
  - slides as a shallow layer of soil, possibly 1 to 2 m deep, down the bank, usually with vegetation still attached, or
  - rotates as a deep 'slipe-circle' type bank failure.
- Bank slumping is most common during the final stages of a flood, and during the days that follow a flood, while the creek banks are heavy with saturated groundwater.



Bank revegetation

Bank reshaping and revegetation

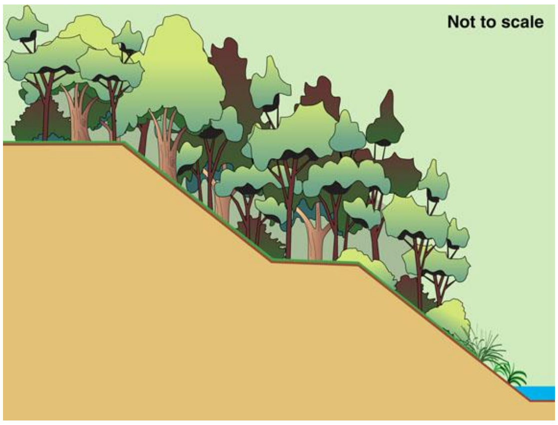
- Bank slumping often occurs when the creek banks are cleared of deep-rooted plants, and covered only in grasses.
- Treatment of a bank slump usually involves reshaping the slumped bank to form a new bank slope, then applying appropriate vegetation.
- It is typical for plants in the lower bank region to be different from the species that dominate the upper bank area.



Benching a creek bank

Benching and revegetation

- The bank treatment can involve the reshaping of the bank to form a bench, then applying appropriate vegetation.
- Benching the bank:
  - increases the bank stability
  - reduces the risk of a major bank slump if bank undercutting continues to occur.
- The bench can be used for:
  - pedestrian access
  - maintenance access.



Fully-vegetated, benched creek bank

Fully planting the bench

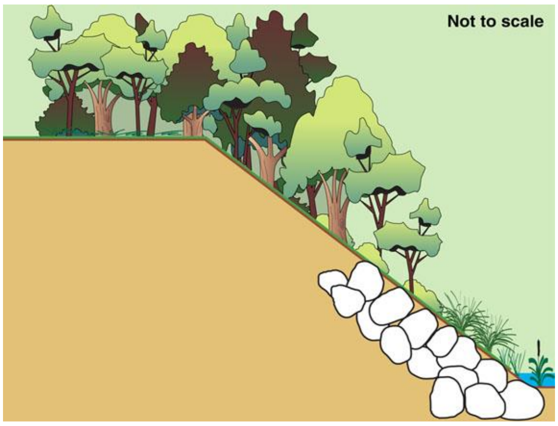
- If the risk of bank slumping remains high, then the bench can be fully planted.
- Planting the bench:
  - increases the bank stability
  - increases the interlocking of tree roots
  - reduces lateral light intrusion into the riparian zone
  - reduces the risk of weed invasion.

Planting in response to bank undercutting

Bank undercutting (Qld)

Introduction

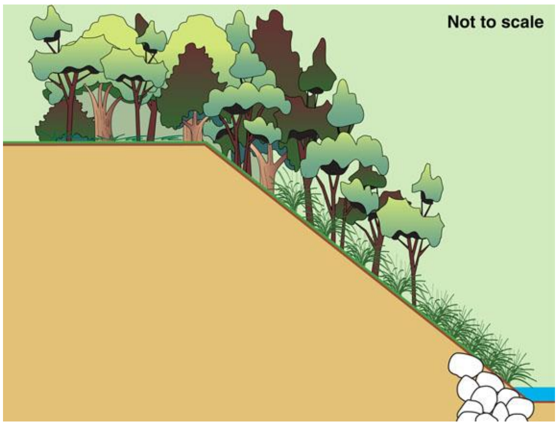
- Bank undercutting is the result of bank scour that has concentrated its effects on the lower bank region.
- Initially the upper bank cantilevers over the lower bank, but eventually the unstable upper bank collapses (slumps), and the fully-exposed bank takes on the appearance of a typical bank slump.
- Tree roots are often exposed by bank erosion.



Vegetated rock stabilisation

Vegetated rock

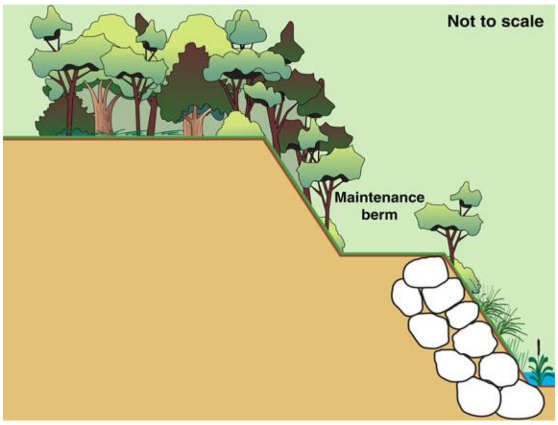
- The most common treatment of bank undercutting is the placement of rock on the affected lower bank region.
- The upper bank is battered back at an appropriate gradient depending on whether the bank is on the inside or outside of a channel bend.



Monoculture lower bank planting

Variations in upper and lower bank species

- The upper bank area should be planted with deep-rooted species.
- Trees planted near the lower bank should have root systems that can withstand partial exposure of their root system.
- All plants placed near the lower bank region should have flexible branches.
- Stiff grasses, such as *Lomandra*, work well in the lower bank area.



Benching of a creek bank

Benefits of benching in the control of bank undercutting

- If ongoing toe erosion and/or undercutting is expected, then benching the bank can provide the following benefits:
  - increased bank stability
  - reduced risk of a major bank slump
  - delayed disturbance/erosion of the upper bank area, which allows a longer establishment period for new vegetation.

Planting in response to lateral bank erosion

Lateral bank erosion (SA)

Lateral bank erosion

- Lateral bank erosion is a form of bank erosion that usually results from the unnatural concentration of stormwater runoff, and the effects of this runoff spilling down unstable banks.
- Even though it is classified as a form of bank erosion, it demonstrates many of the features of bed erosion.
- The treatment of lateral bank erosion is closely linked to the treatment of gully erosion and dispersive soils.

Partially-vegetated batter chute (Qld)

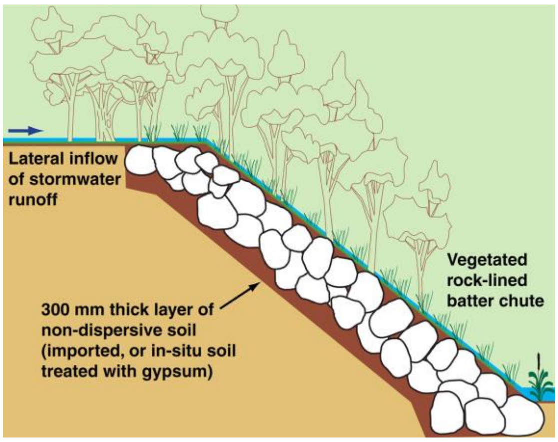
Vegetated batter chutes

- The most common treatment of lateral bank erosion is the construction of a 'batter chute', which is a drainage chute, usually formed from rock.
- Most commonly, these rock chutes are initially formed in a non-vegetated state, but this usually results in weed invasion.
- Ideally, rock chutes should be pocket planted at the time of construction, but stiff grasses should only be placed along the edges of the chute.

Stream flows deflected around a *Lomandra*

Problems associated with the use of stiff grasses in the treatment of lateral bank erosion

- Stiff grasses, such as *Lomandra*, work best when they are operating in deep water.
- In shallow water conditions, such as those found on a batter chute, stiff grasses begin to act as individual plants, rather than as grouped plants, and they begin to deflect passing flows rather than slow them, which means stormwater runoff may be forced out of the batter chute.

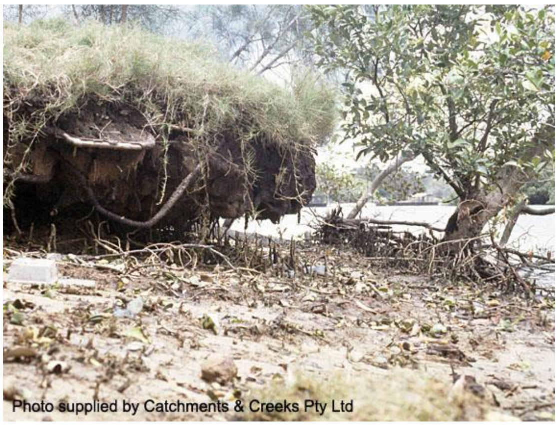


Batter chute built with non-dispersive soil

Management of dispersive and slaking soils

- Lateral bank erosion commonly occurs in locations where the subsoils are dispersive.
- If the lateral bank erosion has exposed some dispersive subsoils, then the overall treatment of the erosion remains largely the same; however, the exposed surface of the dispersive soil must be covered with a suitable layer of non-dispersive soil prior to the formation of the batter chute.

Planting in response to wave-induced bank erosion



Fretting erosion (Qld)

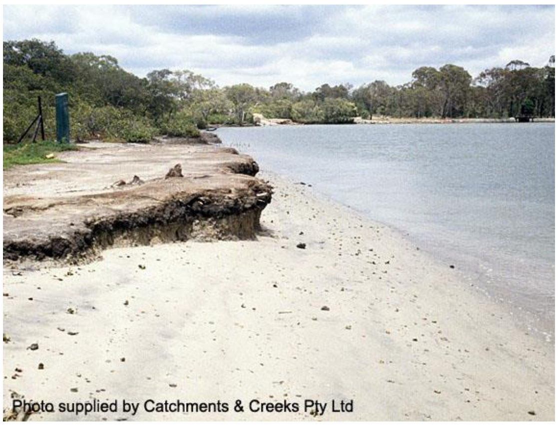
Fretting

- Fretting is just one form of erosion that can be caused by wave action, and is most commonly the result of waves generated by powered boats on rivers, lakes and estuaries.
- At a certain tide level, waves can approach a mangrove bench at just the right elevation to cause the waves to first break, and then wash past mangroves before attacking the earth bank behind the plants.

Boat-generated waves approach a bank

Problems associated with the planting of mangroves near waters subjected to waves

- In general, mangroves do not like aggressive wave action, which means they are mostly found in sheltered estuaries.
- If waves are introduced to mangrove shores, then these waves can wash away the soil bench that makes up the main growing platform for the mangroves.
- This does not mean that waves will always damage mangroves, it just means any problems should be closely monitored.



Wave-induced riverbank erosion (Qld)

Controlling wave-induced bank erosion

- Coastlines manage wave action in two ways:
  - absorbing the wave energy on a beach
  - reflecting the wave off a rock cliff.
- Neither of these solutions traditionally integrate well with vegetation.
- Rock can be used to stabilise river banks, and vegetation can be introduced to this rock work, but the trick is to learn from any successful vegetative outcomes that already exist near the site.

Wave-induced bank erosion (Qld)

Using vegetation in the control of waves

- Reed-beds can be used as a response to wave action generated from boat traffic.
- A 2 m wide reed-bed can absorb about two thirds of the wave energy generated by small boats.
- Reeds can restrict the near-bank flow velocity, and provide some reinforcement to the bank surface through their shallow root mat—in effect, a mini-wetland system can be formed along the banks of water bodies subjected to small boat traffic.

Planting in an area of active bank erosion

Creek bank stabilisation (Qld)

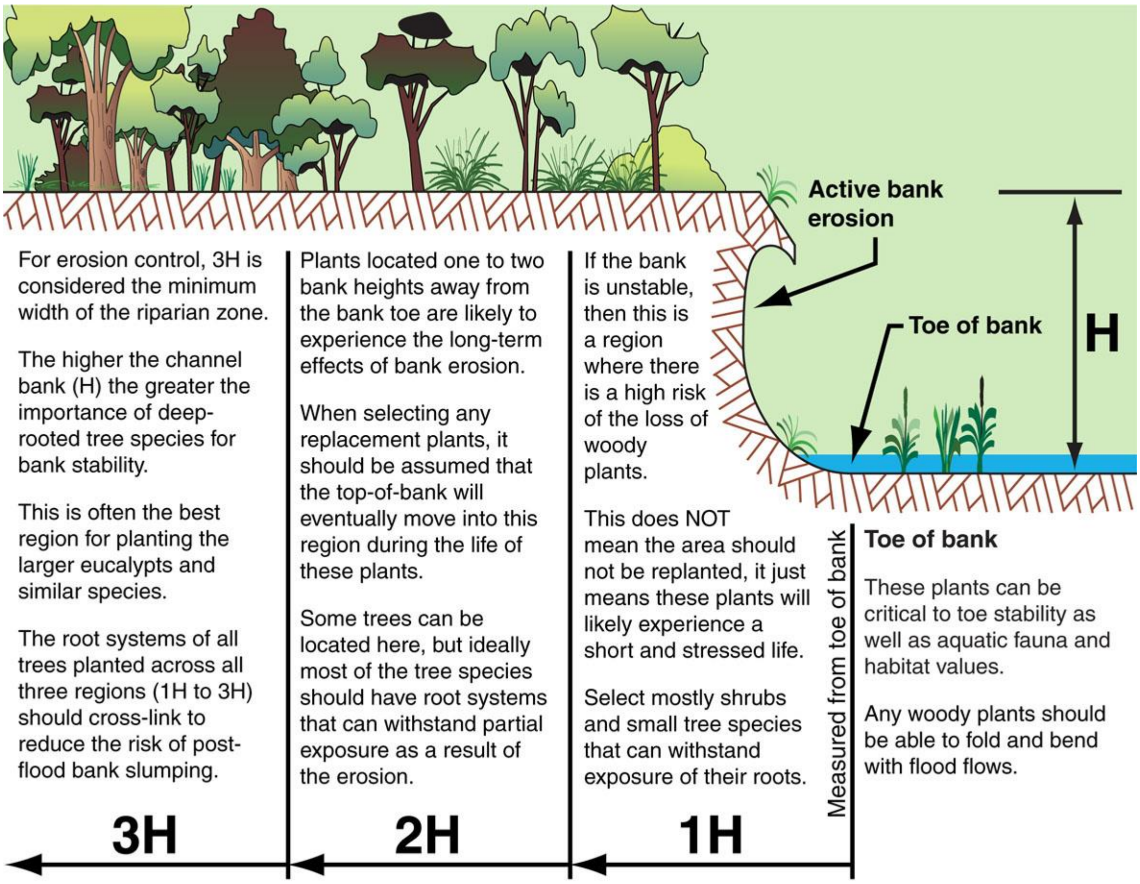
Overbank revegetation (Qld)

Introduction

- In cases of active bank erosion, the treatment options include:
  - allow the erosion process to resolve itself naturally (e.g. in cases where machinery access cannot be provided to the bank without causing damage to riparian areas), or
  - battering and revegetating the eroded bank, which may require the loss or modification of some riparian vegetation.

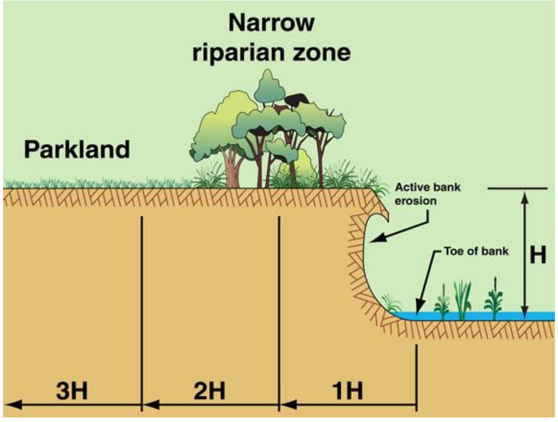
The use of sacrificial plants

- Many people cannot accept the concept of 'sacrificial plants'—the concept of planting a tree knowing that it may never reach maturity.
- However, if we know that the bank erosion will be ongoing, then we must accept that new plants placed near the edge of the bank will likely be lost, while other plants located well away from the bank should have sufficient time to reach maturity (see over page).



Rehabilitating riparian zones adjacent to active bank undercutting

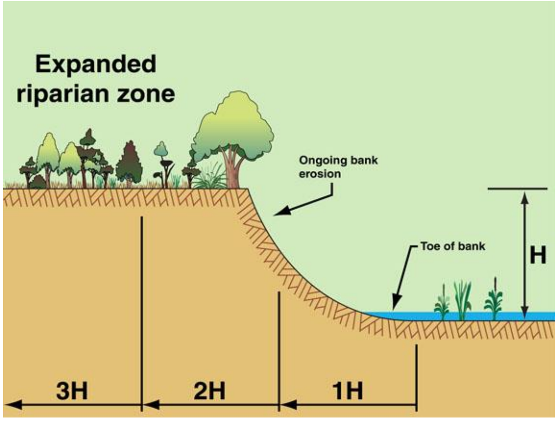
Planting in an area of active bank erosion



Existing site conditions

Introduction

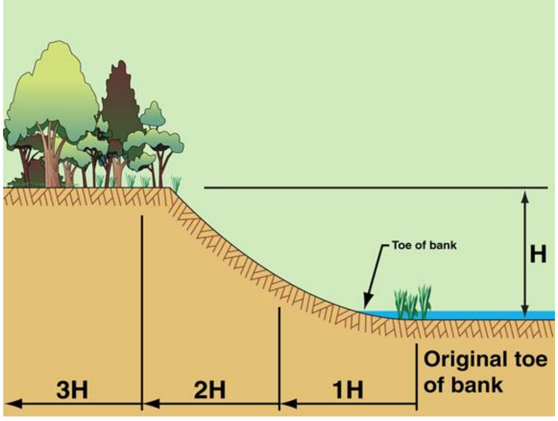
- In some cases, the only remaining habitat and wildlife corridor trees are those that exist within a narrow riparian strip located along the edge of the creek bank.
- If the eroding creek bank were to be 'battered and revegetated', then the creek would lose its wildlife habitat values for a period of time while new trees are establishing along the creek bank.
- This assumes that imported fill cannot be used to rebuild the bank.



Establish new overbank vegetation

Planting for a future bank condition

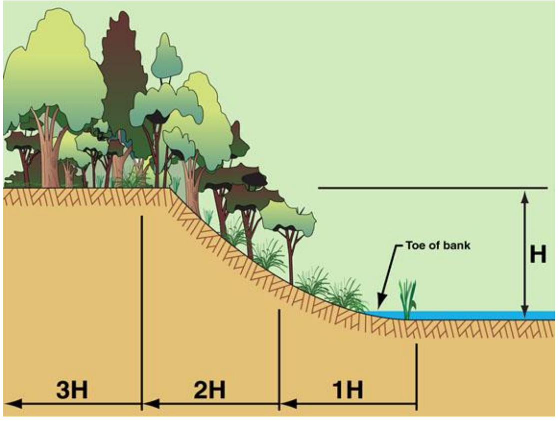
- The alternative approach to dealing with the creek erosion is:
  - to allow the bank erosion to progress naturally, and
  - to focus on establishing new riparian vegetation further inland.
- Depending on the height and gradient of the creek bank, some of these new trees may eventually succumb to the bank erosion (i.e. sacrificial plants).



Effects of ongoing bank erosion

Creek erosion finally forms a stable bank slope

- Retaining the existing riparian vegetation should slow down the progression of the bank erosion, giving additional time for the new plants to establish.
- It is noted that the final bank slope of around 1 in 2 (shown in the diagram) is not absolute, and will vary from location to location—in some cases a stable bank slope may never be reached without human interference.



Final stabilisation of the eroded bank

Final stabilisation of the creek bank

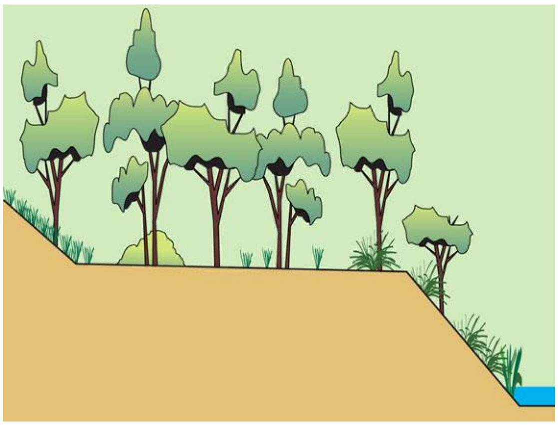
- Once the creek bank has established a stable slope, and the root systems of the new riparian vegetation have penetrated deep into the bank, the rest of the creek bank can be revegetated.
- Benching the creek bank at this stage can:
  - allow better access for bank revegetation, and
  - increase the stability of the final bank.
- Benching is not essential, just a design option.

Planting in flood hazard areas

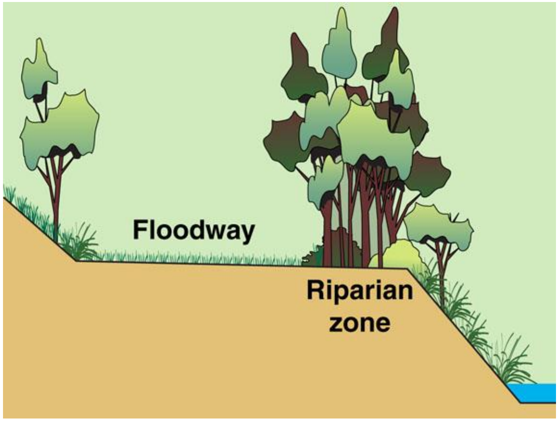
Sparsely treed floodplain (Qld)

Increasing the ecological 'value' of a riparian zone without causing adverse impacts on flood levels

- In many urban creeks, flooding is a significant community concern, and as a result, middle storey plants are often removed from floodplains in order to reduce flood levels.
- It is possible that a better ecological outcome could be achieved (without raising flood levels) by simply reorganising the layout of the riparian vegetation to make room for an open floodway.



Existing sparsely treed floodplain



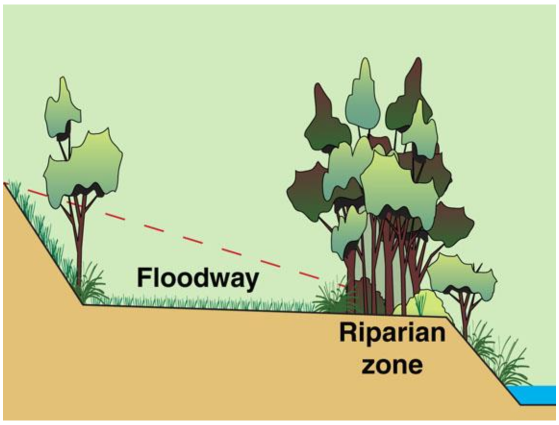
Creation of an open floodway

Constructed floodway (Qld)

Increasing the ecological 'value' of a riparian zone without compromising flow capacity

- In cases where a floodplain does not currently exist adjacent to the urban creek, an open floodway can be created by benching the creek bank.
- Benefits include:
  - enhanced ecological values
  - improved public access
  - improved maintenance access.

Existing sparsely treed floodplain



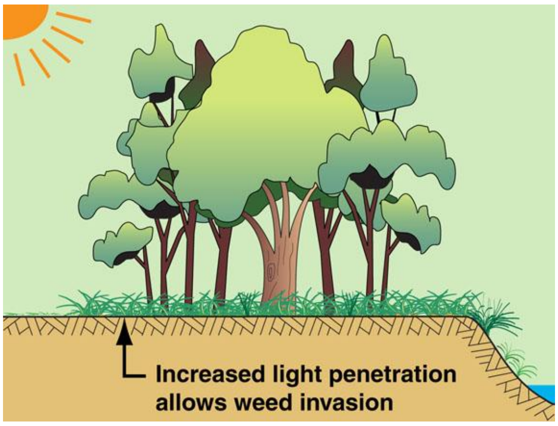
Excavation of a floodway

Planting to control edge effects

Intrusion of light into a riparian area

Introduction

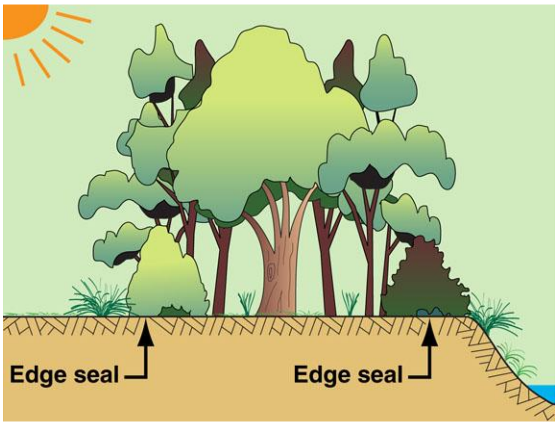
- In both rural and urban areas, riparian zones may consist of just a narrow strip of vegetation each side of the waterway.
- Many of the functions performed by riparian vegetation will be affected by the width of the riparian zone.
- The width of the riparian zone also affects the degree of light that enters the riparian zone as a result of 'edge effects'.



Weed intrusion into the riparian zone

The impact of edge effects on weed invasion

- If the edge effects are not adequately controlled, then the increase in diffuse light will bring with it an increase in weed invasion.
- Recommendations on the minimum width of riparian zones are provided in Section 14.6.



Controlling the edge effects

Controlling edge effects with appropriate planting

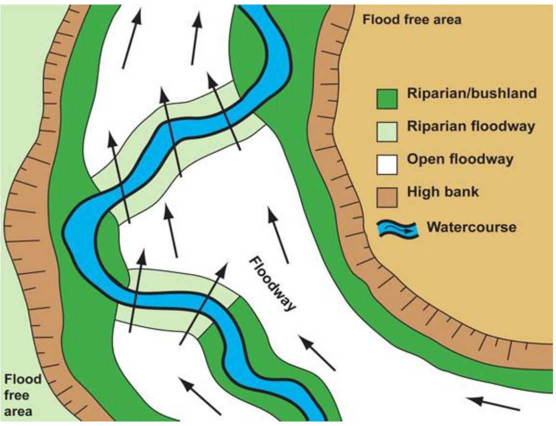
- Middle storey plants and robust ground covers (e.g. stiff grasses) can be used to reduce the degree of diffuse light penetrating into riparian zones.
- Appropriate edge planting can also improve the aesthetics of parks by providing a visual barrier between the highly-maintained open parkland (adjacent the waterway), and the low-maintenance riparian zone.

Forming a 'mowing edge' (Qld)

Using plants to clearly define the edge of riparian areas in order to control mowing activities

- There are over 50 species of *Lomandra* (mat rush), but only two are commonly found near creeks.
- Given the potential overuse of these two species in and around many urban creeks, consideration should be given to the other varieties of *Lomandra*, and the many other varieties of stiff grasses that could be used as edge plants.

Planting in areas of high flow velocity



Riparian floodways

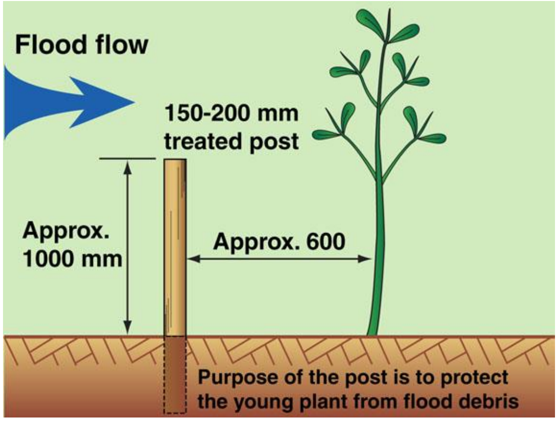
Terminology

- A floodplain is any area that experiences flood inundation as a direct result of creek or river flooding.
- A floodway is that part of a floodplain where the floodwaters have an obvious forward velocity (i.e. not part of an area of land or water known as a 'backwater').
- A riparian floodway is a section of the riparian zone where floodwaters either pass across the waterway, or pass between the waterway and the floodway.

Flood damage to a sapling

Difficulties of planting in floodways

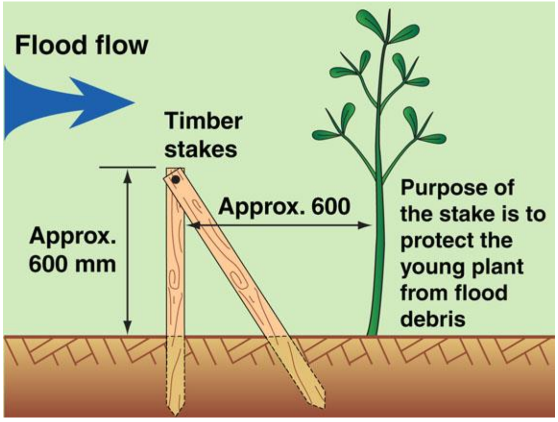
- Newly established vegetation can be damaged by flood events in three ways:
  - plants are pushed over by high velocity flows
  - plants are pushed over as a result of flood debris (typically organic matter) wrapping around the plant
  - turbulence around the base of the plant causes a localised loss of soil (a scour hole).



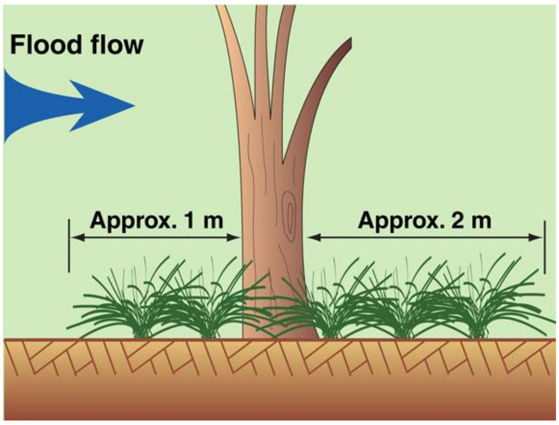
Protecting plants from flood debris

Planting in floodways

- Saplings can be protected from high velocity floodwater by:
  - staking the plant
  - forming a triangular flow screen
  - adopting long-stem planting.
- Saplings can be protected from flood debris by placing a debris trap (post) upstream of the plant.
- Isolated trees can be protected from soil scour around their base by planting stiff grasses (*Lomandra*) around the tree.



Protecting plants from flood debris



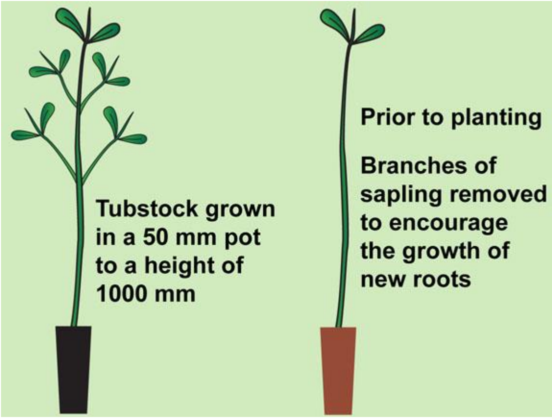
Protection of isolated trees in floodways

Planting within a floodway – Long stem planting

Exposure of roots by severe bank erosion

Introduction

- Depending on the plant species and the environmental conditions:
  - an exposed root system may begin to function as part of the tree's trunk system, and
  - a buried section of a sapling's stem may transform into part of the plant's root system (adventitious roots).
- Long stem plants make use of the latter condition, but only for selected species in appropriate situations.



Establishment of long stem saplings

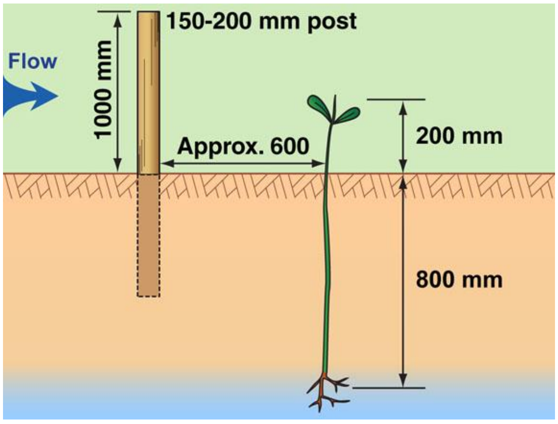
Initial growth stage

- The benefit of long stem planting is the enhanced anchorage of the sapling, which reduces the risk of the young plant being washed from the soil during a flood.
- In order to achieve this enhanced anchorage, the sapling must be planted deep into the soil, which means suitable tubestock need to be prepared:
  - grown in 50 mm pots
  - grown to a height of 1 metre.

Pre-planting preparation

Preparation prior to planting

- Branches of the sapling are removed to encourage the growth of roots.



Planting of long stem plant

Planting of long stem saplings

- Holes dug to a depth of 800 mm.
- Fertiliser pellet placed at the rootball.
- Placing the rootball deep in the soil allows these roots to be beyond the competition zone of other plants (weeds), and closer to a source of water.
- A stake/post can be placed upstream of the sapling to protect the plant from flood debris (in addition to staking the plant).

The hydraulic properties of stiff grasses

Grasses flattened by floodwater (Qld)

Mat-forming grasses

- Domestic, mat-forming grasses are likely to fold flat when subjected to significant surface flows (thus forming a 'mat').
- These plants act as a 'community' and in doing so can help to control soil scour.

Lomandra **in deep water (Qld)**

Stiff grasses in <u>deep water</u>

- When subjected to deep water flows, many stiff grasses also begin to act as community plants, helping to:
  - control soil scour
  - reduce flow velocities
  - help build a thick boundary layer of low-velocity water adjacent the creek's bed and banks.

Lomandra **(Qld)**

Stiff grasses in <u>shallow water</u>

- When subjected to shallow water flows, many stiff grasses begin to act as 'individual plants', which are likely to deflect flows rather than slow these flows.
- In general, stiff grasses should not be used on:
  - dam and basin spillways
  - narrow, high-velocity floodways
  - stormwater batter chutes.
- However, exceptions do exist if the hydraulic effects are fully understood.

Mass planting of ***Lomandra*** **(Qld)**

Stiff grasses used as a monoculture

- A mass planting of stiff grasses can be an effective way of dealing with very high flow velocities; however, ecological values can be diminished by such landscaping.
- The mass planting of stiff grasses can be useful in the following circumstances:
  - high-velocity channels
  - lower bank region on the outside of a channel bend
  - around the base of 'objects' located in floodways, such as isolated floodplain trees.

Use of vetiver grass in creek and gully engineering

Vetiver grass (full growth)

Introduction

- *Chrysopogon zizanioides* is commonly known as 'vetiver grass'.
- Vetiver grass grows in tall clumps, with tall, thin, and rather rigid leaves growing to a height of 2–3 metres, and a root system that grows to a depth of 2–4 metres.
- The plant can survive deep water flow conditions and temporary submergence.
- The most commonly used commercial genotypes of vetiver are sterile, meaning the plant can be propagated only by breaking the clumps.

Flow diversion barrier (Qld)

Use of vetiver grass as a flow diversion system

- Vetiver grass is one of a few grass-like plants that can be used to form a vegetative flow diversion barrier.
- Other species could include *Callide Rhodes*, *Katambara Rhodes* or *Molasses* can also be used; however, suitability and weed-potential of each species must be checked on a case-by-case basis.

Recent planting on a sandy soil bank

Use of vetiver grass in the stabilisation of sandy soils

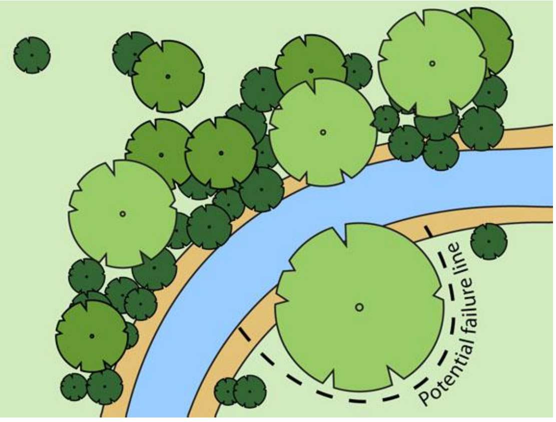
- The very deep, fibrous root system of vetiver grass means this plant can be used to stabilise sandy soils that are subjected to deep water flow conditions.
- Vetiver grass is not suitable for shallow water flow conditions, such as those found along overland flow paths, or down dam spillways (by-wash).

Gully stabilisation with vetiver grass (Qld)

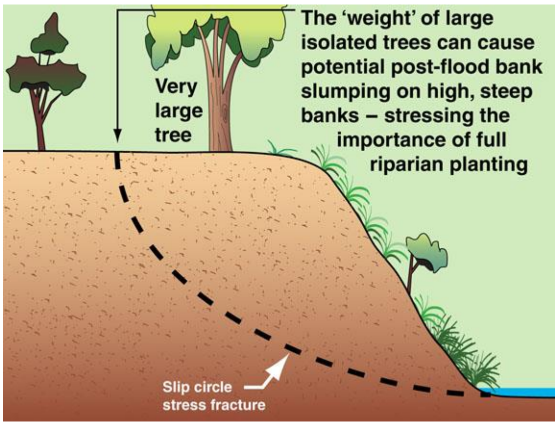
Use of vetiver grass in the stabilisation of gully erosion

- Vetiver grass has been used in the stabilisation of gullies that have formed within a slaking soil.
- Slaking soils are often very sandy, with minimal clay binder.
- Vetiver grass can be used as:
  - vegetative sediment traps spaced at regular intervals along the gully floor
  - revegetation of the gully banks.

Planting large trees on steep banks

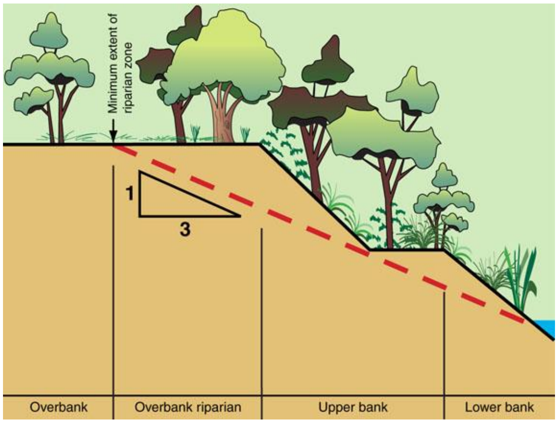


Isolated tree



Slip circle bank failure

Brisbane River, 2011



Minimum riparian width for bank stability

Introduction

- Trees and shrubs provide the anchoring system for earth banks through their root systems.
- In their natural environment, these plants typically exist in 'communities', which are termed 'riparian' when such plant communities have a direct link to the waterway.
- However, in some cases, large riverbank trees can find themselves isolated from their normal plant communities, and instead become surrounded by only ground covers, such as grasses.
- If these isolated trees are very large, and therefore very heavy, then they can pose a risk of causing post-flood bank slumping if they are located near the edge of a steep, high, river bank.
- The risk of such post-flood slumping is increased if the river is located downstream of a gated dam that is able to accelerate the falling period of flood events by quickly raising its spillway gates.

The added effects of strong winds

- The risk of isolated riverbank trees falling increases if such trees are subjected to strong winds.
- Such flood-induced bank slumping is expected to have occurred at several locations along the Lockyer Creek, and Brisbane and Bremer rivers in 2011.
- The risk of such bank slumping is low, and should not dominate the design of riparian zones, but instead should be just one of many issues that need appropriate consideration.

Reducing the risk of bank slumping

- The risk of such bank slumping can be reduced by:
  - benching steep and/or high banks
  - planting middle storey trees around isolated trees
  - restoring riparian areas to their natural condition.
- A geotechnical investigation into the river bank can determine if a risk of bank slumping exists.

Planting on steep banks – Jute bagging

Jute bagging (Qld)

Jute bagging

- In the planting technique known as 'jute bagging', small 'bags' are made from thick jute blankets
- These jute bags are then filled with soil and a single seedling, then pinned to the exposed creek bank.

Weed removal (2005)

Site preparation

- The creek bank should first be cleared of weeds and their roots (as appropriate).
- Unlike for the placement of an erosion control blanket, the bank does not need to be cleared of surface irregularities.
- However, if the bank is likely to be subjected to strong sunlight that is likely to cause excessive drying of the soil, then the bank could be covered with a light mulch, which could be anchored with a well-anchored jute mesh—this may require some further bank preparation.

Planting procedure (2005)

Planting

- The jute bags are then filled with soil and a single seedling, then pinned to the bank.
- The underside of the jute back must have good contact with the bank to allow plant roots to extend (grow) from the jute bag into the bank.
- This technique allows plants to be established on steep earth banks that are likely to be subject to occasional stream flows.

Fully established creek bank (2010)

Long-term outcomes

- As is the case on most creek sites, the long-term outcomes depend on:
  - site preparation
  - plant selection
  - initial plant watering and maintenance
  - weed control
  - 'luck' (in regards to flood damage).
- Stormwater runoff must be able to infiltrate the soil within the immediate overbank area (i.e. no impervious surfaces immediately adjacent to the creek bank).

The use of mulch in riparian areas

Loose mulch applied to a creek bank

A potential source of pollution

- Mulch can provide many benefits to creek rehabilitation; however, it can also be considered a form of pollution for urban waterways.
- Many urban streams experience 'eutrophication' (the enrichment of the waters by nutrients) often leading to excessive algal growth.
- If the mulch is not adequately anchored, then it can contribute to these water quality problems.

Geo logs used on a steep creek bank

Retaining loose mulch on steep banks

- The value of mulch during plant establishment increases in importance as the bank slope increases; however, the difficulties of holding the mulch in place also increase.
- Meshes, logs and geo logs can be used to help retain mulch on steep slopes.

Straw mulch (Qld)

Straw and cane mulch

- Straw and cane mulch should be used with caution adjacent to waterways, unless such mulch can be adequately anchored to prevent it from simply being blown or washed away.

Bush mulch (NSW)

Bush mulch

- Bush mulch has the potential to be more stable than straw mulch, but appropriate care must still be taken to prevent the mulch from being washed from the site.
- Alternatives include:
  - compost blankets
  - rock mulching
  - erosion control blankets (jute meshes).

The use of erosion control blankets in riparian areas

Jute mesh (Qld)

Terminology

- The term 'blanket' is typically used to describe rolled erosion control products that have a low shear strength.
- The term 'mat' is typically used to describe rolled erosion control products that have a high shear strength—making them suitable for high velocity drainage channels.
- A 'mesh' is a blanket that has an open weave, usually made from jute or coir.

Jute erosion control blanket (SA)

Bio-degradable products

- Bio-degradable erosion control blankets are typically manufactured from:
  - jute (made from specific 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 use within waterways.
- Meshes are the type of 'blankets' best suited for use on waterway banks.

Hydraulically-applied blanket (Qld)

Hydraulically-applied blankets

- Hydraulically-applied blankets include:
  - hydroseeding
  - hydromulching
  - compost blankets
- Hydraulically-applied blankets:
  - contain a mix of mulch, site-specific seed, and fertiliser
  - can be applied to creek banks that already contain some vegetation
  - can be applied to very steep banks.

Plastic-reinforced erosion control mat

Problems associated with plastic-reinforced mats

- Some erosion control mats contain a synthetic (plastic) reinforcing mesh that may, or may not, break down under direct sunlight.
- These synthetic reinforced mats should not be used in bushland and waterway environments because ground dwelling animals, such as lizards, snakes, and seed-eating birds, can become entangled in the mesh.