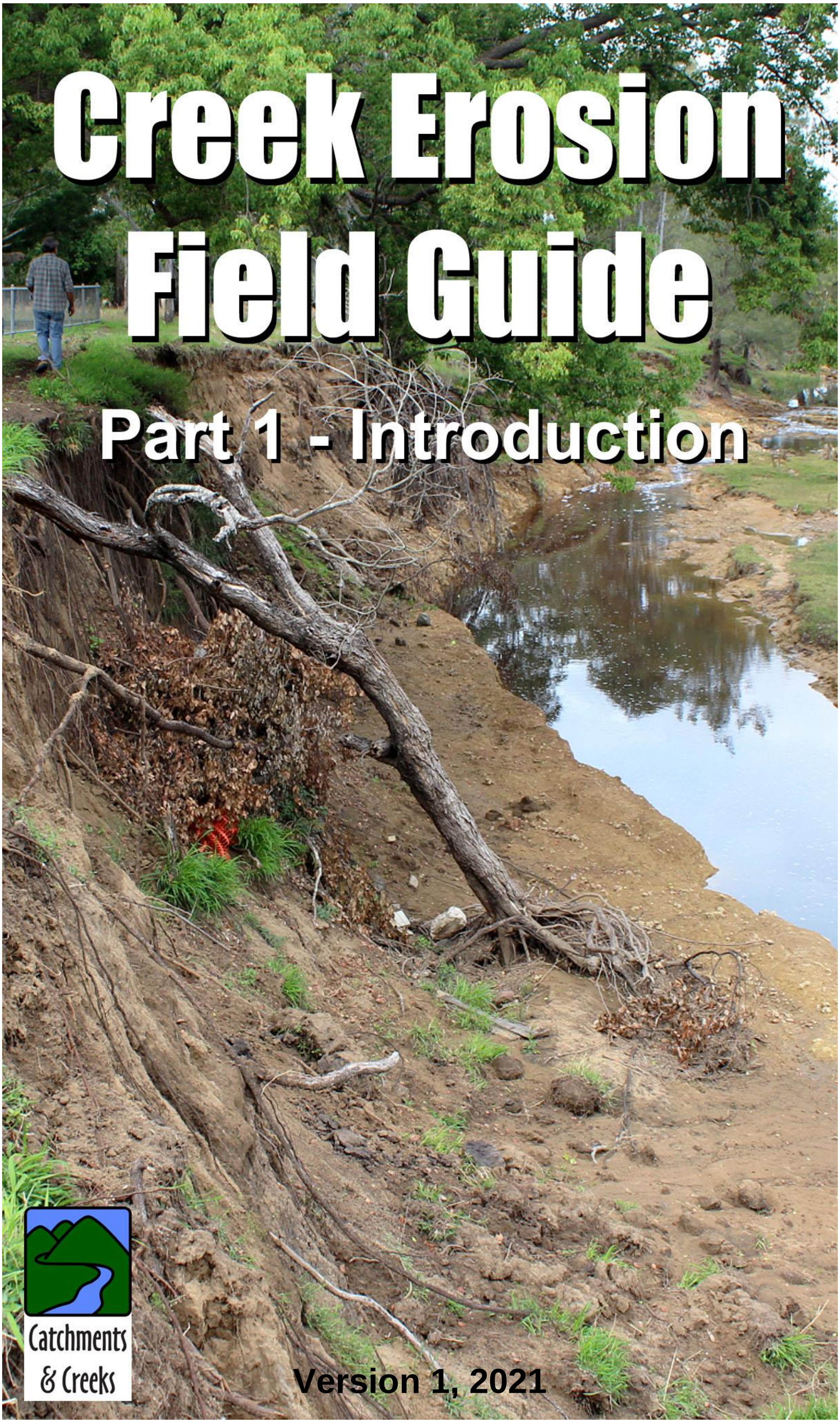
Creek Erosion Field Guide

Part 1 - Introduction



Catchments & Creeks

Version 1, 2021

Creek Erosion Field Guide

Part 1 – Introduction

April 2021

Prepared by: Grant Witheridge, Catchments & Creeks Pty Ltd

Diagrams by: Catchments & Creeks Pty Ltd

Photos by: Catchments & Creeks Pty Ltd, Brisbane City Council

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Copies of this document may be downloaded from: www.catchmentsandcreeks.com.au

Cover image: Purga Creek at Peak Crossing, Queensland, 2011

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 control measures must be appropriately investigated, planned, and designed in a manner appropriate for the site conditions—each site is different, and the solutions to creek erosion are also likely to vary from site to site. This 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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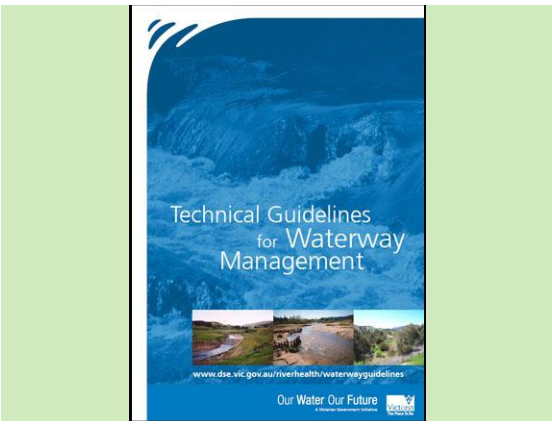
Useful reference documents



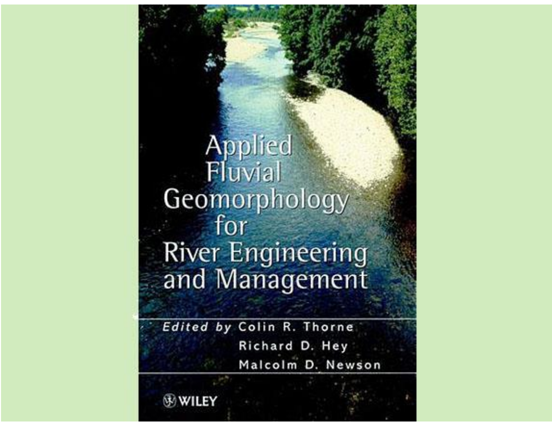
Victoria DSE (2007)

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



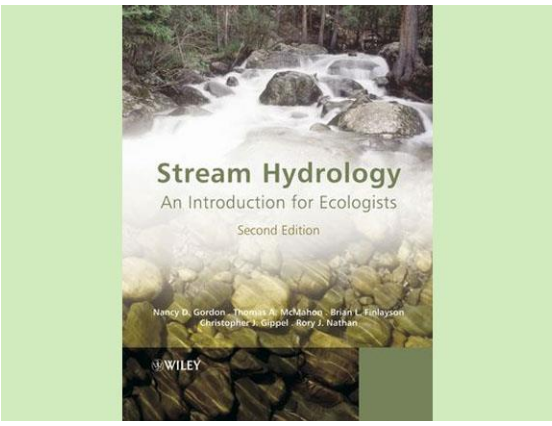
Thorne, Hey & Newson (2003)

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)



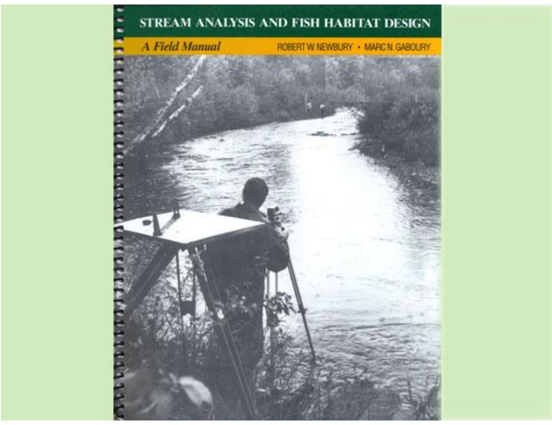
Gordon, McMahon, Finlayson, et al. (2004)

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)

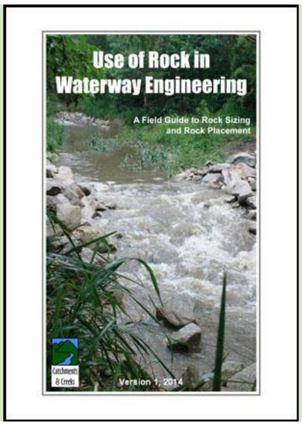
Stream Analysis and Fish Habitat Design

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

Related field guides



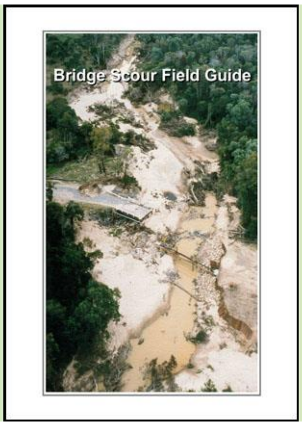
Use of Rock in Waterway Engineering

Use of Rock in Waterway Engineering

Catchments and Creeks Pty Ltd, Bargara, Queensland

Free PDF download from the C&C website.

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



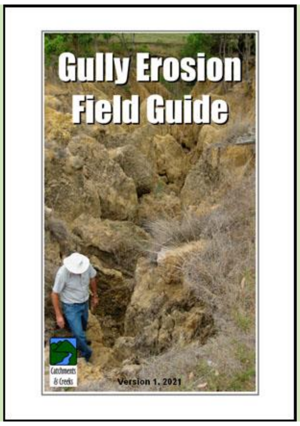
Bridge Scour Field Guide

Bridge Scour Field Guide

Catchments and Creeks Pty Ltd, Bargara, Queensland

Free PDF document from the C&C website.

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



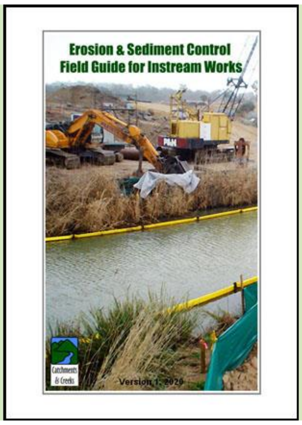
Gully Erosion Field Guide

Gully Erosion Field Guide

Catchments and Creeks Pty Ltd, Bargara, Queensland

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

This field guide is due for release in late 2021.



ESC Field Guide for Instream Works

Erosion and Sediment Control Field Guide for Instream Works

Catchments and Creeks Pty Ltd, Bargara, Queensland

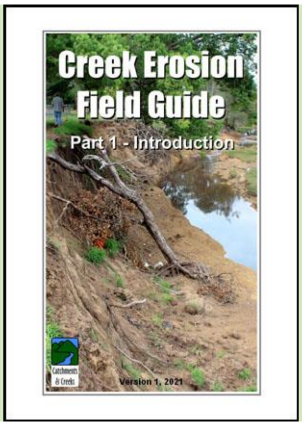
Free PDF document from the C&C website.

First published early 2020, then updated late 2020.

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

Contents

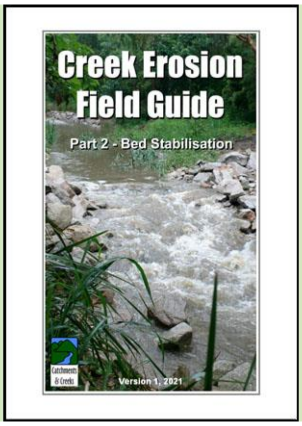
Layout of this four-part field guide



Creek Erosion Field Guide – Part 1

Part 1 – Types of waterways and causes of waterway erosion

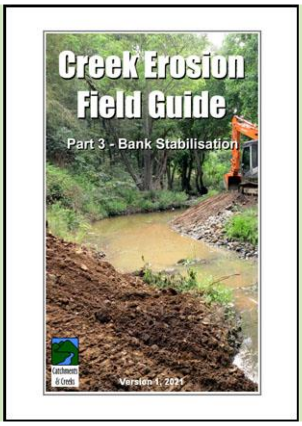
- Designing the appropriate treatment measures for creek erosion depends on knowing:
  - the type of watercourse
  - the type of erosion, and
  - the likely causes of the erosion.
- Part 1 discusses each of these issues, as well as presenting an introduction to creek engineering and fluid mechanics.



Creek Erosion Field Guide – Part 2

Part 2 – Bed stabilisation

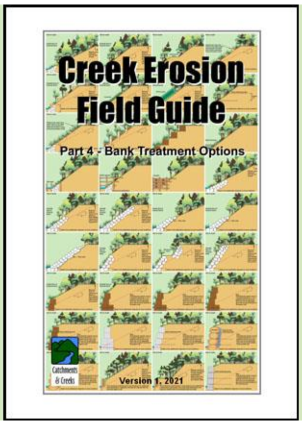
- Prior to presenting detailed information on bed stabilisation techniques, discussion is presented on the following topics:
- fish-friendly waterways
- common properties of rock
- hydraulics of bed structures.
- Information on the treatment of <u>bed</u> erosion is then grouped into two chapters:
-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

Within the industry of waterway management there has been numerous discussions between engineers and scientists over which profession should take the lead role in managing waterways. There has also been minor differences between the science of river morphology (a profession founded within the sciences), and the science of creek engineering (a profession founded within the field of water engineering).

The facts are that over time many engineers develop the necessary knowledge and experience that allows them to perform many of the waterway investigations usually conducted by scientists, and similarly many scientists develop the skills to perform many of the traditional engineering tasks. From my experience dealing with waterways, the suitability of a person to work within this complex field has nothing to do with the person's chosen profession—what really matters is the person's knowledge and experience.

In simple words, **knowledge** is usually what we learn from other people's mistakes, and **experience** is what we learn from your own mistakes. Hopefully all of the professionals participating within the waterway industry will continue to openly talk about, and learn from, their collective successes and failures.

There will be parts of this field guide that some people will disagree with, and that is just fine. I know, for example, that some people are unwilling to accept that different ‘rules’ and design ‘principles’ apply to creeks and rivers. I have been to many lectures in river morphology where the lecturer will state that the principles they are outlining apply equally to both creeks and rivers. They say that the principles they are teaching are universal. Well, that is correct. The laws of science don’t change simply because of the size of the waterway.

When I talk about creeks and rivers behaving differently I am referring to how the *relative importance* of these principles vary from waterway to waterway. It is a bit like learning about fluid mechanics. Both air and water behave as fluids. In both the professions of water engineering and aerodynamics the same basic laws of physics are taught. Neither profession can escape the need to learn about Newton’s laws of motion. But there are differences between air flow and water flow, and these differences lie in the *relative importance* of such things as: viscosity, gravity, thermodynamics, and the speed of a pressure wave. In each case the scientific laws remain unchanged, but the application of these laws, or even the need to consider certain laws at all, change from fluid to fluid, and from application to application.

The same applies to waterway management; the laws remain the same, but the relative importance of such things as, vegetation and bed sediment, can change from waterway to waterway. It is the ability of a practitioner to observe and recognise these minor variations that can make the real difference between good and bad waterway practice.

So what does all this mean to **you**, the reader. Well, it means that you should ponder the following thoughts while you are reading this field guide:

1. Question everything that you read. Ask yourself: does it sound right? Does it align with the things that you have experienced or witnessed happening within waterways? Has the author provided a rational explanation, or is the author simply asking you to accept a statement on faith?

2. Don’t accept a statement as being true simply because you think the author knows more about the topic than you do.

3. Don’t accept a statement as being true simply because the statement reinforces what you really, really want to be the truth.

4. Don’t accept a statement as being true simply because the statement aligns with what you were taught at university. It really concerns me that so many organisations are willing to accept, without question, any and all reports that originate from universities. I have worked in universities for a number of years, and of course they are great places for learning, and they contain some incredibly inspiring people, but they also contain many people that lack real world experience and practical thinking. The lesson: knowledge is not a measure of truthfulness, even though it may increase the probability of the statement being true.

5. It is common for people to *teach what they were taught*. You will find that most teachers and lecturers will largely teach their students the same lessons, and in the same manner, as they were taught. I know that I was guilty of making this very mistake in the early part of my career. I also know of certain false theories that are still being taught today, and continue to be reproduced within waterway management text books, even though these theories remain unproven. In the past I have made the observation that once an explanation appears in five different books it is considered to be true even though it may remain unproven! The lesson: the repetition of a statement is no measure of a statement’s truthfulness, even though it does suggest the statement has wide acceptance.

6. Always keep in mind that there is almost always an exception to every rule. Few statements or recommendations made within this field guide can be taken as absolute. Also, the fact that you may know of an exception to a stated rule does not make that rule incorrect, or even less valid. I am sure that several exceptions can be presented for each of the design principle outlined within this field guide. The lesson: avoid taking an extreme or absolute position on any principle or point of discussion.

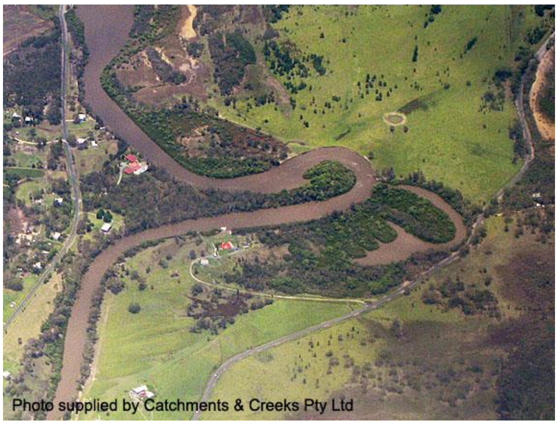
7. Finally, remember that a mind is like a parachute, it only works when it is open.

Introduction

The author during a creek erosion field day

Urban waterway corridor (Qld)

Hard engineering creek stabilisation



Natural river meander

Focus of this document

- The focus of this field guide is on the management of **creek erosion**.
- Readers wishing to learn about *gully erosion* are advised to refer to a separate field guide in this series.
- Readers wishing to learn about *river erosion* can gain significant insight from this field guide; however, there are some important differences between creeks and rivers as discussed in Chapter 2 of this field guide.

The author's basic philosophy to waterway management

- Creeks often represent one of the last remaining wildlife habitats within urban catchments.
- In respect of this fact, the basis of my design philosophy has been to focus on the fauna and flora needs of the waterway, and to <u>avoid</u> turning creeks into:
  - human movement corridors
  - recreational parks with the creek being just another 'water feature'
  - an extension of someone's backyard.

Avoiding synthetic and hard engineering solutions

- Creeks are living systems that provide valuable landscapes within both rural and urban areas, as well as essential habitats for wildlife.
- In treating erosion issues the focus should always be on the use of natural materials.
- There are of course times when hard engineering solutions are required to protect major infrastructure and public assets; however, such solutions should only be used when absolutely necessary.

The 'do nothing' approach

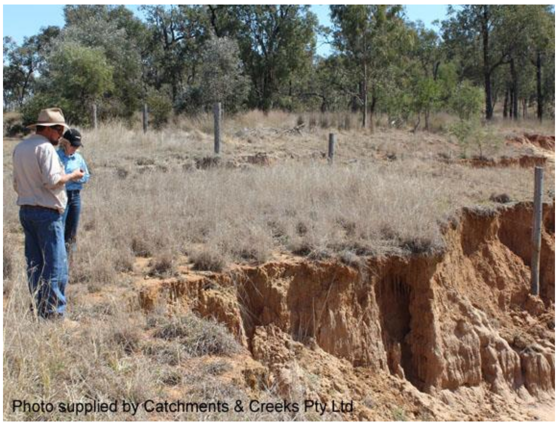
- Creek erosion, in many instances, is a natural process and as such <u>should</u> be allowed to continue.
- The occurrence of creek erosion does <u>**not**</u> mean something bad is happening, or that human intervention must occur in order to arrest the erosion.
- Remedial works are normally only required when the erosion is unnatural, or potentially damaging to a valued asset.

Use of this field guide by different readers

Gully erosion

Introduction

- Even though the analysis of creek erosion is complex and typically requires the guidance of experts, there are occasions when the cost of employing waterway experts cannot be justified.
- Many property owners are forced to deal with creek and gully erosion issues as best they can with just the aid of 'common sense' and the Internet.



Creek erosion

Rural property owners

- Property owners have the advantage of being able to watch their waterway behave during floods, and to regularly inspect any treatment measures they implement.
- 'Watch and Act' is a good philosophy for the management of creek erosion, but don't expect creek erosion to always look exactly like the photos in this field guide.
- And don't give-up or overreact just because things don't work perfectly the first time you try a new idea.

Urban creek erosion

Urban property owners

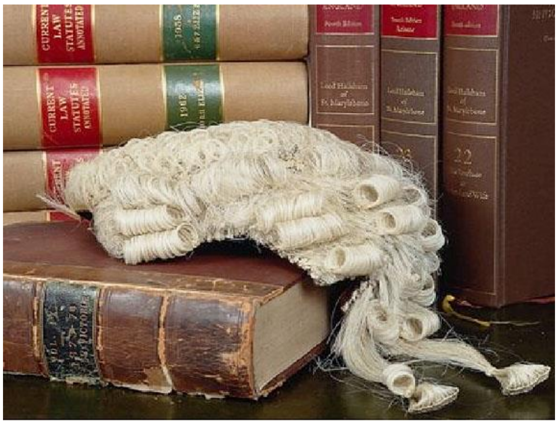
- The treatment of creek erosion within urban areas can be complicated by not knowing what types of government approvals are required.
- Also, don't be tempted to instantly jump to a hard engineering or synthetic solution just because someone is willing to sell you their latest product.
- Remember; most creek erosion can be stabilised with just three products: soil, rock and vegetation.

Community group tree planting

Community groups

- Community groups need to appreciate that creek rehabilitation is very different from bush regeneration.
- Plants often work differently in waterways compared to bushland.
- The focus should not be just on using native plants, but also on putting the right plant in the right place.
- Finally, don't start large-scale weed removal until you are ready to replant; otherwise you may leave the waterway vulnerable to erosion

Legal requirements



Legal issues

Local government (NSW)

Code-based instream works (Qld)

Court house (NSW)

Introduction

- Each state has its own definition of what constitutes a watercourse, and in some cases these definitions will vary from region to region within a given state.
- Approvals (sometimes more than one) are usually required from the state before works can be carried out within a watercourse.
- Owning land does not mean you don't need approval to build a house—similarly, owning a portion of a creek does not mean you can modify that waterway at your will.

Local government requirements

- The need to get local government approval depends on two key issues:
  - are the proposed works a controlled activity as identified within the Planning Scheme (Town Plan), or
  - will any of the works be conducted within land owned or managed by the local government, including land controlled by an easement.
- Note; getting local government approval may not negate the need to get state government approval.

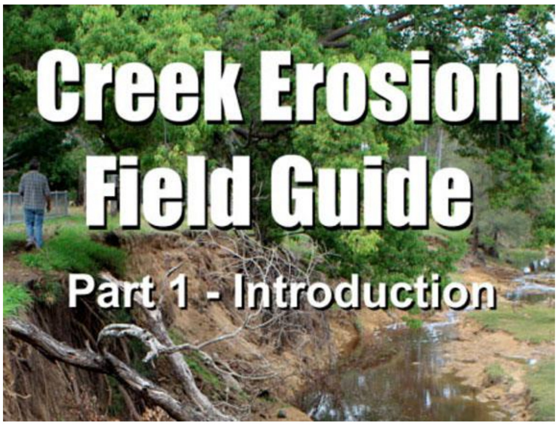
State government requirements

- Instream works may trigger the following state-controlled legal requirements:
  - waterway permits
  - vegetation removal permits
  - fish barrier permits
  - permission to conduct works within land owned or managed by the state
  - general environmental duty.
- Note; approval from one department does not negate the need to get an approval from another interested department.

Common law issues

- 'Common law' is a legal system that gives weight to the principle that it is unfair to treat similar facts differently on different occasions—thus judges' decisions in active cases are informed by the decisions of previously settled cases.
- Under common law, waterways and stormwater are treated very differently.
- In most states, the laws applicable to watercourses have been modified by statute law, which means the principles of common law may not apply.

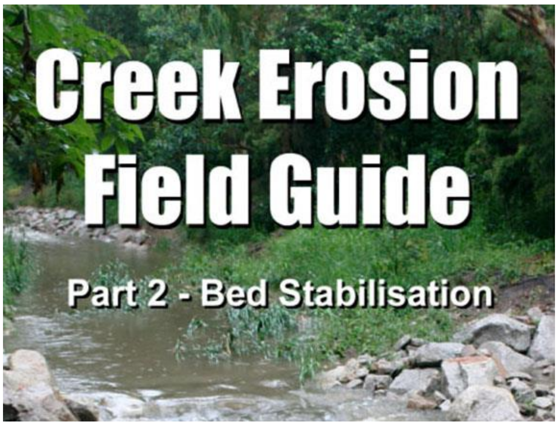
Working through this field guide



Creek Erosion Field Guide – Part 1

Can you identify the type and cause of the erosion?

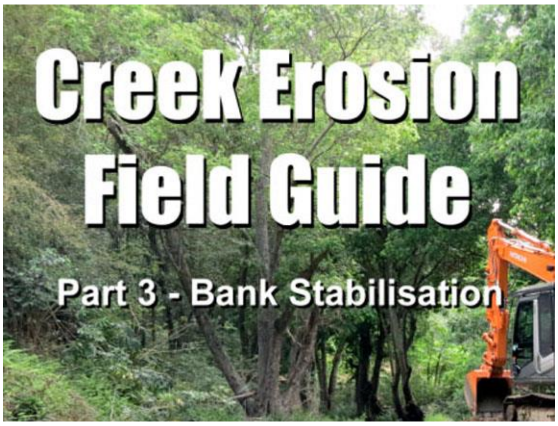
- Review Part 1
  - Chapter 1: types of waterways
  - Chapter 3: types of creek erosion
  - Chapter 5 & 6: causes of erosion.
- Is the erosion problem a form of:
  - Bed erosion, then go to Part 2
  - Bank erosion, then go to Parts 3 & 4.



Creek Erosion Field Guide – Part 2

Treating bed erosion (Part 2)

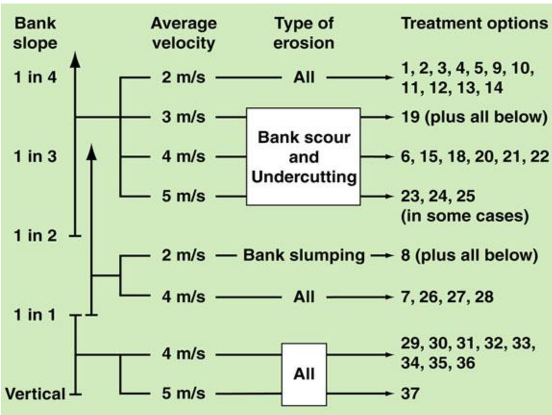
- If you are new to the activity of treating bed erosion, then:
  - Think about getting expert advice, because these are very difficult problems to solve.
  - Review Chapter 8 for guidance on planning your response to creek erosion.
- Chapters 12 & 13 provide advice on various fish-friendly, and non fish-friendly bed stabilisation options.



Creek Erosion Field Guide – Part 3

Treating bank erosion (Part 3)

- If you are new to the activity of treating bank erosion, then:
  - Review Chapter 8 for guidance on planning your response.
  - Chapter 14: soft engineering options
  - Chapter 15: hard engineering options
  - Chapter 18: lateral bank erosion
  - Chapter 19: bank revegetation.
- If you are just looking for a visual guide, then review the diagrams in Part 4.



Technique selection chart (Part 4)

Part 4: Bank stabilisation options

- Part 4 starts with an overview of the various recommendations presented in Part 3.
- Part 4 can be used as a pictorial guide that can be used to show the landowner or other interested persons the range of treatment options.
- If you already know the required bank slope, and the likely flow velocity, then Chapter 21 starts with a simple flow chart to help you select possible treatment options.

Where to get help

Local government community centre

Community training day (Qld)

State government officers (SA)

Waterway consultants (NSW)

Introduction

- When it comes to managing waterways, getting good advice is usually more important than having good intensions.
- Just because you are a ‘good person’, just because you are sympathetic to environmental issues, does not mean that everything you do is ‘right’.
- When dealing with creek erosion issues, residents should always make use of the advice that is often freely provided by government and non-government organisations.

Community groups

- Local community groups can be a good source of information, and they can also have good contacts within the private sector and within governments.
- Try your local:
  - Landcare and Envirolink group
  - Bush rehabilitation group
  - Coast Landcare group
  - NRM (Natural Resource Management) organisation—usually linked to the local river system.

Local and state governments

- The state government department that will most likely have an interest in waterway management will be a department with a title that includes the words: *Natural Resources*, or *Water*.
- Your state’s environment department will likely be interested in general environmental issues, such as water quality and the protection of wildlife.
- Your state’s fisheries department may be interested in any instream works that could impact fish habitats or fish migration.

Waterway consultants

- Private consultants can provide advice on a full range of waterway issues, but the key is finding the right consultant.
- You may get help finding the right consultant by asking a local community group (see above) or asking your local council or councillor.

1. Types of Waterways

Terminology

Gravel-based creek (Qld)

Sand-based creek (Qld)

Navigable waterway (NSW)

Gully erosion (SA)

Introduction

- There are many different ways to classify waterways, and river morphology has its own classification system.
- However, when dealing with creek erosion it is better to classify waterways based on the features that most commonly influence creek erosion, which are:
  - the relative importance of vegetation, and
  - the make-up of the waterway bed (i.e. clay, sand, gravel or rock).

The term 'watercourse'

- A *watercourse* is a channel with defined bed and banks (which can include gullies) along which surface water flows on a permanent or semi-permanent basis, or at least under natural conditions for a substantial time following periods of heavy rainfall within its catchment.
- Constructed drainage channels are usually not considered to be watercourses; however, the adoption of *Natural Channel Design* principles is beginning to change that status.

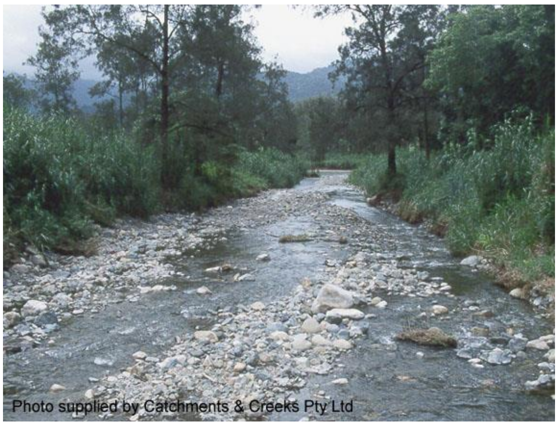
The term 'waterway'

- Historically, the term *waterway* referred only to navigable watercourses.
- In rural communities, this term can also be used to describe a shallow drainage line that crosses farmland (in urban areas such a drainage line would be termed an *overland flow path*).
- In the fluvial (waterway) industry it is common for the terms 'waterway' and 'watercourse' to be considered interchangeable, which will be the case throughout this field guide.

The term 'gully'

- A *gully* is typically described as an open, incised, erosion channel that is deeper than 30 cm.
- Gullies are formed by complex processes, but a major factor is a concentrated flow of surface water, hence they are frequently found along drainage lines, or where surface runoff spills from a floodplain into a channel.
- The management of gully erosion is the subject of another field guide located on the *Catchments and Creeks* website.

Types of waterways



Gravel-based alluvial watercourse (Qld)

Dry, ephemeral, semi-arid waterway (NSW)

Well-vegetated drainage line (Qld)

Ephemeral watercourse (Qld)

Alluvial waterways

- Alluvial waterways are formed from flood-laid deposits of silt, sand and gravel, but the term most commonly refers to sand-based and gravel-based waterways.
- These are 'moving bed' waterways that experience significant natural sediment movement (as opposed to 'fixed bed' waterways).
- The term is generally not applied to clay-based creeks, even if these creeks contain significant quantities of unnatural sediment (e.g. sediment generated by urban runoff).

Arid and semi-arid waterways

- Arid and semi-arid waterways are often treated as a separate waterway category due to the reduced influence of vegetation on the channel's form and stability.
- In arid regions it can be difficult to distinguish between a *waterway* and a *drainage line*.
- However, these waterways can share many characteristics with coastal waterways, including the wide flat channel bed found in most sand-based and gravel-based waterways.

Drainage lines

- A drainage line is a stormwater drainage pathway (or overland flow path) that carries concentrated flow (not sheet flow).
- These drains are likely to flow only while rain is falling, and for short periods (hours) after rainfall has stopped.
- Drainage lines are generally <u>not</u> considered to be waterways.
- The classification of waterways is usually a matter for state governments, while the mapping of drainage lines is more commonly done by local governments.

Ephemeral watercourses

- An ephemeral watercourse is a waterway that is expected to experience periods of zero-flow on a regular basis.
- In many locations, dry ephemeral waterways can look remarkably similar to drainage lines—even experts can disagree on what is a 'dry creek' and what is a 'drainage line'.
- An ephemeral watercourse may contain permanent pools that may or may not be fed by sub-surface flows.

Types of waterways

Major waterway (Ipswich, Qld)

Major waterways

- Major waterways are most commonly referred to as 'rivers'.
- In some regions of Australia, as well as within the upper regions of most rivers, these waterways can be so narrow that their behaviour is more closely aligned with the behaviour of minor waterways.
- In major waterways, bank vegetation can play a major role in providing post-flood bank stability, but during a flood, it is the floodwater that usually dominates over the vegetation.

Minor urban waterway (Brisbane, Qld)

Minor waterways

- Within this field guide, the term 'minor waterway' is used to describe narrow-bed waterways where vegetation type and density is often a dominant factor in determining the size and stability of the channel.
- 'Springs', 'brooks' and 'creeks' are the waterways most likely to be referred to as minor waterways.
- These waterways normally have a low stream order classification (i.e. 1, 2, or 3).

Small rural stream (Guyra, NSW)

Springs, streams and brooks

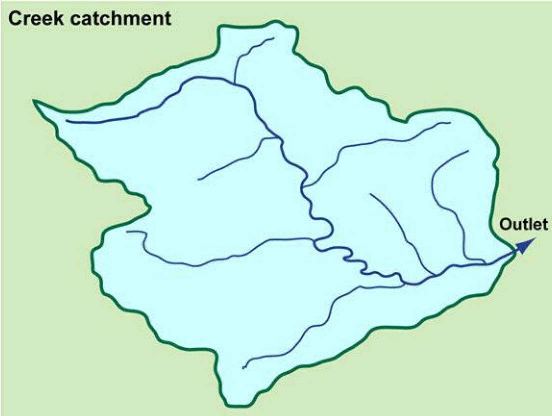
- These are minor waterways that experience a sustained base flow that may or may not be permanent.
- Typically these waterways are sourced from well-established groundwater springs or seasonal snowmelts.
- These waterways can be ephemeral, but a near-constant base flow (dry weather flow) is a more common occurrence.

Tidal waterway (Brisbane, Qld)

Tidal waterways

- Tidal waterways can be grouped under a variety of classifications including, creeks, rivers and estuaries.
- The treatment of erosion within tidal waterways can be very different from that applied to freshwater streams because of:
  - the different plant species
  - the potential impacts of waves on the marine plants and bank stability
  - the different needs of aquatic life, and their potential interaction with any proposed scour control measures.

The size of waterways and catchments



Creek catchment

An unnamed drainage line (Qld)

Upper reaches of Snowy River, NSW

Nepean River, Penrith, NSW

Introduction

- As stated previously, this field guide focuses on bed and bank erosion within creeks, as opposed to rivers.
- There are several characteristics that can separate 'creeks' and 'rivers', but the main characteristic is the size of the channel, and/or catchment.
- In general, the size of the catchment can be described as:
  - small
  - medium
  - large

Small drainage catchments

- Within the context of this field guide, a small drainage catchment is a catchment where a general vehicle inspection of the catchment would take a matter of hours.
- Such waterways are often referred to as:
  - drainage lines
  - urban stormwater drains
- These waterways are likely to have a catchment area less than a few hundred hectares.

Medium catchments (minor waterways)

- A medium drainage catchment is a catchment where a detailed inspection of the catchment would take a matter of days.
- Such waterways are often described as:
  - springs
  - streams
  - creeks
  - brooks
- These are the waterways that are the primary focus of this field guide.

Large catchments (major waterways)

- A large catchment would require several weeks for a hydrology team to conduct a detailed catchment inspection.
- Such waterways are often referred to as rivers.
- These waterways are likely to have a catchment area greater than a hundred square kilometres (> 10,000 hectares).

A waterway classification system suitable for <u>minor</u> waterways

Gravel-based waterway (Qld)

Introduction

- River morphology text books often classify waterways according to their channel form, such as: straight, braided, meandering and anastomosed.
- However, this field guide has adopted an alternative classification system, which is based on the type of bed material (clay, sand, gravel or rock).
- This classification system has been adopted because it is more appropriate form small waterways, and it is useful in technique selection.

Flood damage to a sand-based creek (Qld)

Understanding the impact of severe floods on waterways

- Clay-based, sand-based, gravel-based and rock-based creeks all respond differently to major (1 in 10 to 1 in 100 year) and severe (> 1 in 100 yr) floods.
- An understanding of how different floods affect different types of waterways is a useful piece of knowledge when it comes to responding to any form of flood damage.
- For more discussion, refer to Chapter 6.

Pile field bed stabilisation (Vic)

Assessment of bed stabilisation options

- If the proposed creek works involves the stabilisation of a <u>bed</u> erosion problem, then the treatment options are highly dependent on:
  - the type of bed material (clay, sand, gravel, cobbles, boulders or bedrock)
  - the need for bed material (and fish) to be able to freely pass over the bed stabilisation measures.
- For more discussion, refer to chapters 12 and 13.

Pile field toe stabilisation (NSW)

Toe stabilisation

- If the proposed creek works involves the stabilisation of a <u>bank</u> erosion problem, then the treatment options are to incorporate some type of toe stabilisation.
- The options available for the stabilisation of the toe of a bank depend on:
  - the type of bed material (clay, sand, gravel, cobbles, boulders or bedrock)
  - the expected depth of bed movement
  - the risk of long-term bed erosion.
- For more discussion, refer to Section 14.8.

A waterway classification system based on bed material

Clay-based waterway (Qld)

Clay-based waterways

- The bed and banks of clay-based waterways are primarily formed from clayey soils.
- These are 'fixed bed' waterways that typically have minimal natural sediment flow or bed movement—this allows mature woody vegetation to establish close to, or even on, the channel bed.
- Typically these waterways have a U-shaped or V-shaped channel profile (i.e. not a wide, flat channel bed).

Sand-based waterway (Qld)

Sand-based waterways

- Deep, loose sand dominates the make-up of the bed.
- The depth of the sand can exceed the depth of the root systems of much of the bed and bank vegetation.
- These are alluvial waterways that experience significant bed movement (sand flow) during both minor and major flood events.
- Bed vegetation (if any) typically consists of quick-response, short-lived, non-woody species.

Gravel-based waterway (NSW)

Gravel-based waterways

- Bed material is made-up mostly of well-rounded gravels, cobbles or boulders.
- These are alluvial waterways that often feature pools and riffles, which can completely reform during severe floods.
- The movement of the bed material during major floods means the channel bed is usually flat (similar to sand-based rivers).
- Woody vegetation can struggle to form on the channel bed if the bed movement is significant—which may not be the case in the upper reaches of the waterway.

Rock-based waterway (Tas)

Rock-based waterways

- The bed material of rock-based waterways is made-up of exposed rock outcrops, often separated by sections of clay, sand or gravel-based channels.
- These are fixed-bed, 'spilling' waterways usually containing waterfalls or riffles followed by deep pools within which energy dissipation occurs.
- These waterways are sometimes referred to as 'rocky-spilling' or 'steep pool-fall' waterways.

Examples of Australian clay-based waterways

Albany Creek, Brisbane, Qld

Clay-based waterways

- Many of the urban creeks found in Adelaide, Brisbane, Melbourne and Sydney can be classified as clay-based waterways.
- Due to the clayey soils it can be difficult to cross these waterways in vehicles at bed level; thus making bed level vehicle crossings (fords) impractical.
- Correct plant selection and planting densities are critical for achieving long-term channel stability.

Little Cabbage Tree Ck, Brisbane, Qld

Roma, Queensland

Rapid Creek, Darwin, NT

Norman Creek, Brisbane, Qld

Kedron Brook, Brisbane, Qld

West of Cobar, NSW

Examples of Australian sand-based waterways

Ten Mile Creek, North of Mackay, Qld

Sand-based waterways

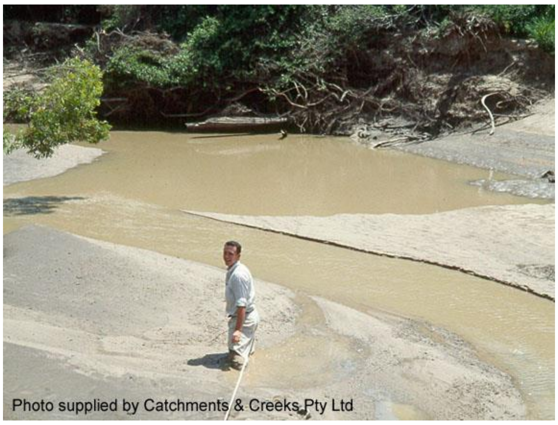
- Sand-based waterways are often found in landscapes dominated by granite rock (of course exceptions do exist).
- Geologists can point out the relationship that typically exists between the make-up of your waterway and the parent rock that exists within the catchment.
- Sand-based waterways are also commonly found in catchments containing dispersive or slaking soils.

Tributary of the Upper Burnett River, Qld

Ipswich, Qld

Chinchilla, Queensland

Fern Creek, Coffs Harbour, NSW



Oxley Creek, Brisbane, Qld

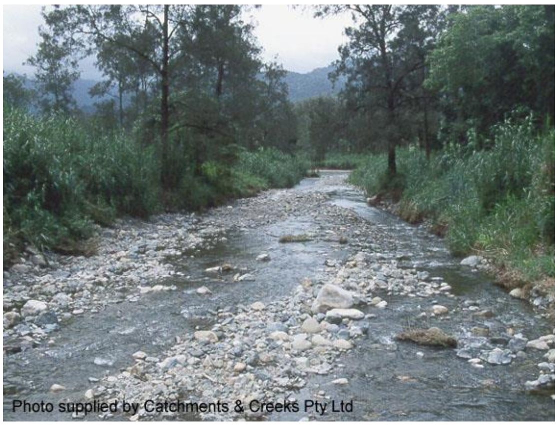
Brogo River, Bega, NSW

Examples of Australian sand-based waterways

Tributary of the Upper Burnett River, Queensland

Bogie River, Queensland

Examples of Australian gravel-based creeks



Broken River, Eungella, Qld

Gravel-based creeks

- Gravel-based waterways are the sleeping giants of our waterways.
- These waterways can look so calm and peaceful for decades; they are the waterways that people love to photograph and have as posters on their office walls.
- But when disturbed by a major flood, these waterways can be very destructive, causing significant bank erosion and damage to long-established vegetation.

Liffey Falls, Tasmania

Buaraba, Esk, Queensland

Samford, Queensland

Snowy Mountains NP, NSW

Marne River, South Australia

Upper South Pine River, Samford, Qld

Examples of Australian gravel-based creeks

Cedar Creek, Closeburn, Queensland

Franklin River, Tasmania

Examples of Australian rock-based creeks

Naps Creek, Beaudesert, Qld

Rock-based creeks

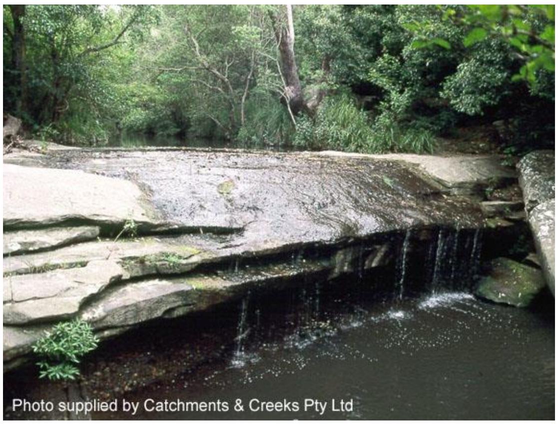
- Sections of rock-based creeks are often produced by the exposure of bed rock within a small section of an otherwise, clay, sand or gravel-based creek.
- However, in the steep, upper reaches of some creeks and rivers, the exposed rocky bed may extend for a significant length of the waterway.
- Waterfalls are common, but not essential to the formation of a rock-based creek.

Gowrie Creek, Toowoomba, Qld

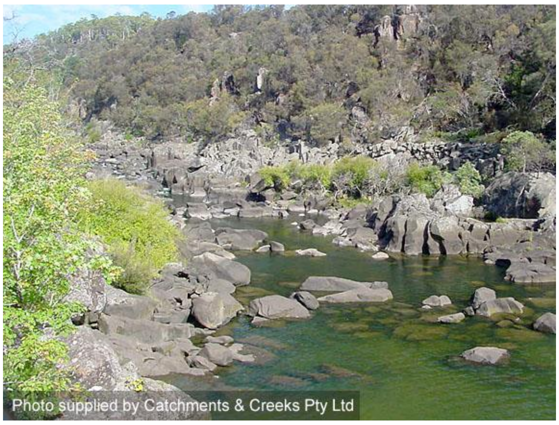
Spicers Creek, near Wellington, NSW

Ithaca Creek, Brisbane, Qld

Upper reaches of South Pine River, Qld

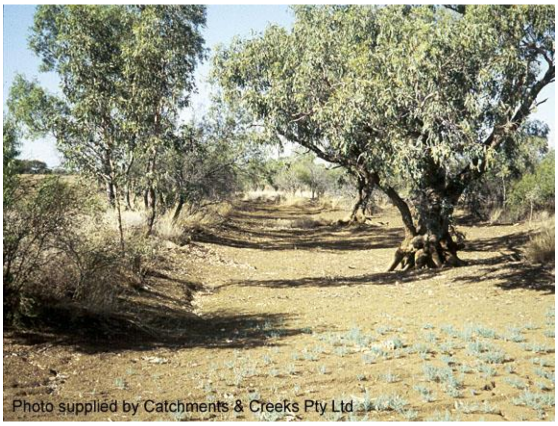


Terrys Creek, Sydney, NSW



Cataract Gorge, Launceston, Tas

Examples of Australian arid and semi-arid waterways



Central Queensland near Alpha, Qld

Arid and semi-arid waterways

- Arid and semi-arid waterways can be difficult to classify.
- Minor arid waterways are more likely to behave like clay-based waterways if located away from rocky escarpments.
- Major arid waterways can behave like sand-based waterways given the large volumes of mobile bed sediment.
- Arid waterways that are sourced from rocky escarpments can behave like gravel-based waterways.

Kings Canyon, Northern Territory

West of Cobar, NSW

Dolo Creek, Broken Hill, NSW

Black Hill Creek, Silverton, NSW

Simpsons Gap, Northern Territory

Todd River, Alice Springs, NT

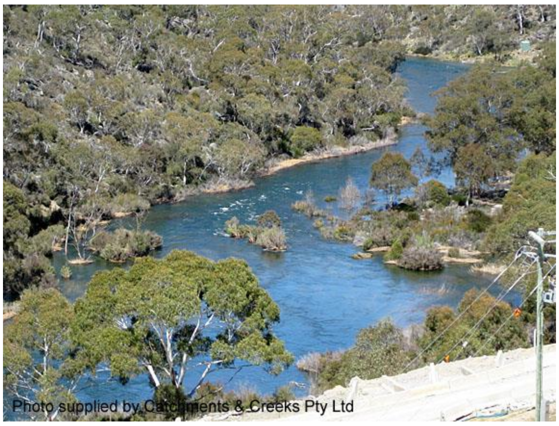
Examples of Australian river systems

Darling River, Wilcannia, NSW

River systems

- The term 'river' is not always a good description of a waterway.
- Most rivers originate as minor waterways that are best described as 'creeks'.
- Also, what may be termed a 'river' in the southern parts of Australia could well be titled a creek in the northern parts of Australia.

Murray River, Paringa, SA

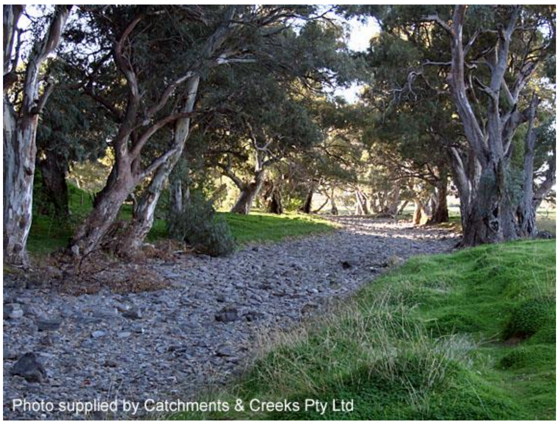


Snowy River, Jindabyne, NSW

Upper reach of South Pine River, Qld

Brisbane River, Queensland

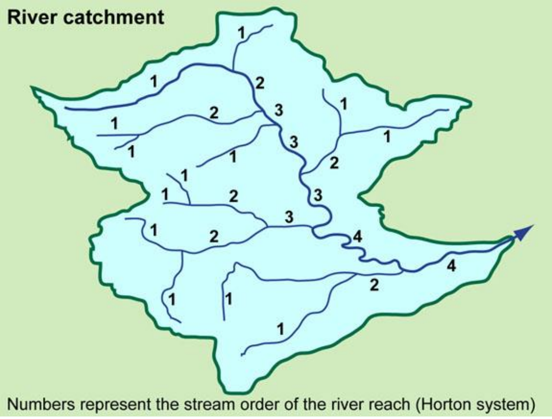
Franklin River, Tasmania



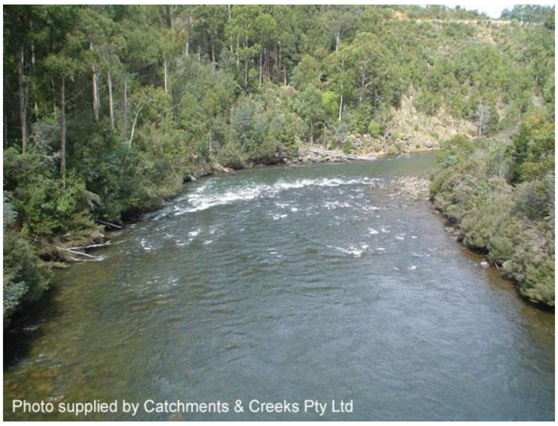
Marne River, South Australia

River systems

Bluff River (NSW)



Example of the Horton stream order



Riffle system on the Nive River (Tas)

Rock stabilisation of a river bank (NSW)

Waterway classification

- Classifying waterways as either creeks or rivers is not always useful because these terms do not necessarily relate to waterway features that are uniformly recognised across all regions.
- What may be referred to as a river in southern Australia, may be considered a creek in northern parts of the country.
- Also, the uppermost reaches of most rivers may behave like a 'creek', but the local sign-post will (correctly) title it a river.

Stream order

- Stream order is a system for ranking the individual reaches of a waterway.
- There are a number of ranking systems.
- In the Horton system a first-order stream has no contributing branches based on a specified mapping scale (the choice of map scale is critical).
- A second-order stream has at least two contributing first-order branches.
- A third-order stream has at least two contributing second-order branches, etc.

Typical features of a river

- Rivers typically exhibit the following characteristics (but not always):
  - a near constant flow (generally these are not ephemeral waterways)
  - significant quantities of mobile bed sediment (known as the bed load)
  - wide pools and riffles that extend across the full width of the bed
  - a significant change in vegetation type from the bed to the banks (bed vegetation may consist only of aquatic plants).

Controlling bank erosion in rivers

- It can be very difficult to control bank erosion within rivers on a long-term basis, other than through expensive, hard-engineering measures.
- Typically the focus is on controlling the types of bank erosion issues that arise in the periods between major floods.
- It is important to remember that the occurrence of bank erosion is not necessarily a sign that someone has done something wrong, and it is not necessarily a bad thing for the river.

2. An Introduction to Waterway Morphology

River morphology

Meandering river channel (Qld)

Introduction

- There are numerous features common to both creeks and rivers, but there are also key differences.
- The science of river morphology generally involves the study of long-term geological processes, which typically occur over hundreds or thousands of years.
- Key topics in river studies often centre around sediment transport and channel mobility, while creek studies are more likely to focus on bed and bank stability.

Sediment flow along a riverbed (NSW)

Sediment flow

- Most river systems have a significant degree of loose bed sediment that slowly migrates down the waterway.
- The quantity of sediment flow (bed load) typically increases with the size of the catchment, thus small waterways often have minimal sediment flow.
- Due to the high sediment flow experienced in most rivers, slow-growing, woody plant species can find it difficult to establish across a riverbed.

Pool/riffle in the Queanbeyan River (NSW)

Pools, riffles and low-flow channels

- In rivers, pools and riffles typically extend across the full width of the channel bed.
- Deep pools most commonly exist at channel bends.
- Riffles are commonly located near the mid-point between channel bends.
- The rocks that make up the riffles constantly migrate down the river; however, the riffle itself often stays in the same location, with any displaced rocks being replaced by new rocks migrating down the river.

An artist impression of channel relocation

Impact of vegetation on channel stability

- Vegetation is always important for short-term *bank stability*, but possibly not for long-term *channel stability*.
- If a flood wants to cause a river to relocate or change its meander pattern, then it is unlikely that any existing vegetation will prevent this from occurring.
- Vegetation performs many important roles in river morphology, but rarely is it stronger than the destructive power of a major flood.

How <u>creek</u> morphology differs from river morphology

Urban clay-based creek (Qld)

Creek morphology

- In essence, the science of creek engineering is the same as river morphology—the differences lie in the relative importance of key features, such as vegetation.
- Creek engineering is most commonly focused on short-term processes, such as the impacts of urbanisation, bushfires and regular floods, because these are the factors likely to be of prime interest to the local community.

Unnatural sediment in an urban creek

Sediment flow

- Relative to rivers, most creeks experience minimal <u>natural</u> sediment flow, especially clay-based creeks.
- In the absence of significant sediment flow, slow-growing woody vegetation can establish close to, or even on, the channel bed.
- In many urban creeks, most of the bed sediment is likely to have resulted from unnatural processes, such as urban runoff.

Creek with a narrow low-flow channel

Pools, riffles and low-flow channels

- Not all creeks have pools and riffles—these features appear mostly in sand and gravel-based waterways.
- If pools and riffles do exist, then they are often contained within a narrow low-flow channel that behaves like a small channel existing within the wider main channel.
- In creeks, pools and riffles can be found anywhere along the channel, not just at channel bends and inflection points.

Restored urban creek (Qld)

Impact of vegetation on channel stability

- One of the main differences between creeks and rivers is the relative importance of vegetation with respect to providing channel stability during floods.
- In creeks, the type of vegetation, its health and density, can be the dominant factor in determining the size of the channel.
- If you change the vegetation, for example by suddenly removing all weeds, you can cause significant changes to the channel's size, meander pattern, or location—in creeks, plants rule!

Impacts of creek erosion and sedimentation

Damage to a road culvert (NSW)

Damage to land and assets

- Creek erosion not only causes changes to the waterway, it can also cause damage to adjacent infrastructure and properties.
- Common impacts include:
  - loss of farmland
  - damage to bridges and culverts
  - damage to roads and parks
  - loss of critical riparian vegetation, such as habitat trees, and
  - the creation of unsafe bank slopes.

Sediment removal from an urban creek

Sediment deposition

- Scientific studies have determined that a significant proportion of the sediment carried by waterways originates from in-channel erosion.
- Coarse sediments, such as gravel and sand, migrate along the waterway bed.
- The deposition of coarse sediments in waterways can:
  - smother aquatic (bed) habitats
  - initiate or aggravate bank erosion
  - cause channel instabilities.

Sediment-laden (turbid) urban creek (Qld)

Damage to freshwater habitats

- The release of clay-sized particles and turbid water into creeks can:
  - adversely affect the health and bio-diversity of aquatic life within permanent pools
  - adversely affect native fish populations
  - increase the concentration of nutrients and metals within permanent waters
  - reduce light penetration into pools
  - increase the frequency, cost and damage of de-silting operations.

Sediment-laden floodwater (Qld)

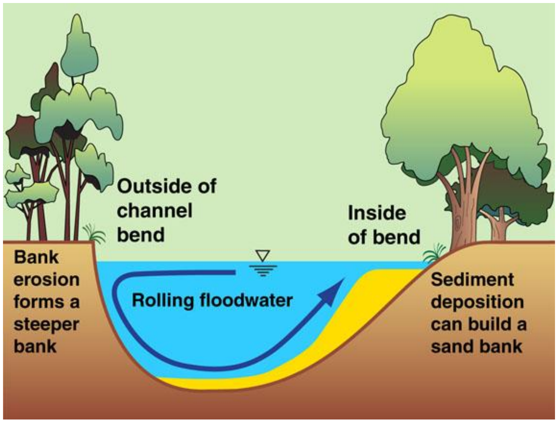
Damage to marine environments

- The release of clay-sized particles and turbid water into rivers, estuaries, bays and oceans can:
  - adversely affect the health and bio-diversity of aquatic life
  - increase the concentration of nutrients and metals
  - smother coral and aquatic habitats
  - alter natural species diversity
  - cause the loss of critical seagrass habitats following flood events.

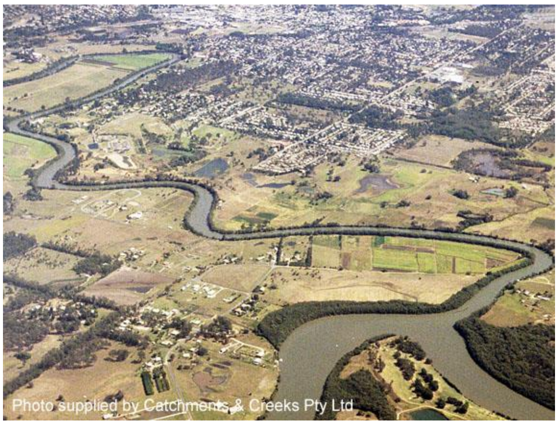
Impacts of erosion and sedimentation on creek behaviour

Bank erosion (left) & sedimentation (right)

Sedimentation on inside of channel bend



Flood hydraulics at a channel bend



Meandering river channel (NSW)

Impacts of in-bank erosion and sedimentation on a channel's top width

- Bank erosion frequently occurs on the outside of channel bends, but it can occur at almost any location along a creek.
- The effects of bank erosion, however, do not necessarily mean that the channel's width will constantly increase.
- In general, the channel's top width and bankfull flow area will try to remain constant along any given reach of a waterway.
- Waterways do this by allowing sedimentation to occur along one bank while bank erosion is occurring along the opposite bank (but not always).
- If such a process did not occur, then waterways would simply get wider and wider, year by year.
- This erosion and sedimentation process is all about maintaining a certain bankfull flow velocity along any given reach of a waterway.
- This means that over time, a channel can migrate across a floodplain while maintaining an almost constant top width and cross-sectional area.

Hydraulics at channel bends

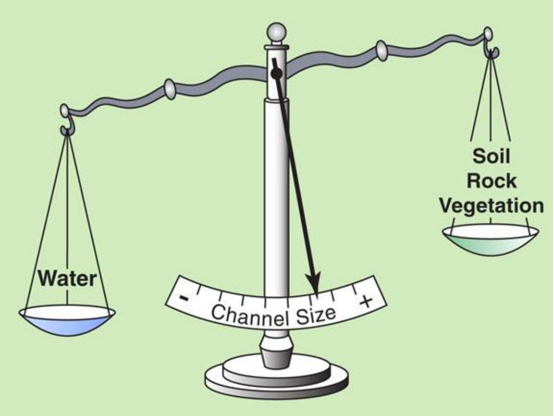
- As floodwaters flow around a channel bend, the following actions occur:
  - high-energy surface water (flowing along the centre of the channel) pushes its way towards the outside bank causing bank erosion
  - water that was previously near the outside bank is now forced to fold under this high-energy flow dragging sediments onto the channel bed
  - the 'rolling' water then carries this bed sediment towards the inside bank.

Channel meandering

- The rolling action of water observed at channel bends most often occurs when floodwaters approach bankfull conditions.
- The occurrence of these unique hydraulic conditions at channel bends means that it is difficult for the radius of a channel bend to become smaller (i.e. tighter) than 2 to 3 times the channel's top width.
- Thus if the channel's width changes, then the channel's bend radius is also likely to change, thus influencing the migration of a channel across the floodplain.

Actions followed by reactions

Brisbane River & Norman Creek in flood



A balancing act of opposing forces

Early stages of a meander being formed

Chess game

Introduction

- Most of the physical changes that occur within a waterway happen as a result of *pulsing* and *cyclic* actions.
- Floods can initiate a series of events to occur within a waterway (the action).
- But floods are infrequent (the pulse), which means there is time for the waterway to repair itself and thus resist future flood damage.
- In the periods between floods, the waterway will commence a rebuilding phase (the reaction).

Cyclic actions of expansion & contraction

- Floods regularly cause erosion within waterways:
  - which causes channels to expand
  - which causes flow velocities to reduce
  - which causes an increase in sedimentation
  - which causes channels to reduce in width or depth
  - which causes flow velocities to increase
  - which causes channels to expand (and the cycle repeats).

Waterways twist and turn

- In general, waterways do not like to exist as straight channels.
- At some point, sediment will deposit on one side of the channel:
  - which causes flows to move closer to the opposite bank
  - which causes an increase in erosion along that bank
  - which causes the channel flow to sightly change direction
  - which causes further bank erosion, etc.

For every ***action*** there is a ***reaction***

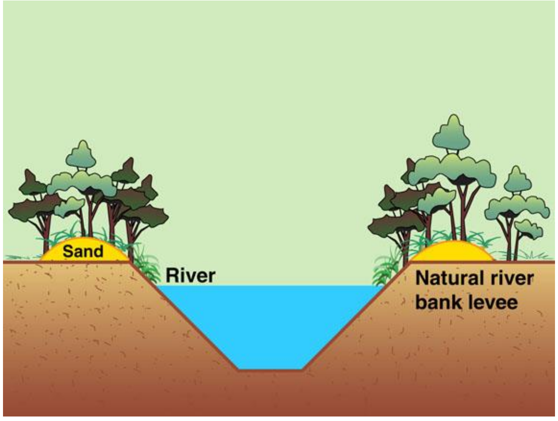
- The key to working with waterways is to be able to anticipate how a creek or river will respond to your actions, or to a recent flood event.
- It is like playing a game of chess with nature, you make your move only after you have considered the creeks next move, and if you are good, you will be planning several possible future moves.
- The real experts in creek erosion are those that can accurately predict the long-term consequences of creek works.

The movement of sediments down a waterway

Constituent components of a soil

Gravel-filled creek bank (Qld)

Sand deposited during a severe flood



Formation of natural levee banks

The make-up of soil

- Once disturbed by an erosion process, soils typically break down into their constituent components:
  - clays
  - silts
  - sands
  - gravels
  - organic matter
- Clays, silts and sands settle-out at different rates depending on their weight and their resistance to flow turbulence.

The movement of gravels in waterways

- Gravels can originate from the erosion of bed rock in the upper catchment, or from channel banks and floodplains.
- River banks often contain large quantities of gravel, which is why gravel extraction industries are often located within floodplains.
- Once gravels enter the waterway, they normally migrate along the channel bed.
- Only during severe floods will gravel be lifted out of the channel.

The movement of sands in waterways

- In undisturbed catchments, sand-sized particles are usually filtered from stormwater runoff by grasses and riparian vegetation well before they are able to enter a waterway.
- Most of the sand found in pristine waterways is likely to have originated from bank erosion within the waterway.
- In urban catchments, however, sand-sized particles can directly enter the waterway via the stormwater drainage system.
- Once in a waterway, sand usually migrates down the channel, constantly forming and reforming *sand slugs* (which migrate down the channel) and *sand bars* (which remain at a given location).
- At channel bends, sand is often deposited on the inside of the bend.
- During flood events, sand can be lifted out of the channel and onto the floodplains.
- Once the sand leaves the channel it rapidly settles out of the floodwater, often forming natural levee banks along the edges of the waterway.

The movement of sediments down a waterway

Silt deposited within a flooded home

Post-flood clean-up, Brisbane, 2011

The movement of silts in waterways

- Silts (particles between 0.002–0.02 mm) can originate from the erosion of floodplains and river banks, as well as entering the waterway via drainage pipes.
- Silts are very fine, and are therefore easily transported by floodwater.
- Silts generally settle out of floodwater only when the water reaches an area of low turbulence, such as when floodwater passes onto open floodplains.
- At the end of a flood, any silt contained in the remaining floodwater will settle to the bottom of the river or lake, and the depth of this silt will increase year by year until it is disturbed by the next major flood.
- By chance, organic matter often settles out at about the same rate as these silts, which means silts and organic matter often collect together on river beds.
- This means the silts that are deposited on floodplains during a flood are often rich in nutrients, thus helping to increase plant growth and farm production.

Brown floodwater entering a bay

Floodwater plume spilling into the ocean

The movement of clay-sized particles

- As floodwaters approach marine environments (i.e. estuaries, bays and oceans) the sediment-laden freshwater separates from the river bed and floats over the cleaner, but heavier, saline seawater.
- Aerial photographs can only show the brown surface water, but hidden below, at least for a short period, is a separate layer of clean saline water.
- Over the following days, tidal action mixes the fresh and saline waters causing the suspended sediment (consisting of only clay-sized particles) to settle to the river or ocean bed.
- It is the ‘salt’ in the seawater that helps the clays to settle out of the brown plume—this is why our oceans are ‘blue’ and not ‘brown’.
- As the sediment settles over the ocean floor, they smother marine plants and introduce high nutrient and metal concentrations into estuaries and bays that can be very harmful to aquatic fauna and flora.

Case study: 2011 Brisbane River flood

Brisbane River flood of 2011

Deposition of black, smelly silt

Sweeping the silt back into the river

Sediment plume enters Moreton Bay

The 2011 Brisbane flood

- In January 2011, Brisbane River experienced a significant flood event that inundated many homes.
- With the exception of a relatively minor flood in May 1996, this 2011 event was the first major flood the river had experienced since 1974, and since major dredging had been stopped within the river.

The 'smell' of a flood

- People remember the devastation of a flood, noise of a flood, and the *smell* of a flood.
- When a flood control dam is built on a river, the frequency and severity of major floods are reduced.
- This means the silts and organics that settle on the bed of the river are not regularly flushed from the river as would occur naturally.
- Instead, the organically-rich sediments anaerobically (without oxygen) digest on the bed of the river.
- When such material is finally disturbed by a flood, it is lifted out of the river channel where it settles on floodplains and in homes.
- As the flood recedes, the silt is exposed to oxygen, and gases are released that have a smell very similar to raw sewage.
- This silt is heavier than floodwater, and as the city was being cleaned, this smelly silt was washed or swept back into the river, but this action didn't harm the river water because the silt quickly settled back onto the river bed.

Sediment washed into Moreton Bay

- The sediment that flowed into Moreton Bay was not the gravels, the sands, or the silts, but the clay-sized particles.
- It is the clay that makes floodwater 'brown', and it is the clay particles that transport most of the real harmful pollutants, such as nutrients and metals.
- Gravels, sands and silts can cause harm within the upper reaches of rivers, and within most creeks, but harm to marine environments is mostly caused by the transportation of clay-sized particles.

3. Types of Creek Erosion

Mechanics of soil erosion

Raindrop impact

Direct impact erosion

- There are four primary forces that cause water-induced soil erosion, they are:
  - direct impact (e.g. raindrop impact)
  - scour (resulting from flow velocity)
  - gravity, and
  - electro-magnetic dispersion.
- Raindrop impact erosion does not play a major role in creek erosion—its activity is generally limited to the greater catchment, but it can cause minor erosion on exposed creek banks.

Velocity-induced soil scour (NSW)

Soil scour

- Soil scour is the result of excessive flow velocity and/or turbulence causing the direct wearing away of an exposed soil.
- Soil scour is possibly the most well known form of soil erosion; however, it is **incorrect** to assume that all examples of creek erosion are solely the result of high flow velocities.
- This form of erosion can occur on both the bed and the banks of a waterway.

Gravity-induced stress cracks on a slope

Gravity-induced bank slumping

- Gravity, or 'soil weight', is a major contributor to soil erosion on steep slopes.
- Soil surfaces are usually at their heaviest after a flood or prolonged rainfall, when all the voids in the soil profile are filled with water instead of air.
- Ultimately it is the weight of the soil that causes the slumping of earth banks, either as the sole force, or in association with soil scour that may have undercut the channel bank.

Electro-magnetic soil dispersion

Electro-magnetic soil dispersion

- Electro-magnetic soil dispersion is a form of soil erosion that is closely linked to the chemistry of the soil.
- This form of soil erosion happens at a molecular level, and is most commonly (but not always) the result of excessive available sodium in the soil.
- When these soils become 'wet', the swelling of the sodium ions can cause individual clay particles to separate from soil clumps, resulting in the clay dispersing and clouding the water (*turbidity*).

Types of creek erosion

Braided river channel (Qld)

Severe streambed erosion (Qld)

Bank erosion, Clarence River (NSW)

Lateral bank erosion (Qld)

River morphology

- Watercourse erosion can be subdivided into two main categories:
  - bed erosion
  - bank erosion
- River morphology often classifies waterways according to their channel form, such as: straight, braided, meandering and anastomosed.
- Each of these channel forms is the direct result of various types of bed and bank erosion.

Bed erosion

- Bed erosion is potentially the most damaging form of creek erosion because it not only impacts on the channel bed, but it can also initiate bank erosion in response to the lowering of the channel bed.
- The various forms of <u>bed erosion</u> include:
  - bed scour
  - head-cut erosion (a form of bed scour)
  - scour holes (a form of bed scour)
  - soil dispersion (also known as electro-magnetic soil dispersion).

Bank erosion

- Bank erosion problems are the most common form of creek erosion to be treated by a landholder.
- The various forms of <u>bank erosion</u> include:
  - bank scour
  - bank slumping (including shallow bank slips and rotational slip-circle failures)
  - bank undercutting
  - soil dispersion and slaking
  - dry-cracking
  - fretting.

Lateral bank erosion

- Lateral bank erosion is a form of bank erosion that mimics the erosion processes that commonly occur in head-cut erosion.
- In its early stages, lateral bank erosion can be identified as a form of bank erosion; however, as the erosion progresses into the bank it begins to operate as a form of gully erosion.
- Gully erosion is often viewed differently from watercourse erosion, but the processes are basically the same.

3.1 Bank Scour

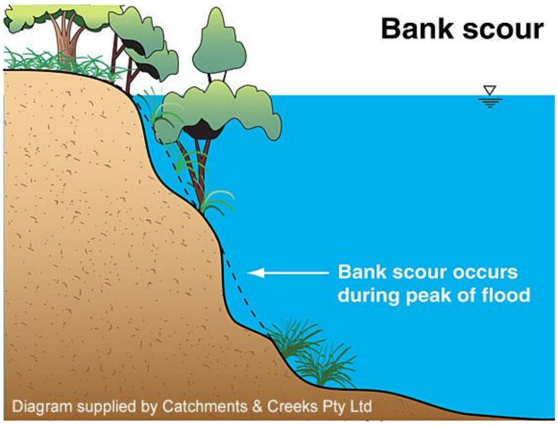
Flood-induced bank scour (Qld)

Bank scour

- Bank scour is the direct removal of material from the channel bank as a result of stream flows detaching and entraining the bank material into the floodwater.
- Horizontal scour marks can often be seen in the bank immediately after a flood; however, these mark can be removed during the subsequent days as a result of ongoing rainfall, or bank slumping.
- The degree of erosion usually varies with the strength of each soil horizon.

Bank scour showing horizontal scour marks in the soil profile, Buaraba Creek, Qld

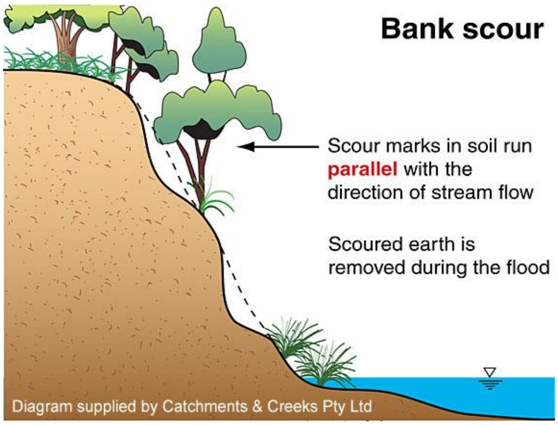
Bank scour



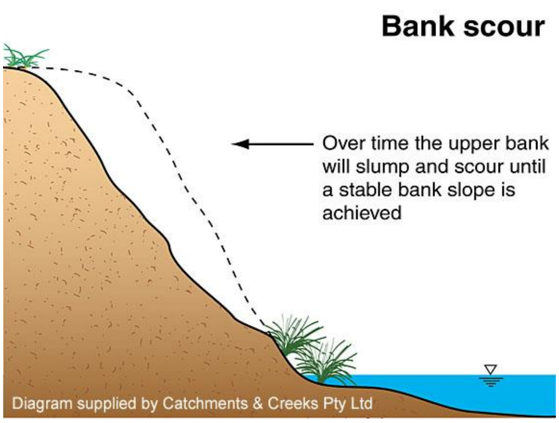
Initiation of bank scour by a flood

Bank scour

- The degree of bank damage depends on:
  - the flow velocity, and the duration of these high flow velocities
  - variations in the scour resistance of each soil layer (soil horizon)
  - the type of vegetation cover
  - the thickness of the approaching flow boundary layer.
- The duration of the flood not only affects the extent erosion, but also the degree of vegetation damage.



Horizontal scour marks visible in soil



Ongoing erosion can remove scour marks

Flood-induced bank scour (Qld)

Bank scour

- The most common cause of bank scour is high velocity flood flows.
- In-bank flow velocities are usually highest when the channel is flowing near full (bankfull flow); however, there are many examples where flow velocities actually reduce during the peak of a flood.
- Other causes of bank scour include high flow turbulence, and increases in the local flow velocity caused by debris blockages or protruding bank vegetation.

Removal of topsoil by bank scour (Qld)

Tree roots exposed by bank scour (Qld)

Bank scour – The north bank problem (southern hemisphere)

Erosion along a shaded north bank (Qld)

The 'north bank problem'

- In general, the smaller the waterway, the greater the influence vegetation has on achieving channel stability.
- A heavily shaded northern bank is often more prone to erosion than a well-vegetated southern bank because shade can reduce vegetation strength.
- In the southern hemisphere, the northern bank is more likely to be in shade than the southern bank, but the likelihood of this problem occurring reduces north of the Tropic of Capricorn.

Erosion along a shaded north bank (Qld)

Shaded north bank on an urban creek (Qld)

Erosion along a shaded north bank (Qld)

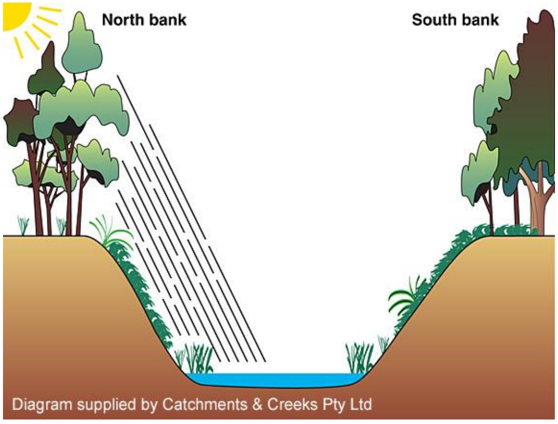
Bank slumping along the north bank (Qld)

Ephemeral waterway, Port Lincoln (SA)

Semi-arid regions and areas of low rainfall

- In some dry regions, the opposite effect can be observed.
- In these regions, water retention within the soil is critical, and as a result, 'shading' can be beneficial to plants by helping to retain soil moisture.
- In such cases it maybe the southern (sun-exposed) bank that has the least vegetation cover, and consequently experiences the more severe bank erosion, but not always!

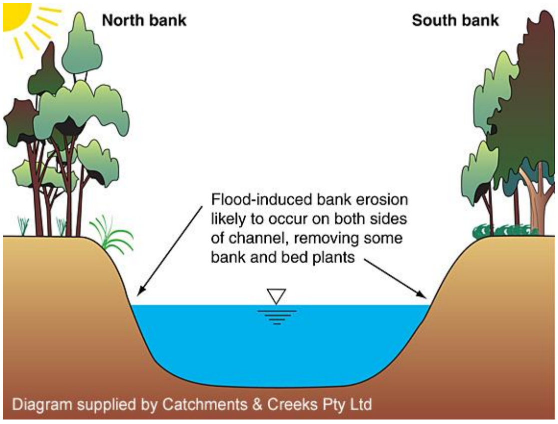
Bank scour – The north bank problem



Partially shaded northern bank

Stage 1

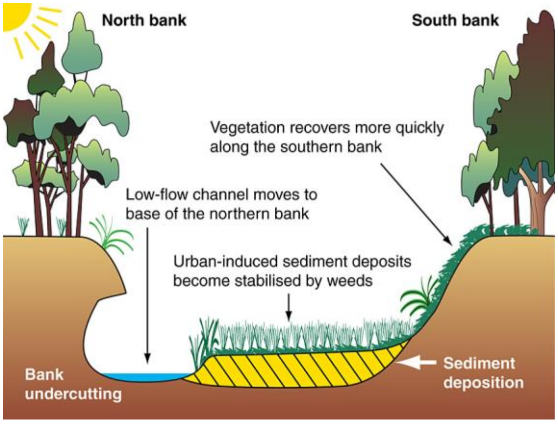
- South of the Tropic of Capricorn, the sun will always appear in the northern part of the sky, shading the northern bank (i.e. the bank that faces south).
- This means that the type of plants, and the plant density, that establishes along the northern bank can be different to those observed along the southern bank.
- Channel banks that face east or west can also be shaded for part of the day, but there is usually a better balance of light and shade on these banks.



Floodwaters cause plant loss & bank scour

Stage 2

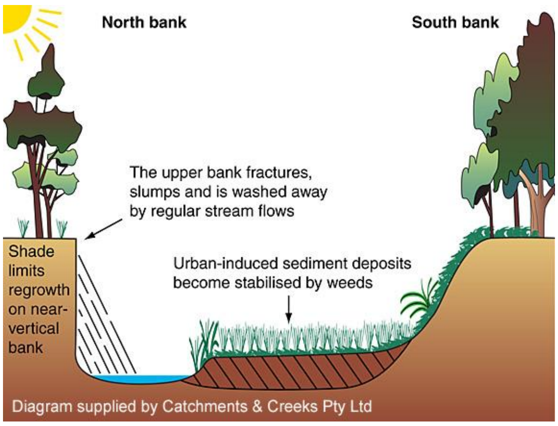
- If the waterway experiences a significant flood, or a series of high-velocity flows, then the resulting channel erosion can cause a temporary enlarging of the channel, and a loss of bank vegetation.
- Erosion could occur along both banks, but the northern bank is likely to experience more intense erosion due to the reduced vegetation strength.
- In some cases this can be the final stage of the erosion problem, but in other cases sedimentation can complicate the issue.



The northern bank becomes undercut

Stage 3 (may not occur on each site)

- Sediment released by urbanisation or instream erosion can settle along the bed of the waterway.
- In urban areas this sediment can be rich in nutrients, which can result in rapid weed growth stabilising the sediment.
- This can cause the low-flow channel to move towards the base of the northern bank, which can result in the further undermining of this bank.



Bank erodes to a near-vertical face

Stage 4 (may not occur on each site)

- Earth slumped from the bank can be washed away by stream flows.
- This can cause the northern bank to establish a near-vertical face, which increases the effects of bank shading.
- This means the northern bank struggles to revegetate, and as a result, it can slowly migrate north into the floodplain.
- If the northern bank forms the <u>inside</u> of a channel bend, then the erosion associated with a channel bend will usually dominate over this north-bank problem.

Bank scour – Erosion on the outside of channel bends

Results of bank undercutting on a river bend, Clarence River, Tabulam, NSW

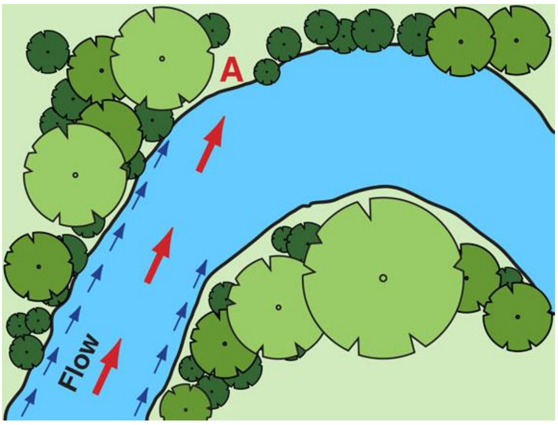
Bank erosion on a sharp creek bend (Qld)

Bank erosion on channel bends

- Bank scour often occurs along the outside of channel bends.
- Such bank erosion can:
  - affect the full height of the bank, or
  - affect only the lower portion of the bank causing 'bank undercutting'.
- This type of bank erosion can be made worse if the bank is also the shaded north bank.

Shaded north bank on the outside of a channel bend (Qld)

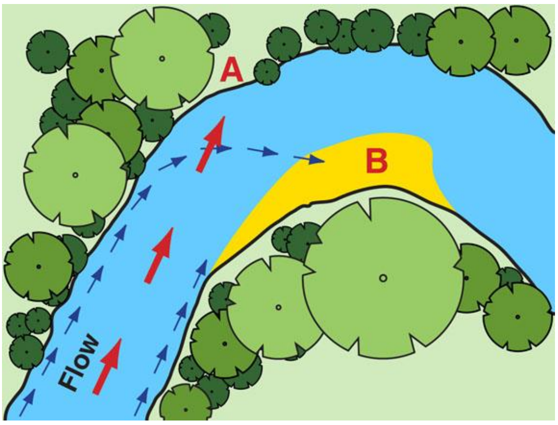
Bank scour – Erosion on the outside of channel bends



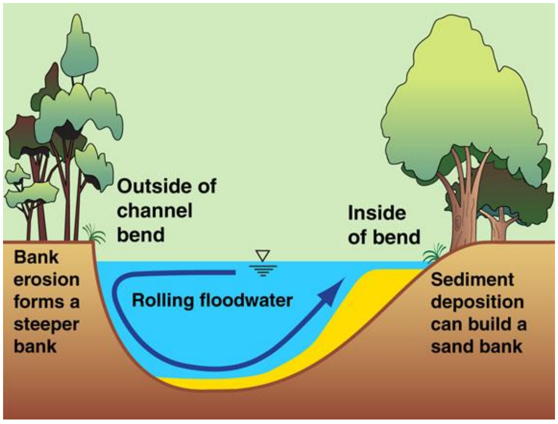
Stream flows approaching a channel bend

Flow in the centre of the channel

- In a straight section of a waterway channel, the highest flow velocities are typically found on the surface of the flow, in the centre of the channel.
- Flow velocities near the bed and close to the banks are generally much lower due to the effects of friction.
- This means that at a channel bend, the central flow has sufficient *momentum* to push towards the outer bank **(Point A)**.



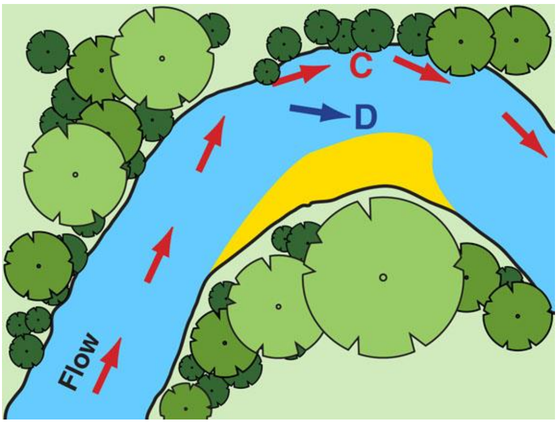
Flows can rotate at channel bends



Formation of an inside sand bank

The rolling action

- The water that was previously flowing near the outside bank is forced to move out of the way of the dominant central flow.
- This water is pushed down towards the bed of the channel causing the water in the channel to rotate.
- Any sediment eroded from the outside of the channel bank either settles to the bed of the channel, or is carried away by the rolling channel flow.
- Eventually this rolling water passes over the bed and begins to rise up towards the water surface, this time on the inside of the bend.
- Depending of the velocity of the flow, certain sized particles will be carried up the inside bank to form a sand bank **(Point B)**.
- Larger-sized sediment particles, such as gravels, usually stay on the creek bed where they will slowly migrate down the channel.
- The outside bank eventually erodes into a steep bank, while the inside bank reshapes into a mild-sloping bank.



Continued outer bank erosion

Erosion along the outside bank

- The central core of fast-flowing water either stays near the water surface continuing to cause bank erosion **(Point C)**, or parts of the flow can be carried by the rolling channel water down towards the channel bed **(Point D)**.
- The potential rolling action of this high-energy flow can contribute to the formation of a deep pool near the outside of the channel bend, which can further destabilise the outside channel bank.

3.2 Bank Slumping

Retained vegetation after bank slump (SA)

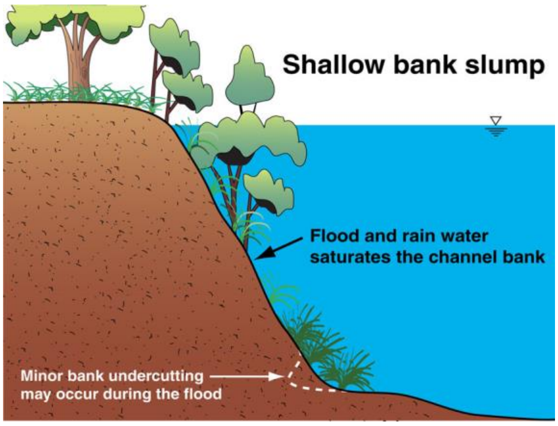
Bank slumping

- Bank slumping is the mass movement of bank material, primarily through the actions of gravity.
- The primary cause of most bank slumping is an increase in soil weight as a result of soil saturation, either as a consequence of prolong rainfall, or flood inundation.
- The actual slumping of the bank normally occurs <u>after</u> flood levels have fallen; consequently, the slumped earth often rests undisturbed, usually with vegetation still attached.

Bank slumping on the Murray River, Murray Bridge, South Australia

Bank slumping – Shallow bank slumps

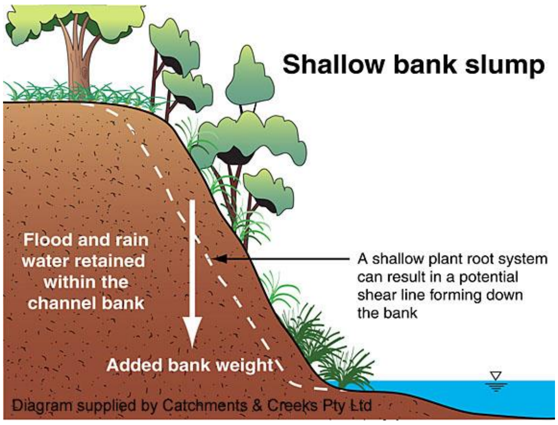
Post-flood, shallow bank slump on Brisbane River, Goodna, 2011



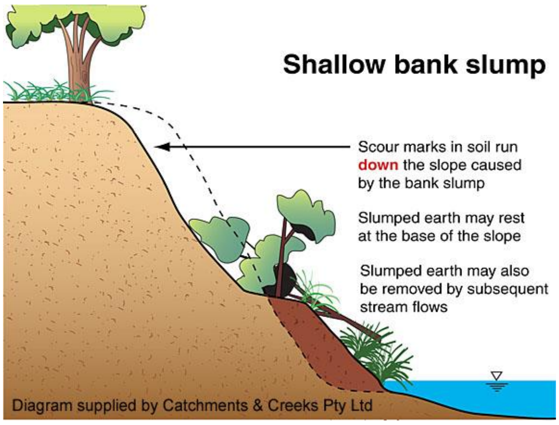
Flooding saturates the bank soil

Shallow bank slumping (landslip)

- Bank slumps may either be shallow in depth, or deep slip circle failures.
- Shallow slumps are common on gradual-sloping river banks, while deep rotational bank slips are more likely on steeper bank slopes.
- Shallow bank slumps are also possible when the river bank is covered primarily by shallow-rooted plants—in such cases the uniform, shallow root system can help to hold the slip together as it slides down the face of the bank.

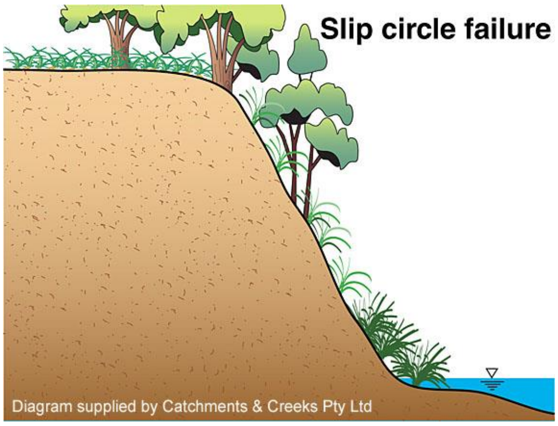


Flood levels fall leaving water in the bank



Bank slumps in the days after a flood

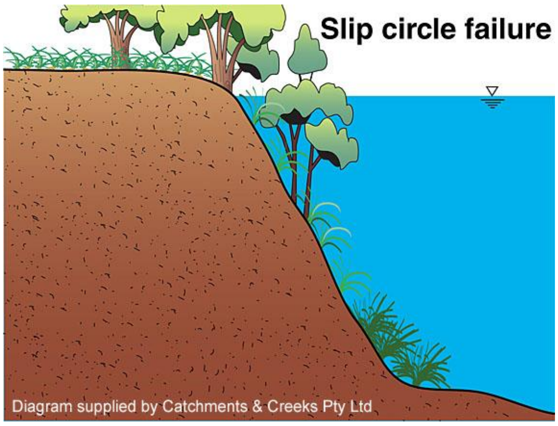
Bank slumping – Rotational (slip circle) bank failures



Pre-flood soil conditions

Introduction

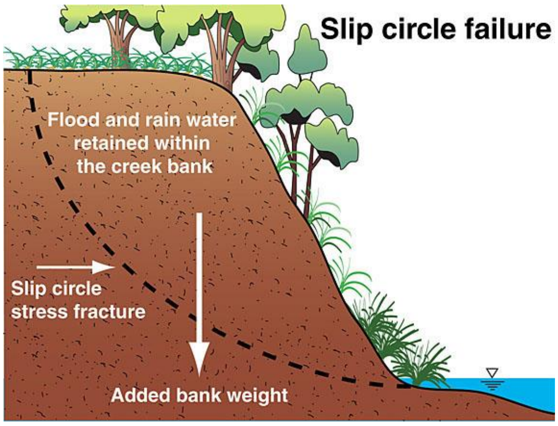
- The causes of rotational (slip circle) bank failures can be very complex and hard to identify.
- Such bank failures have been known to occur when:
  - deep-rooted trees are able to hold and anchor the bank in a manner that reduces the risk of a shallow bank slip, but
  - the root systems of these large trees do not cross-link with overbank trees.



Flooding saturates the bank soil

During a flood

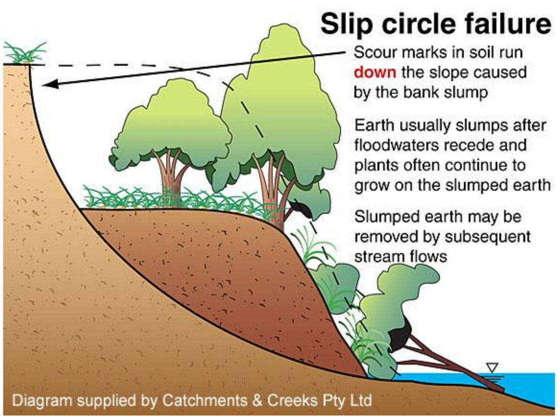
- As floodwaters rise within a creek, the air that was previously contained within the voids of the earth are replaced by water.
- The saturated bank now weighs more than when the soil was dry.
- In addition to the weight of the saturated soil, large trees can also place a significant load on the bank.
- Even though tree roots are known to help anchor steep banks, the weight of large trees can add a significant load to the bank during and after floods.



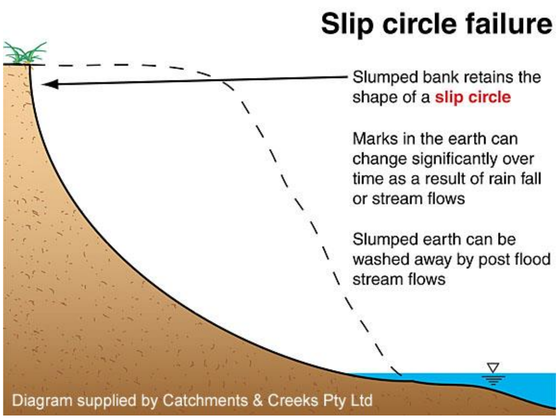
Flood falls leaving water in bank soil

Post-flood bank slips

- Once flood levels fall in the river, the additional weight of the saturated bank begins to put additional stress on the already weakened soil.
- Shortly after flood levels fall, the bank cracks and slips down towards the channel bed.
- In such failures it is common (but not always) for trees to rotate with their roots pointing towards the channel.
- Subsequent stream flows can wash the slumped soil down the river.



Bank slumps in the days after a flood

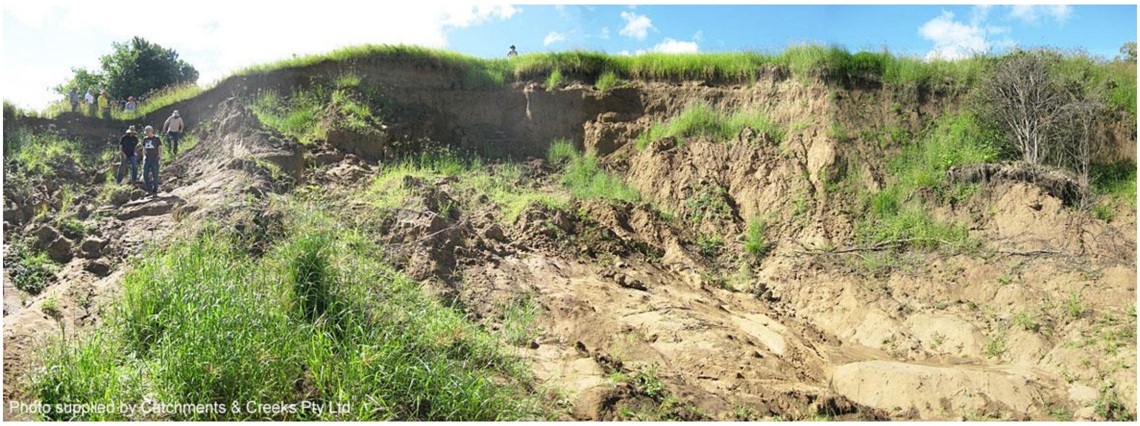


Ongoing erosion can remove more soil

Bank slumping – Rotational (slip circle) bank failures

Post-flood, slip circle bank slump, Bundaberg, Queensland, 2011

Post-flood, slip circle bank slump, Lockyer Creek, Queensland, 2011



Post-flood, slip circle bank slump, Bundaberg, Queensland, 2011

Post-flood, slip circle bank slump, Lockyer Creek, Queensland, 2011

Bank slumping – Impact of vegetation cover

Post-flood bank slumping (small tributary of Brisbane River, 2011)

Post-flood bank slumping (Qld)

Tree felled by bank slump (Qld)

Impact of vegetation cover

- Flood-related bank slumping is most commonly associated with inappropriate (unnatural) vegetation cover.
- The most common cause is the removal of deep-rooted plants (such as trees) from steep or high river banks.
- However, growing very large, very heavy trees on river banks can add significant weight to the river bank; and, if these trees are isolated from other trees, then this can help to trigger bank slumping once the ground becomes saturated.

The rotation of fallen trees

- As previously discussed, when trees fall during a bank slump it is common for the trees to slide with the rootball pointing towards the channel.
- Exceptions to this can occur when strong winds cause the tree to fall in the direction of the wind, or floodwaters fell the tree in the direction of the stream flow.
- If the bank slump is only mild, then the tree may simply slide with the slump and continue to grow within the slumped earth.

3.3 Bank Undercutting

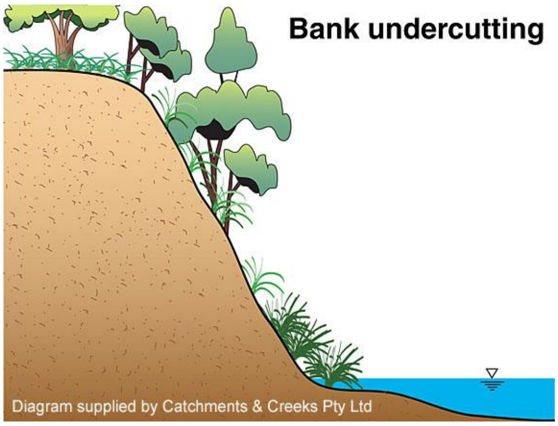
Cracks along the edge of the bank (Qld)

Bank undercutting

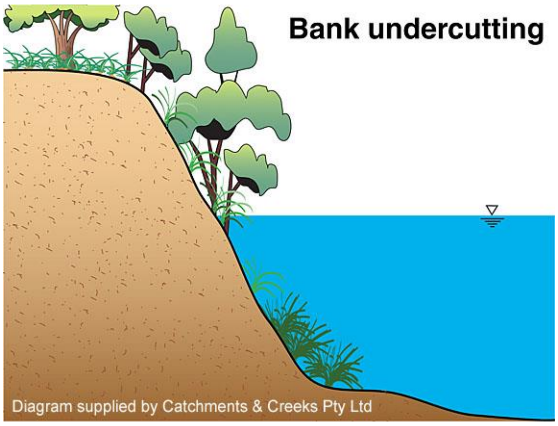
- Bank undercutting is the combination of bank scour along the lower portion of the bank, followed by the slumping of the upper bank.
- This form of erosion usually results in the formation of a temporary overhanging bank, which can fail during a flood causing the slumped material to be washed away.
- However, there are many instances where the undercut bank remains after a flood, which can create a safety issue for those walking near the bank's edge.

Ongoing post-flood bank slumping following earlier bank undercutting, Queensland

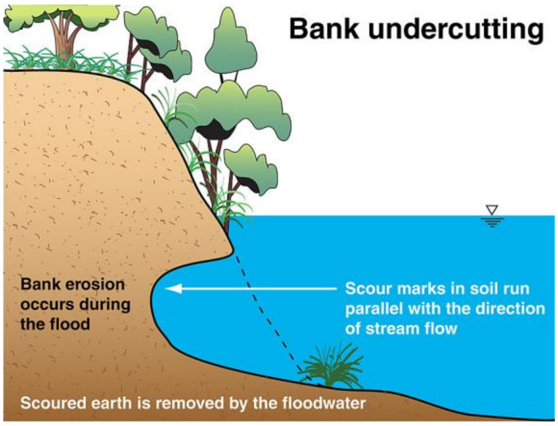
Bank undercutting



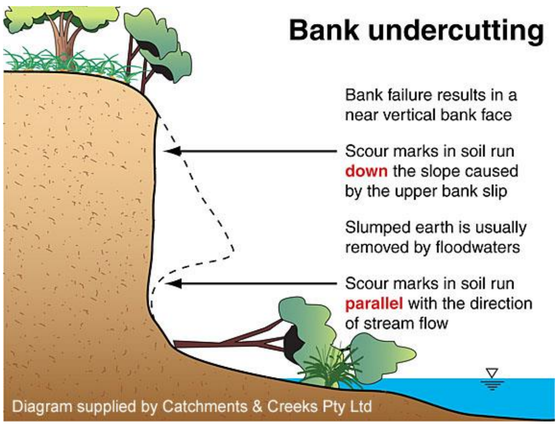
Pre-flood, well-vegetated bank



In-bank flows scour the lower bank



Bank undercutting



Failure (slumping) of the upper bank

Introduction

- Bank undercutting occurs when the actions of bank scour are concentrated on the lower areas of a bank.
- This outcome can result from:
  - the soils in the lower levels of the bank being weaker than the upper layers (which is a common problem)
  - the existence of weaker vegetation along the lower levels of the bank
  - the occurrence of several minor stream flows that are below bankfull conditions.

Early stages of flood damage

- Bank undercutting primarily occurs during elevated stream flows, whether or not these stream flows are below bankfull (freshes) or above bankfull (floods).
- On some occasions, bank undercutting can result from the low-flow channel migrating too close to the creek bank.
- Bank undercutting is also common on the outside of channel bends.

Bank scour during a flood

- Soil scour occurs along the lower bank while the flow velocities are elevated.
- If the bank collapses during the flood, then it can be difficult to identify whether the bank failure was the result of bank undercutting or bank slumping.
- If the bank is observed immediately after the flood, and the slumped earth is still at the base of the bank, then it is likely to be a case of *bank slumping*; however, if the fallen earth has already washed away, then *undercutting* could be the cause.

Post-flood bank slumping

- In many instances, the upper bank does not collapse or slump until days after the flood.
- The end result is often a near-vertical upper bank, as opposed to a more curved bank failure (which is more commonly associated with bank slumping).
- If large trees fall as a result of bank undercutting, then they often (not always) fall with their branches pointing towards the channel.

Bank undercutting – Impact of vegetation cover

Bank undercutting on a channel bend adjacent a small bank slump, Miles, Queensland

Tree roots exposed by undercutting

Tree falls after bank undercutting

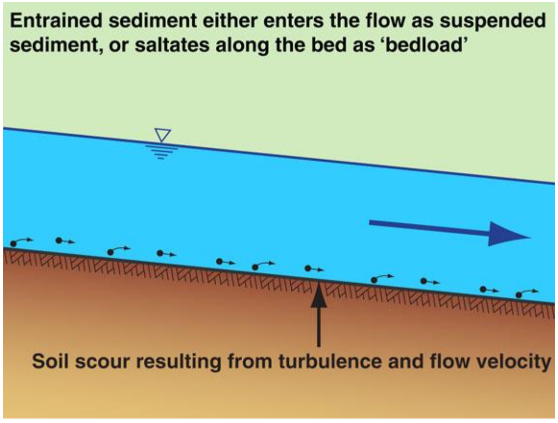
Impact of vegetation cover

- Good vegetation cover on river banks may slow the effects of bank undercutting, but if the bank is higher than the plant's root system, then the lower bank scour will either:
  - wash the soil from the root system exposing it to excessive drying, possibly killing the plant, or
  - completely undermine the rootball.
- Only certain tree species can survive such severe exposure of their root system.

The rotation of fallen trees

- Bank undercutting normally results in trees falling with their branches pointing into the channel.
- Once again, exceptions to this can occur when strong winds topple the tree in the direction of the wind, or stream flows further disturb and rotate the tree.
- Appropriate lower-bank vegetation can help protect the upper-bank; while appropriate upper-bank vegetation can help to reduce the risk of bank slumping.

3.4 Bed Scour



Mechanics of bed scour

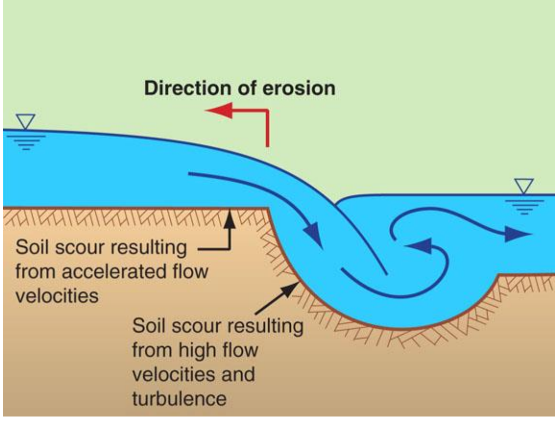
Bed scour

- Bed scour is the direct removal of material from the channel bed as a result of high-velocity flows detaching and entraining the soil or sediment into the flow.
- Bed scour also includes the following forms of channel erosion:
  - 'head-cut' erosion where a small erosion head (waterfall) migrates up the bed of the channel, and
  - 'scour holes' where isolated holes are formed in the channel bed or floodplain.

Plant roots exposed by bed scour, Magnetic Island, Queensland

Bed scour – Head-cut erosion

Head-cut eroding (migrating) up a waterway channel, Queensland



Mechanics of head-cut erosion

Head-cut erosion

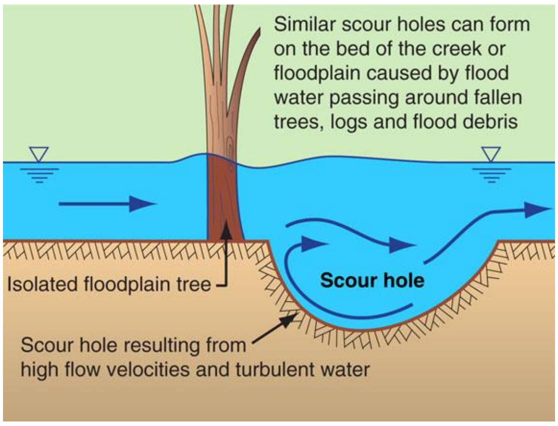
- Bed scour most commonly occurs through the actions of a migrating head-cut.
- A 'head-cut' is a sudden drop in the bed level, which usually migrates up the channel during flood events, but can also continue to migrate during regular dry weather flows.
- Immediately downstream of the head-cut there is usually a scour hole that also migrates up the channel.
- The existence of the scour hole is critically important for energy dissipation.

Migrating head-cut erosion (Qld)

Migrating head-cut erosion (Qld)

Bed scour – Scour holes

Scour hole located within an ephemeral tributary, Queensland



Scour hole formed downstream of tree

Isolated scour holes

- Scour holes are caused by local flow turbulence, usually associated with standing or fallen trees, or a channel constriction.
- The main feature that separates 'scour holes' from 'head-cut' erosion is that there is usually no change in land level across a scour hole, which means scour holes usually do not migrate up the channel.
- Scour holes can turn into permanent pools; but, can also be filled with sediment during subsequent flood events.

Scour hole within a floodplain (Qld)

Scour hole in bed of an ephemeral creek

3.5 Fretting

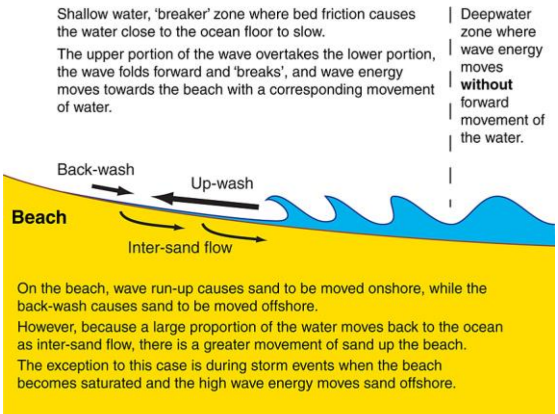
Boat-generated waves approach a bank

Wave-induced 'fretting'

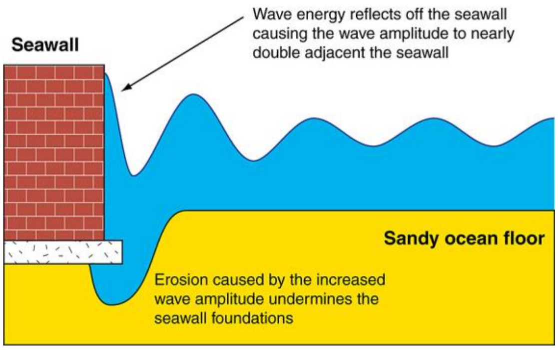
- Fretting is a relatively rare type of bank erosion.
- Fretting is the erosion of a bank at a specific elevation, or at a point of weak soil, as a result of wave action.
- This form of bank erosion is primarily caused by waves generated from power boats or water skiing.
- The erosion is closely associated with the breaking of waves as they approach a soil bench formed on the lower levels of a river bank (often covered with mangroves).

Fretting of a river bank caused by boat-generated waves, Brisbane, Queensland

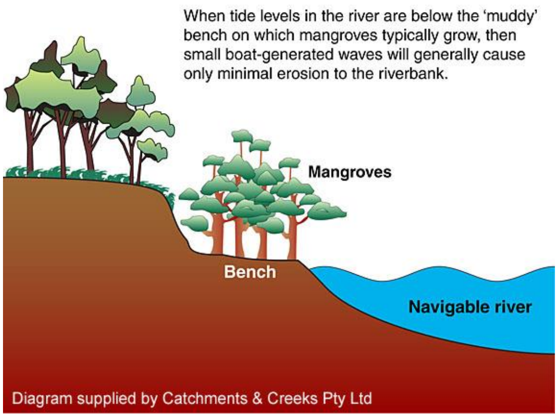
Fretting – The effects of wave action on river banks



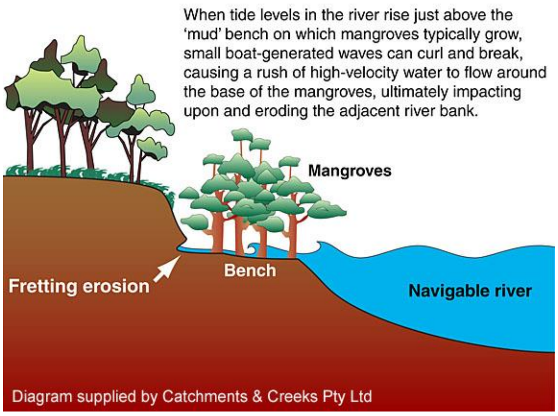
Mechanics of wave action on beaches



Mechanics of wave action against walls



Wave action during low tide



Wave action during mid-tide

The mechanics of wave action on beaches

- Nature has developed two primarily responses to wave action; the formation of beaches, and the formation of cliffs.
- As waves approach a beach, the lower part of the wave is slowed by friction, causing the wave to curl and break—resulting in wave run-up (the up-wash).
- Sandy beaches can absorb this wave energy by allowing part of the up-wash to return to the sea as inter-sand flow, thus more sand is pushed up the beach by water than is dragged down the beach.

The mechanics of wave action adjacent to cliffs and seawalls

- If waves approach a cliff or seawall, then the waves do not break until they smash against the cliff or seawall.
- Wave energy is not totally absorbed by the cliff, and some is reflected out to sea.
- This causes a dramatic increase in the effective wave height adjacent the cliff, as well as causing a scour hole to be formed at the base of the cliff.
- This is what causes many seawalls to be undermined.

Wave action adjacent river banks

- In their natural state, tidal rivers and creeks do not experience significant wave action, which allows mangrove flats (benches) to form at the base of river banks, usually around mean tide level.
- If waves are introduced to a river by boat traffic, then during low tide these waves will approach the river bank below the height of the mangrove benches, and most of the wave energy will be reflected back out into the river.
- During, and just above mid-tide level, boat-generated waves approach the river bank just above the height of these mangrove benches. As the waves approach these benches they curl and break just like on a beach.
- After breaking, wave energy is transferred into a forward rush of water, which erodes the mud from the base of the mangroves, before the wave finally crashes into the adjacent river bank.
- Over time the mangrove bench and the mangroves can be removed by this wave action, and the adjacent bank will be undermined.

3.6 Lateral Bank Erosion

Lateral bank erosion (Qld)

Lateral bank erosion

- Lateral bank erosion is the erosion of a creek bank as a result of stormwater runoff spilling down an unstable bank.
- These lateral inflows are normally the result of local stormwater runoff, but they can also result from flood flows spilling off a floodplain and back into the creek.
- Lateral bank erosion often expands into a gully that migrates laterally from the creek bank.

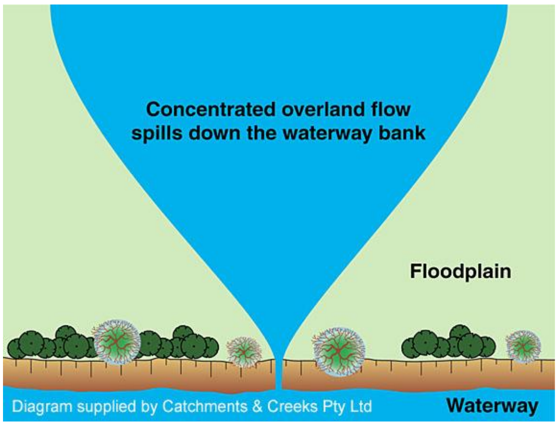
Lateral bank erosion caused by farm runoff spilling into the creek (Qld)

Lateral bank erosion – The formation of a gully

Branching of gully erosion (SA)

Formation of a gully

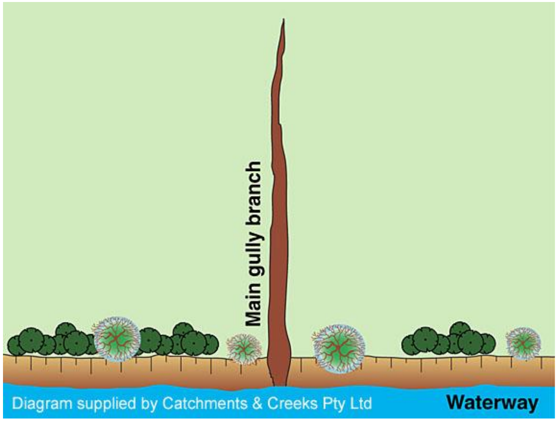
- Gullies are commonly formed from the growth of lateral bank erosion.
- These gullies often expand by forming several connected branches that mimic the tributaries of a waterway.
- These expanding branches typically spread in all directions, radiating out across the floodplain or valley.
- The erosion of the gully head is usually much faster than the erosion of the gully's banks.



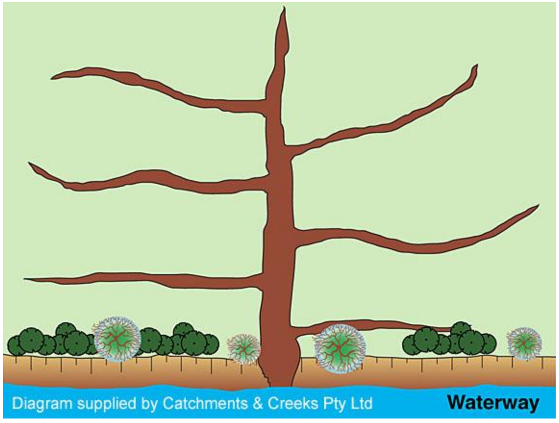
1. Initial triggering of gully (plan view)

Branching of gully erosion

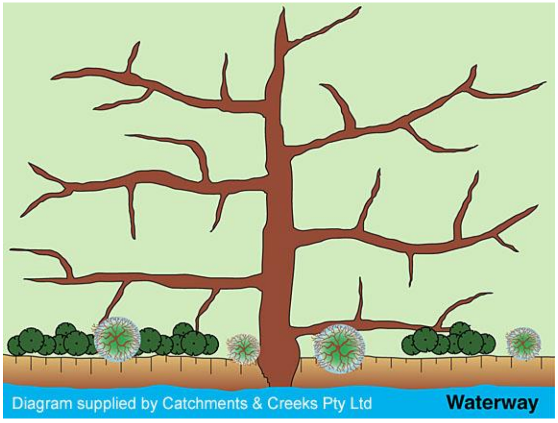
- The following five diagrams demonstrate the various stages of gully erosion:
  - initial triggering of the gully erosion
  - lateral growth of the main gully line
  - expansion of the gully through the actions of lateral bank erosion
  - widening of the gully through ongoing bank erosion.
- Eventually the gully erosion will completely reshape the landscape forming a new valley and ephemeral watercourse.



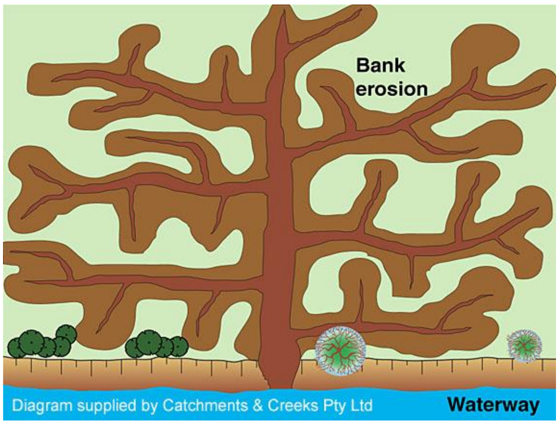
2. Lateral migration of the gully head



3. Initial branching of the gully



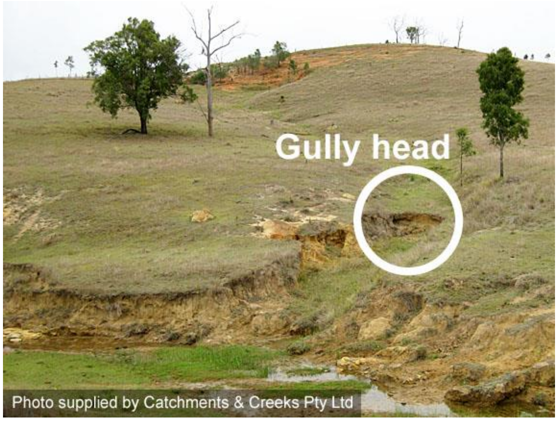
4. Further branching of the gully



5. Widening of the gully by bank erosion

Gully erosion

Gully erosion within a dispersive soil, Port Lincoln, South Australia



Initial stage of gully erosion (Qld)

A well-established gully head (Qld)

Gully erosion

- Gully erosion is a collective term that describes the type of channel in which the erosion is occurring, rather than the erosion mechanism.
- Gullies are recently formed channels, as opposed to waterways that have existed for centuries.
- Most gully erosion starts as a form of lateral bank erosion, but then continues through a process of head-cut erosion, followed by bank scour, bank slumping and bank undercutting.

Causes of gully erosion

- The causes of gully erosion can be similar to those found for creek erosion.
- However, unlike creek and river erosion, the critical flow condition (i.e. the flow that dictates the size of the gully) is not the bankfull flow.
- The severity of gully erosion is generally related to the soil type, the valley slope (or gully slope), and the frequency and duration of flows.

3.7 Soil Dispersion

Erosion of a dispersive soil (NSW)

Bank erosion resulting from soil dispersion

- Electro-magnetic soil dispersion is a form of erosion that results from unstable soil chemistry.
- This type of erosion is most commonly associated with sodic soils that have excessive quantities of exchangeable sodium cations in the soil.
- When clay particles become wet they find it easy to separate from the soil (as turbid runoff), causing the soil structure to collapse and the coarse (sandy) soil particles to fall to the bed of the creek.

Fluting erosion on the bank of an ephemeral watercourse, Port Lincoln, SA

Soil dispersion

Textured surface of a dispersive soil (Qld)

Fluting and tunnel erosion

- Dispersive soils can often be identified by their textured surface and scour marks.
- Soil surfaces that are <u>not</u> exposed to direct rainfall, but are exposed to water splashed from an adjacent surface, often develop a textured surface similar to the appearance of a termite mound.
- Exposed creek banks often develop a regular pattern of closely-spaced, vertical rills known as ***fluting***.
- These soils can also experience tunnel erosion problems.

Textured surface of a dispersive soil (SA)

Fluting of a channel bank (Qld)

Fluting and tunnel erosion (Qld)

Fluting of a gully bank (Qld)

Tunnel erosion (SA)

Tunnel erosion (Qld)

Soil erosion resulting from slaking soils

Severe gully erosion in a slaking soil in the Bowen River basin, Queensland

Gully erosion through a sandy soil (Qld)

Bank erosion resulting from 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 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.

Soil pinnacle (Qld)

Soil pinnacles (NSW)

Soil erosion resulting from cracking clays (dry bank slumping)

Crumbling soil (grey cracking clay) spills down a creek bank, Beaudesert, Queensland

Cracking clay (dry condition), NSW

Bank erosion resulting from cracking clays

- The term 'clay' can be used to describe the smallest of the soil particles (< 0.002 mm), or it can be used to describe a soil that has a high clay content.
- 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 fall to the bed of the creek.

Crumbling soil bank (Qld)

Crumbling soil bank (Qld)

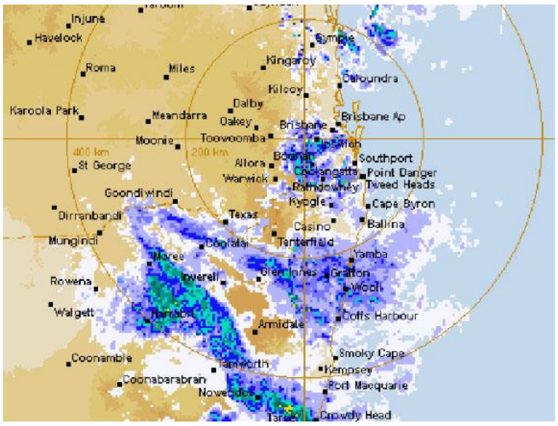
4. Catchment Hydrology and Open Channel Hydraulics

Introduction

Post graduate training course

Purpose of this chapter

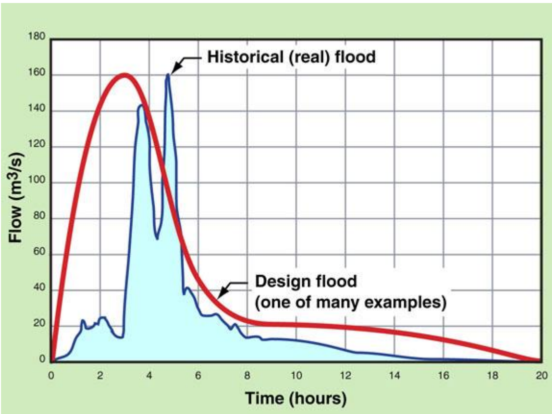
- This field guide is likely to be used by a wide variety of people, some of which may be experienced in catchment hydrology and hydraulics, while others may have no previous training in water engineering.
- To assist those readers that do not have formal training in water engineering, this chapter provides an introduction to catchment hydrology and open channel flow hydraulics.
- The chapter ends with some advanced discussion on open channel hydraulics.



Weather radar map

Catchment hydrology

- In creek engineering, one of the first tasks is often to determine the peak discharge generated by a specified *design storm*, or a recent flood event.
- *Hydrology* is the study of the movement of water over or under the land, and it is this science that we use to calculate peak discharges.
- A *design storm* is a theoretical storm that is based on an analysis of the historical storms that have been recorded at a given location.



Example historical and design floods

Design storms vs historical floods

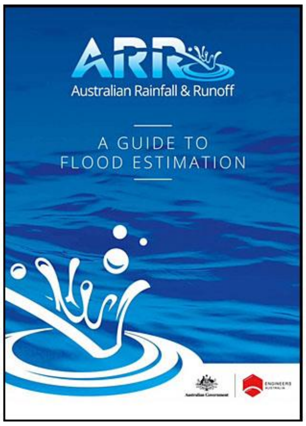
- Engineers use design storms to design new drainage systems, which from time to time may include the design of erosion control measures within a waterway.
- If erosion control measures are being designed for a waterway that has recently experienced a flood event, then the design procedure will usually involve checking the proposed design of the flow conditions that existed during the recent flood event.

Constructed drainage channel (NSW)

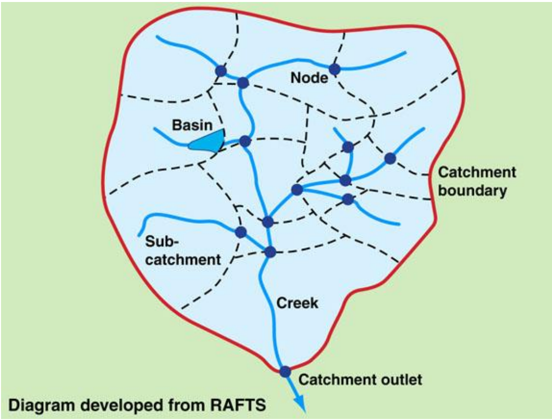
Open channel hydraulics

- Once a peak discharge has been determined, the next step is usually to determine the flow velocity that existed within the waterway at the time of the peak discharge.
- *Hydraulics* is the study of the flow conditions within a conduit or channel.
- *Open channel hydraulics* is the study of the flow conditions in a channel where the water surface is exposed to air (even if the flow is inside a pipe or culvert).

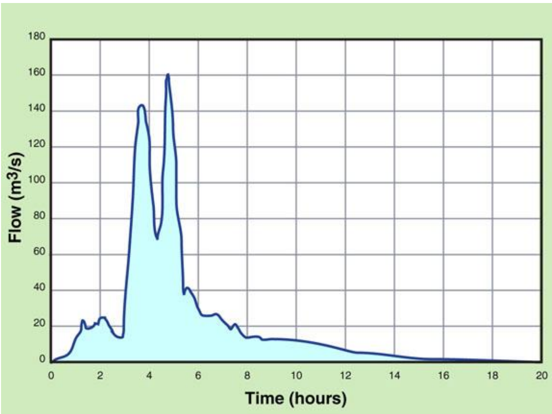
Catchment hydrology



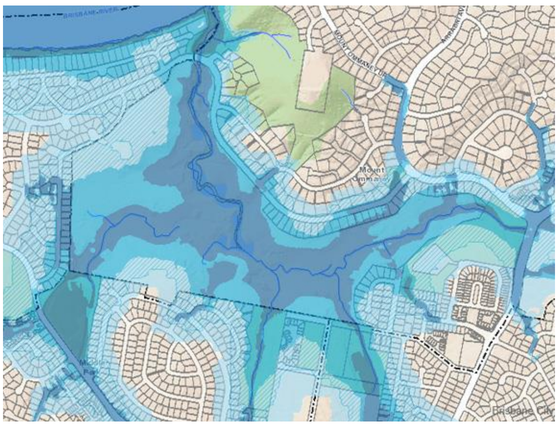
Australian Rainfall and Runoff, 2016



Drainage catchment model



Flood hydrograph



Flood inundation map

Introduction

- Flow velocity is one of the primary variables used in the design of erosion control measures.
- In order to be able to estimate the flow velocity it is usually necessary to first determine the relevant flow rate within the waterway.
- Flow rates may be based on historical flood gauging, historical rainfall data, or a prescribed *design storm* in accordance with the recommendations of a relevant flood manual.

Hydrologic models (rainfall-runoff models)

- Hydrologists can use a variety of methods to generate flood hydrographs and peak discharges.
- In most cases, detailed *hydrologic models* are developed that simulate the runoff characteristics of a particular drainage catchment.
- Rainfall data, known as *temporal patterns*, can be based on actual recorded data, or generated from the procedures specified within a flood manual.

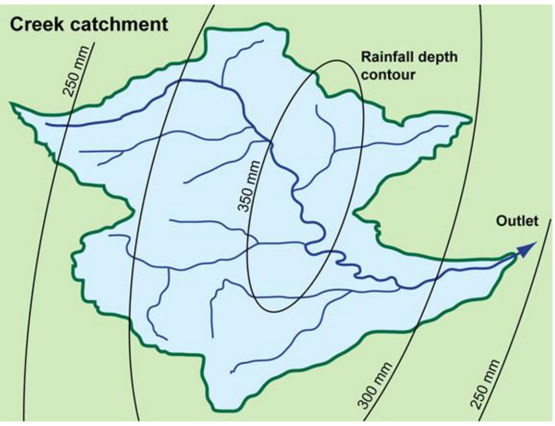
Flood hydrographs and peak discharges

- *Flood hydrographs* are a plot of stream discharge verse time at a given location.
- There are several different methods for generating a flood (discharge) hydrograph:
  - physical stream gauging of a real flood
  - statistical analysis of historical flood events
  - numerical models that convert rainfall data into flood hydrographs
  - empirical equations.

Flood levels

- Flood levels are either determined by:
  - recording actual flood levels
  - statistically analysing peak water levels from historical flood events
  - numerical models that convert flood hydrographs into peak flood levels.
- Flood levels can be affected by many factors, so it is possible for two adjoining properties to record different peak flood levels during the same flood event.

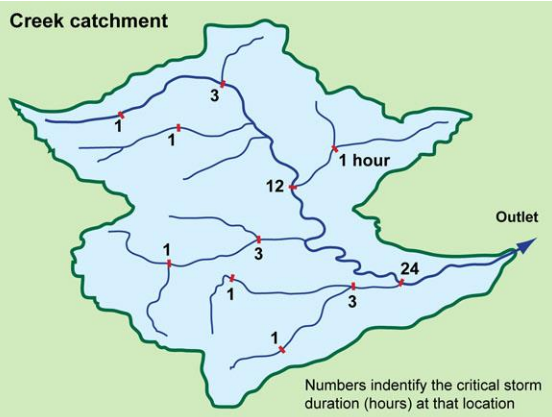
Catchment hydrology



Rainfall map for a single storm

Urban development (Qld)

Storm event (Qld)



Critical storm duration

Calculating peak discharge

- There is a wide range of numerical models that can be used to calculate peak flows for a given catchment and storm event.
- In very simple cases, engineers can use the *Rational Method* to determine a peak discharge.

Q = (C.I.A)/360

- ♦ Q = peak discharge (m^3/s)
- ♦ C = a coefficient (dimensionless)
- ♦ I = average rainfall intensity (mm/hr)
- ♦ A = catchment area (hectares)

Catchment conditions (C)

- The peak discharge generated by a particular storm event will depend on the conditions of the catchment, which can include:
  - soil moisture levels
  - impervious surface area (urbanisation)
  - percentage of grass and forest cover
  - the ability of the catchment to hold water on the land surface (e.g. ponds).
- The effect of these variables is included in the equation's coefficient '**C**'.

Rainfall conditions (I)

- The Rational Method cannot be used to analyse all storm events.
- The Rational Method can only be used to analyse what is termed the *critical storm event* for a given catchment.
- The *average rainfall intensity* (I) is the average rate of rainfall (mm/hour) measured over the *critical storm duration* for the catchment, even if the duration of the actual storm exceeded the critical storm duration.

Critical storm duration

- The *critical storm duration* for a given catchment is defined as the time taken for water to travel from the most remote part of the catchment to the point on the waterway where the peak discharge is being calculated.
- Every property along a waterway will have a unique critical storm duration.
- That means every property along a waterway will experience a different degree of flooding during any given storm event.

Different storms cause different flows at different locations

Satellite image of a storm (WA)

Flood level gauge, Rockhampton (Qld)

Not every property along a waterway will experience the same degree of flooding during any given flood

- The severity of the flooding **at your property** is not directly related to the storm frequency as reported by the council or the media (e.g. a 1 in 100 year storm).
- The severity of the flooding at your property is dependent on many factors, one being the *critical storm duration* for **your property**, which will be different from the critical storm duration of other properties along the waterway.

Storm duration is a critical factor

- Storm duration is a critical factor in determining where the worst flooding will occur during any given flood.
- Short duration storms (lasting a few hours) usually cause severe flooding within the smaller waterways.
- Long duration storms (lasting a few days) typically cause severe flooding further down the catchment, in the larger creeks and within rivers.
- It can take five days of heavy rainfall to cause a flood in many of our rivers.

Understanding 'your' critical storm duration

- Every location along a waterway will have its own critical storm duration, which will ultimately determine the severity of flooding during any given storm event.
- The critical storm duration for a property is determined by calculating how long it would take for floodwater to travel from the top of the catchment to the property.
- If the critical storm duration for your property is 3 hours, then stream flows at your property, at any given point in time, will be strongly influenced by the total depth of rainfall that occurred over the previous 3 hours, even if the storm lasts longer than 3 hours.
- This means that if a storm lasts for 2 days, then the severity of the stream flows at your property will be largely dependent on the depth of rainfall that occurred during the worst 3-hour period of rainfall during those two days.
- It also means that your property will only experience a 1 in 100 year flood event if the rainfall intensity averaged over the worst 3-hour period during a given storm is equal to the predicted 1 in 100 year, 3-hour average rainfall intensity that has been determined from an analysis of historical rainfall records for your catchment.
- Consequently, if your waterway catchment experiences a 1-hour, 1 in 100 year storm burst, then the flooding will be worst for those properties that have a 1-hour critical storm duration, while your property (which has a 3-hour critical storm duration) may only experience a 1 in 20 year or 1 in 50 year flood level.
- Similarly, if your waterway catchment experiences a 4-day, 1 in 100 year storm, then the flooding will be worst for those properties that have a 4-day critical storm duration, while your property may only experience a 1 in 1 year flood level, or possibly no flooding at all.
- In a waterway catchment the size of the Murray-Darling basin, there can be many, many different types of 1 in 100 year storm events, each causing different flow conditions within different parts of the catchment, which is one reason why so many 1 in 100 year storm events are reported by the media.

Catchment conditions and their influence on catchment hydrology

Town centre (Tas)

Commercial and city centres

- The volume of stormwater runoff is strongly influenced by the percentage of the land covered by impervious surfaces, such as roads and roofs.
- Areas such as city centres, and industrial and commercial precincts, have extensive amounts of impervious surfaces.
- These surface areas also provide few opportunities for stormwater to pool on the surface of the land (known as: *surface storage*).

Residential area (Qld)

Urban areas

- Urban areas contain significant amounts of impervious roads and roofs interlaced with areas of vegetated soil.
- Modern, high-density residential areas typically consist of around 70 to 90 per cent of impervious surfaces.
- Older, low-density residential areas typically contain around 40 to 80 per cent of impervious surfaces.
- These areas also facilitate only limited amounts of temporary surface storage.

Cleared bushland (Qld)

Grassed surfaces

- Land surfaces covered with shallow-rooted vegetation, such as grasses and most commercial crops, typically capture and hold less rainwater than land surfaces covered by dense bushland.
- Land clearing can significantly increase the total volume of stormwater runoff that will be discharged from a drainage catchment on an annual basis.
- The impact that land clearing has on the runoff from individual storms is very complex, and varies from storm to storm.

Bushland (Tas)

Bushland

- Natural bushland typically has the greatest infiltration capability of all land surfaces, with the exception of sand dunes.
- It takes around 100–200 mm of rainfall to saturate bushland, compared to just 20–50 mm of rainfall to saturate grassland.
- Bushland can also hold large volumes of rainwater on leafy surfaces and within the leaf-litter that covers the ground.
- Bushfires, which remove leafy matter, can cause significant short-term changes to the runoff characteristics of the land.

Flood frequency, probability and grouping

Introduction

If you are currently facing the task of repairing flood damage to your local creek, then you may well have listened to the media reporting on the frequency of this latest flood. The media may have reported the storm as being a 1 in 100 year event, but then you think to yourself: this is the third 1 in 100 year flood that has occurred over the past 10 years. So is it all just media hype?

Well the first thing to know is that there is a BIG difference between a 1 in 100 year storm, and a 1 in 100 year flood. Also, a 1 in 100 year storm does not necessarily produce a 1 in 100 year flood! It depends on such things as the wetness of the catchment at the start of the storm. It also depends on the size of the storm relative to the size of the catchment.

If a 1 in 100 year thunder storm occurred in the upper parts of the Murray River, then it is likely that water levels in the river would remain unaffected by such a storm. A thunder storm would simply not produce enough stormwater runoff to influence the greater Murray River.

The truth is, over a catchment that is the size of the Murray–Darling basin, there would be several 1 in 100 year thunder storms every year. But actual 1 in 100 year river floods would occur much, much less frequently.

So the next time you listen to a report from the Bureau of Meteorology, listen carefully, did they say that it was a 1 in 100 year storm, or a 1 in 100 year flood?

Flood frequency

So does the 1 in 100 year flood occur just once every 100 years? Well, no!

The term 1 in 100 years simply means that there is a 1/100 per cent (i.e. 1%) probability of that flood level being equalled or exceeded during any 12 month period.

This means that over a period of say, 1000 years, there should be approximately 10 floods that equalled or exceed the predicted 1 in 100 year flood level.

It also means that over a period of 10 years there should be approximately 10 floods that equalled or exceed the predicted 1 in 1 year flood level. But this does not mean that you will get 10 floods that are exactly the height of a 1 in 1 year flood.

Consider the following *ideal* scenario; over a 10 year period there may be:

- one 1 in 10 year flood
- one 1 in 5 year flood
- one 1 in 3 year flood
- two 1 in 2 year floods, and
- five 1 in 1 year floods.

That means there were two floods that equalled or exceeded the 1 in 5 year flood level, and 10 floods that equalled or exceeded the 1 in 1 year flood level over that 10 year period (but that is in an ideal world).

Flood probability

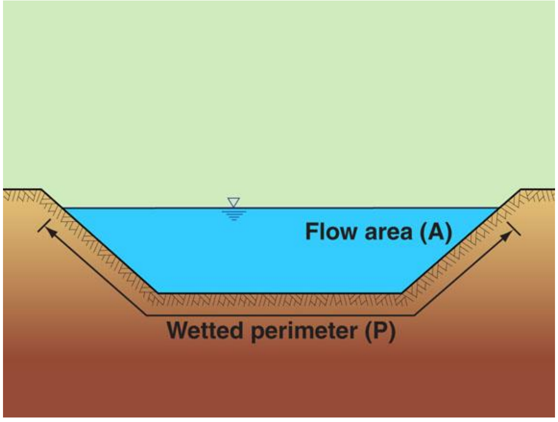
Because of the fact that so many people have trouble understanding the true meaning of the term; 1 in 100 years, flood engineers are now beginning to refer to floods according to their 'probability' rather than their 'frequency'. So instead of the flood being referred to as a 1 in 100 year flood, it is now called a 1% flood.

Flood grouping

A study of historical flood records will show that major floods generally occur in 'groups', separated by long periods of only minor flooding. We know that there is a 1 year cycle to our weather: summer–autumn–winter–spring, but there is also **approximately** a 10 year cycle to our weather that is linked to El Nino and La Nina cycles.

However, historical records also show that there is **approximately** a 100 year cycle to our flooding. Most of the major floods in the 1800s occurred in the last 50 years of that century. Similarly, most of the major floods in the 1900s occurred in the last 50 years of that century (1956, 1974, 1986, 1988, 1996). Note that the 1920s was a period of severe droughts around the world, which was one of the factors adding to the Great Depression.

Open channel hydraulics



Channel cross-section

Trees with high branches (Qld)

Mat-forming grasses in an urban waterway

In-bank vegetation damaged by a flood

The flow capacity of a channel

The discharge capacity of simple channels may be estimated using Manning's equation:

$$Q = (1/n)\ A\ .\ R^{2/3}\ .\ S^{1/2}$$

where:

- Q = discharge (m^3/s)
- n = Manning's roughness coefficient
- A = cross-sectional area of flow (m^2)
- R = hydraulic radius (m) = A/P
- P = wetted perimeter of flow (m)
- S = channel slope (m/m)

Channel roughness (n)

- It is not surprising that the hydraulic capacity of a waterway is inversely proportional to its roughness.
- In engineering, channel roughness is typically defined using the Manning's roughness coefficient 'n'.
- The type of vegetation that exists along a waterway can have a significant impact on the channel roughness and flow velocity.
- Trees with branches above the water level typically represent only minor roughness.

Hydraulic roughness

- To the human eye, plants can represent significant roughness within a channel, but during a flood some branches and leafy matter can fold flat and 'smooth'.
- For example, grasses can fold down to form a hydraulically-smooth mat.
- The term *hydraulic roughness* simply reminds us humans to consider the roughness that exists during a flood, rather than the roughness we see when the waterway is not in flood.

Plants with flexible branches

- Trees and shrubs with low branches can represent significant channel roughness.
- During floods, these low-branches must either bend with the flow, or they could become over-stressed and break.
- Consequently, the riparian plants that survive best over the long-term are those that are made from flexible timbers, such as many of the *Callistemons*.
- Many grasses fold flat during floods; however, 'stiff' grasses try to resist water flow.

The hydraulic roughness of different plants

Lomandra plant with fibrous root system

Introduction

- Plants help to control creek erosion in two ways:
  - the root system can help to anchor the soil, which is very important during and immediately after floods
  - while the leafy and woody matter above the ground can help to slow flow velocities, which reduces the erosion potential along the waterway.
- The benefits of using plants to control creek erosion will be discussed later.

Trees without middle storey plants

Trees (upper storey plants)

- I love trees, especially eucalypts, but I am afraid trees are often credited for a lot of the erosion control work that is actually performed by shrubs and groundcovers.
- Trees are 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; however, their hydraulic roughness may not be as much as some people fear.

Riparian shrubs (Qld)

Shrubs (middle storey plants)

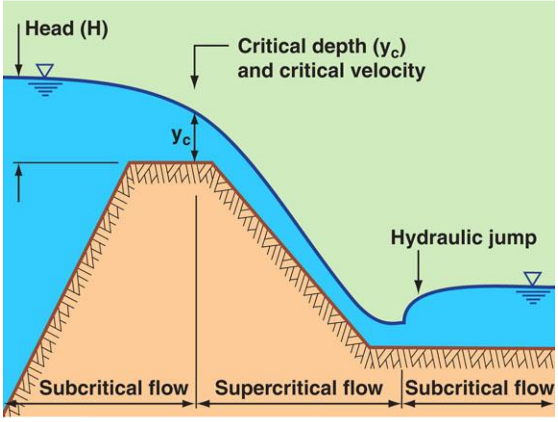
- Shrubs and other middle storey plants are often the undervalued plants of our bushland and waterways.
- Shrubs can contribute significant hydraulic roughness to a channel (which can increase flood levels), but it is the existence of these shrubs that can help protect many of our riparian trees.
- The ability of a shrub to bend with the flow, and then quickly recover after a flood, is a very important attribute for a riparian plant.

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 erosion during floods.
- What primarily stops soil scour is not the part of the plant that lies within the soil (the root system), but the part of the plant that stands above the soil.
- Groundcovers generally do not add much to the overall channel roughness.

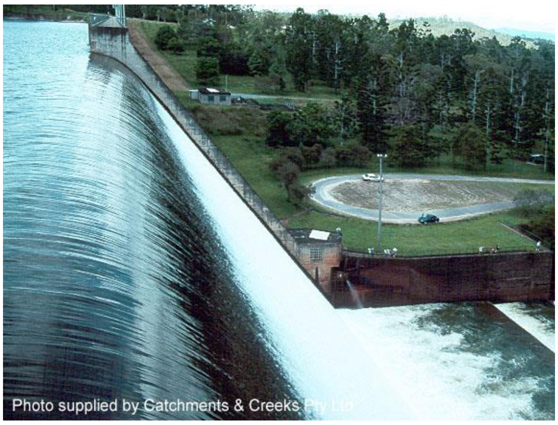
Subcritical and supercritical flow conditions



Flow conditions on a dam spillway

Subcritical flow in an urban creek (Qld)

Supercritical flow down a mountain stream



Critical flow at the crest of a dam spillway

Introduction

- Most people are aware that there are two types of air flow, subsonic and supersonic, which relates to the speed of sound.
- The speed of sound is important because it is the speed of a pressure wave in air.
- Well, there are also two types of water flow, subcritical and supercritical, which relates to the speed of a surface wave.
- The speed of a surface wave is important because it is the speed that *pressure changes* move through water.

Subcritical flow condition

- Most of the flood events that you have seen on TV are representative of subcritical flow.
- During subcritical flow, the elevation of the water (the flood level) is governed by the flow conditions that exist downstream of the point of interest.
- This means that as floodwaters approach a coastline, the height of the flood will eventually become influenced by the tide level into which the waterway is flowing.

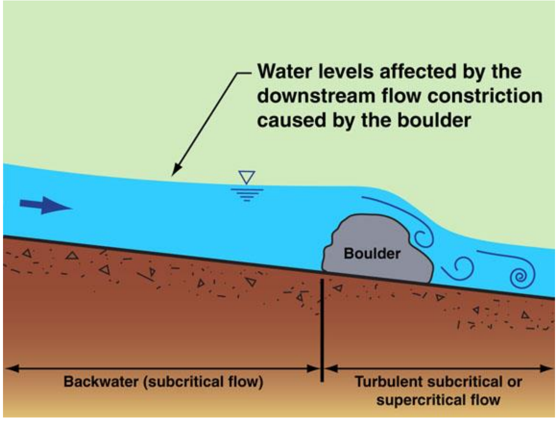
Supercritical flow condition

- Most people would have observed supercritical flow by simply watching stormwater flowing down a roadside gutter.
- Only on very flat roads will stormwater be moving at subcritical velocities.
- In waterways, supercritical flow normally exists only in the steep upper reaches.
- During supercritical flow, the elevation of the water, and its flow velocity, will be governed by the flow conditions that exist upstream of the point of interest.

Critical flow condition

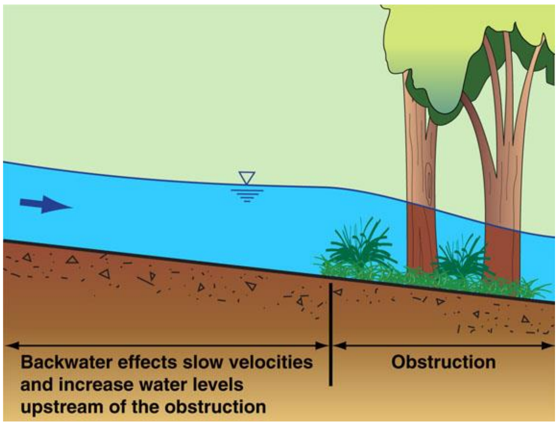
- Critical flow is a third flow condition that exists at the point where stream flows convert from subcritical to supercritical.
- In theory this condition also exists when flows convert from supercritical to subcritical, but this particular condition is so unstable it is difficult to detect.
- Critical flow may be important to hydraulic engineers, but it does not play a major role in creek engineering, or in the control of creek erosion.

The backwater effect



Example of backwater effects

Subcritical flow causing bank erosion



Backwater effects of channel vegetation

High tide backing-up into a coastal drain

Introduction

- The term 'backwater' has two meanings.
- It can mean a region of a channel or floodplain where there is no measurable flow velocity, which means water levels will be totally controlled by the immediate downstream water level.
- The term is also used in creek engineering to refer to subcritical flow conditions where water levels and flow velocities are strongly influenced by the channel conditions downstream of the point of interest.

The importance of subcritical flow in creek engineering

- Creek erosion can occur at any location along a waterway, but it is usually within the lower reaches of a waterway where public interest is the greatest.
- This is because of the population density and the weaker soils that are often found in these lower floodplain areas.
- It is also within this lower catchment region where subcritical flows are likely to exist.

The backwater effects of channel roughness

- Because of the backwater effects that exist in subcritical flow, adding vegetation at a certain location along a waterway will provide the following outcomes:
  - a likely increase in flow velocities at the location of the new vegetation
  - a likely decrease in flow velocities upstream of the new vegetation, but this effect will reduce the further you go upstream.

Tidal influences

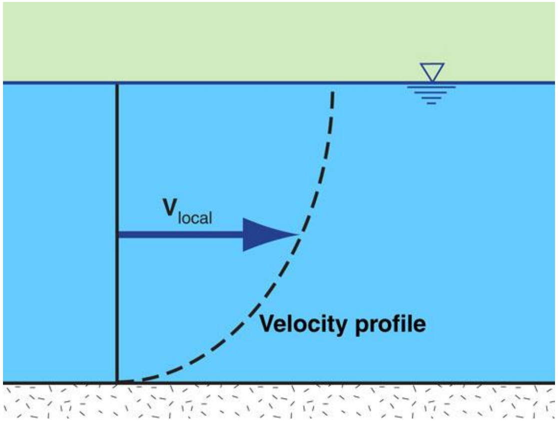
- Near the coast, water levels can be strongly influenced by tide levels.
- However, during flood events, the influence of tides reduces rapidly as you move inland from the coast.
- Tidal effects on flood levels generally:
  - decreases with increasing flood severity, and
  - extend inland a distance significantly less than the normal tidal limits of the waterway.

Defining flow velocity

High-velocity stream flow (Qld)

Flow velocity

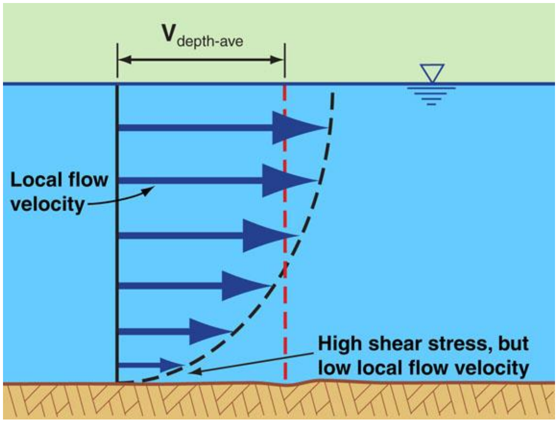
- There are several different ways to measure flow velocity, including:
  - local flow velocity (measured at a point)
  - depth-average velocity
  - average velocity (full cross-section)
  - critical velocity (special flow condition)
- Flow velocities can vary significantly across the depth and width of a stream, consequently the 'average flow velocity' is often much less than the maximum flow velocity within a waterway.



Local flow velocity

Local flow velocity

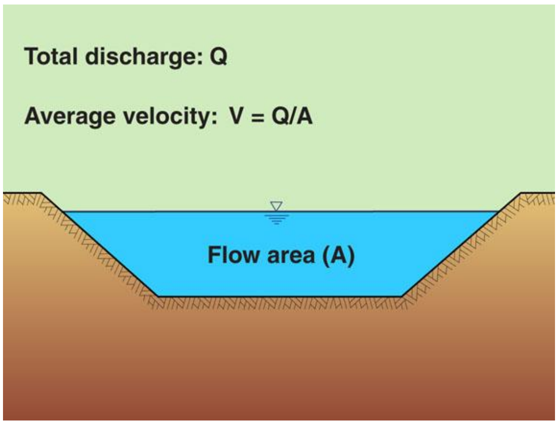
- The local flow velocity is the flow velocity at a specific point within a cross-section.
- The local flow velocity is the velocity of most importance to fish because it is this velocity that they confront when swimming upstream.
- In creek engineering, the local flow velocity is rarely used because it is so hard to calculate mathematically, even though it is relatively easy to measure in a creek.



Depth average flow velocity

Depth-average flow velocity

- The depth-average velocity is the average of the local flow velocities measured down through a vertical plain.
- The depth-average velocity typically varies across the width of a channel.
- This flow velocity is used by creek engineers in the design of some scour protection measures, such as rock.
- It is noted that some engineers refer to the depth-average velocity as the 'local velocity' (which can cause confusion).



Cross-sectional flow parameters

Average flow velocity

- The average flow velocity is defined as the total discharge (Q) divided by the total flow area (A).

$$V = Q/A \quad [m/s]$$

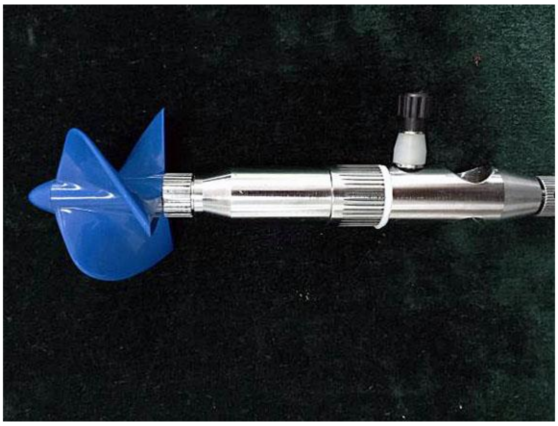
- In complex cross-sections there may be areas of zero flow due to flow isolation; in such cases these areas may be excluded from the total flow area.
- The symbol for velocity is normally a lower case 'v', but an upper case 'V' is often used in publications to highlight its importance.

How the various velocity terms are used in creek engineering

Measuring local flow velocity at a culvert

Introduction

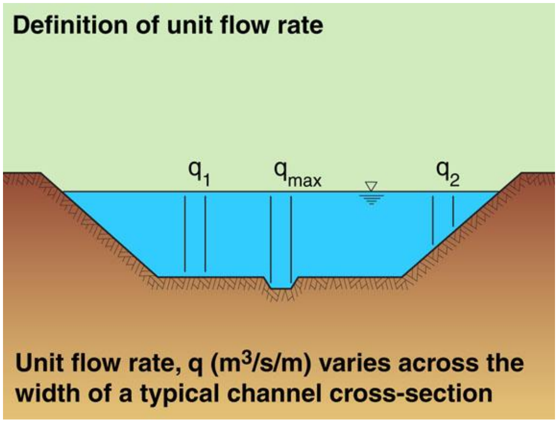
- Flow velocity is important in creek engineering because of its close connection to so many of the different forms of soil erosion.
- Another flow condition that directly influences creek erosion is the degree of *turbulence*.
- Turbulence always exists in creek flow, but it can be amplified by vegetation and surface irregularities on the bed and banks of the channel.



Water velocity propeller meter

Local flow velocity

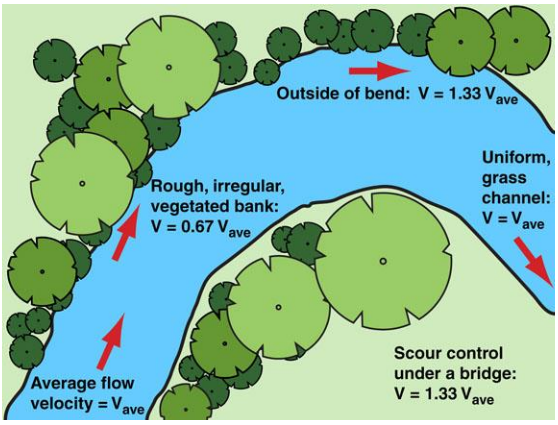
- Creek engineers often measure the local flow velocity across a predetermined grid that spans the full cross-section of a channel.
- These flow measurements can then be used to determine:
  - the total discharge (Q)
  - the average flow velocity (V)
  - and where necessary, the depth-average flow velocity at different locations across the channel.



Defining the unit flow rate (q)

Depth-average flow velocity

- Erosion control techniques, such as rock, are often sized based on the worst-case flow conditions within a cross-section.
- Calculating the depth-average flow velocity at various locations across a creek will allow you to determine the worst-case flow condition.
- Some design procedures use the flow per-unit-width **'q'** (m^3/s/m) as the primary design variable instead of the depth-average flow velocity.

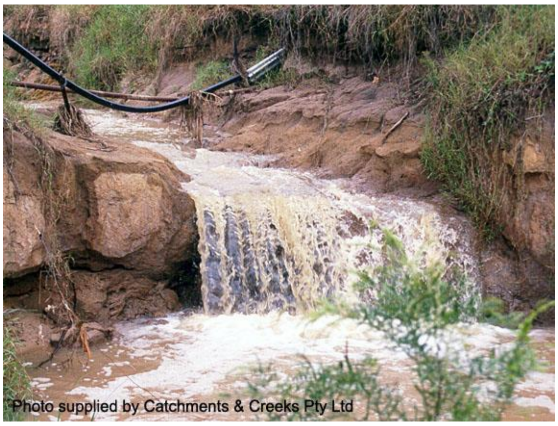


Velocity multipliers for design purposes

Average flow velocity

- The average flow velocity of a stream is easy to calculate in a computer model, but hard to measure within a real creek.
- Because of the ease of calculating the average flow velocity in a computer model, creek engineers often use this term as the main variable in the design of scour control measures.
- To account for the variations in flow velocity across a creek, the average velocity is often multiplied by a nominated design factor (as shown left).

Allowable flow velocity



Soil scour (Qld)

Constructed rock riffle (Qld)

Vegetated channel (Qld)

Flood damage to a grass-lined channel

Introduction

- Research into creek erosion has naturally focused on determining the flow velocity that is likely to initiate soil erosion, or cause flood damage to a waterway.
- However, when designing erosion control measures our focus is not on designing these control measures so that they operate close to the point of failure, but to adopt a conservative design approach.
- Two design approaches can be used:
  - use of safety factors
  - use of an allowable flow velocity.

The use of safety factors

- Some design procedures, or design equations, incorporate a *safety factor* (SF), which either:
  - increases the forces acting on the creek, or
  - increases the dimensions or strength of the scour control measures.
- Many of the equations used to size rock incorporate a safety factor, which changes depending on where the rock is placed within a creek.

Allowable flow velocity

- An alternative design procedure is to size the erosion control measures based on an *allowable flow velocity* that is less than the critical (failure) velocity.
- An allowable flow velocity is typically used when designing vegetated channels.
- An allowable flow velocity is also used in the design of open soil drains (such as drains on farmland), or in the design of grass-lined drains.

The allowable flow velocity for vegetated waterways

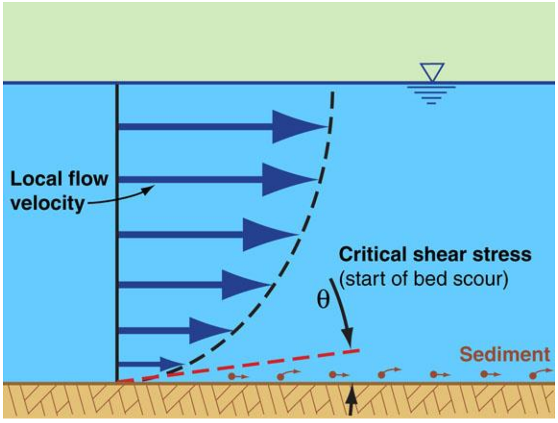
- Nominating an allowable flow velocity for vegetated waterways is complicated by the fact that:
  - the flow velocity that causes damage to the vegetation typically varies with the duration of the flow
  - the critical (failure) velocity varies as the flow depth varies.
- The allowable flow velocity for grass-lined channels depends on the flow duration.

<u>Advanced</u> waterway hydraulics (suitable for those with previous training)

Creek flooding (Qld)

Lesson 1 – Stream power

- There is no doubt that catchment hydrology and open channel hydraulics are difficult subjects to understand.
- The following pages expand the discussion on four important topics that are often misunderstood in creek engineering.
- The first topic is *stream power*—an important term in river morphology, but a term that does not play as important a role in creek engineering.



Critical shear stress

Lesson 2 – Shear stress

- The second lesson is that flow velocity is <u>not</u> the ideal parameter for assessing the soil erosion risk.
- The problem is that the *critical (failure) velocity* that causes soil scour changes as the flow depth changes.
- In creek engineering we generally deal with this problem by simply ignoring it!
- *Shear stress* may be a better indicator of soil erosion, but it makes the mathematics just that bit harder.

Bankfull flow (Qld)

Lesson 3 – Bankfull flow conditions

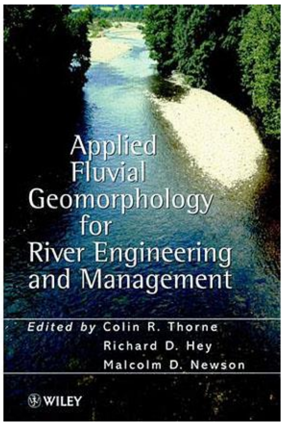
- The *bankfull discharge* can be one of the most powerful flow conditions for a waterway, which means it can be a useful parameter for assessing channel stress.
- But in some waterways, the bankfull height can be difficult to define.
- There is also the idea that the gross form of a channel may in some cases be influenced more by *rare floods*, than the more regular bankfull flows.

Flood damage to in-bank plants (Qld)

Lesson 4 – The hydraulic roughness of vegetation

- The Manning's roughness of vegetation is not a 'constant'.
- The hydraulic roughness of plants varies with:
  - the depth of flow
  - the flow velocity
  - the height of the vegetation prior to the flood (specifically for grasses), and
  - the duration of the flow.

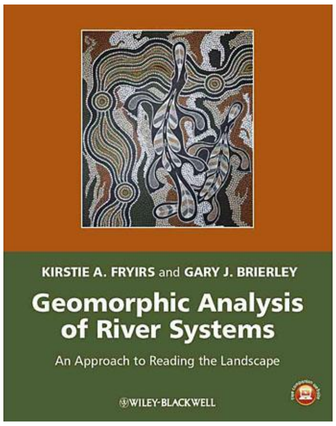
Lesson 1: The importance of stream power



Thorne, Hey and Newson (1997)

Introduction

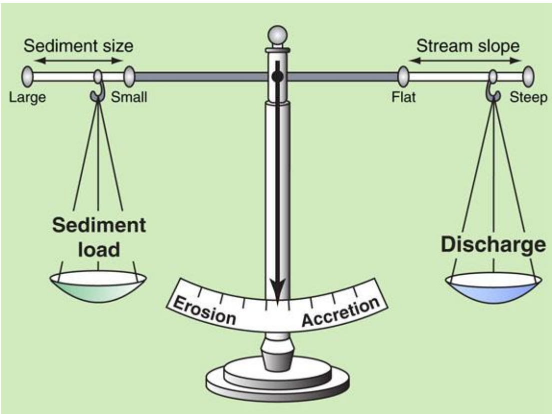
- Before we begin a discussion about the usage of the term *stream power*, it is important to first explore some of the differences between river morphology and creek engineering.
- Firstly, I must stress that this is not a criticism of the science of river morphology—there is nothing wrong with the science.
- My discussion is all about which parts of the science the two professions focus on.



Brierley and Fryirs (2005)

Contemporary river morphology

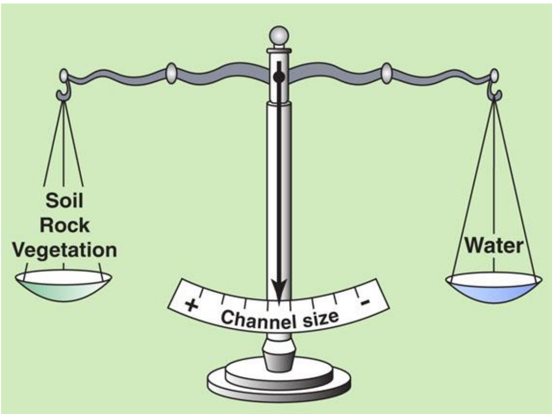
- River morphology text books present a significant amount of discussion on how rivers should be:
  - defined
  - described
  - measured, and
  - compared.
- These discussions are important if you wish to compare the erosion risk in one river with the erosion risk in another river.



Sediment–flow balance in a river

Erosion risk in rivers

- In river morphology, much of the erosion risk discussion is focused on sediment transport.
- The principal drivers of sediment transport are:
  - particle size
  - stream power (discharge and slope)
  - the capacity of the channel to deliver and transport sediment.
- The dynamics of this process is often depicted in a simple 'scale' diagram.



The key 'drivers' in creek erosion

Creek engineering

- As discussed in the beginning of this document, the role of vegetation in the control of channel erosion generally increases with the decreasing size of the channel.
- In your typical creek, vegetation, and exposed rock, play a major role in controlling the erosion risk.
- In some fixed-bed creeks, sediment flow can be a minor factor; instead, the focus is on the in-situ soil, the water flow, and the vegetation cover.

The importance of stream power

Introduction

Stream power is a term that is often referenced in river morphology text books, but its use in everyday creek engineering can be very limited. I have worked on the design of erosion control measures in creeks for some 30 years, and during that time, I have never found the need to use stream power as a design variable.

What is stream power

Stream power is a measure of a waterway's capacity or energy to perform geomorphic work within the channel. It is a measure of the energy available to move bed sediment, or reshape a channel during a flood.

How is stream power used

Stream power can be used for a number of purposes, including:

- the study of sediment transport in alluvial streams
- predicting the channel planform morphology, and the transition between a meandering and a braiding channel
- predicting the width, depth, slope and velocity of alluvial channels
- predicting the rate of change (movement) of a meandering channel.

Stream power can also be used to assess which reaches of a waterway are most likely to experience erosion during the next flood, which can assist in the forward planning of those measures used to protect public assets, such as roads and bridges.

Types of stream power

Bankfull stream power: $\omega_b = \rho.g.Q_b.S$

where: Q_b = the bankfull discharge (m^3/s)

Stream power per unit of streambed area: $\omega_a = \rho.g.R.S.V$

Unit stream power: $\omega_L = \rho.g.Q.S/b$

where: b = bed width (m)

Note: $\omega_a = \omega_L$ for wide, rectangular channels

Stream power per unit of stream length: $\omega_L = \rho.g.Q.S$

Total stream power ($kg.m/s^3$ = Watts/m): $\Omega = \omega_L = \rho.g.Q.S$

The critical stream power is the power needed to transport the average sediment load supplied to the stream.

What discharge (Q) should be used in the analysis of stream power

The choice of which discharge to use in calculating stream power is critical. If your project requires you to compare the stream powers within different waterways, then it is essential to compare 'apples with apples', and therefore to be consistent in the definition of the discharge parameter. The use of bankfull discharge would seem to be a reliable choice.

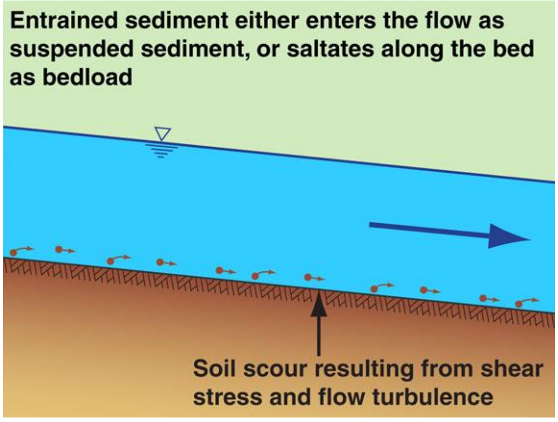
Caution should be applied when using the peak flood discharge because a significant proportion of the flood energy will be exerted on the floodplains rather than within the channel. In such cases the useable 'discharge' may be restricted to the flow area defined by imaginary vertical lines extending from the top of each bank (i.e. only that flow within or above the channel).

What if sediment flow is not your major concern

In many small rural creeks, minimal sediment flow may exist, and your focus may by on repairing the recent flood damage to a creek bank, which means flow velocity will be more important than stream power.

In urban creeks there may be significant sediment flow, but this sediment may have resulted from urban runoff; so and again, flow velocity will likely be more important than stream power.

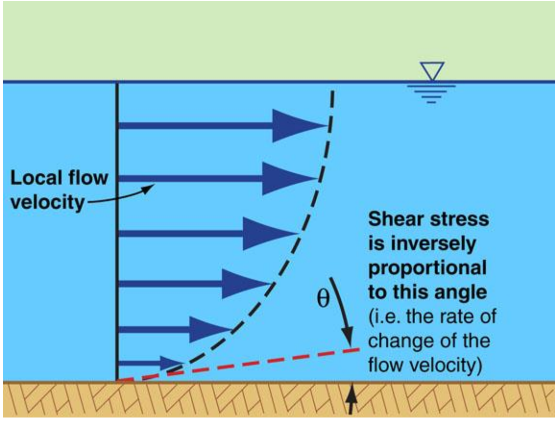
Lesson 2: The importance of shear stress



Soil scour

Flow velocity vs shear stress

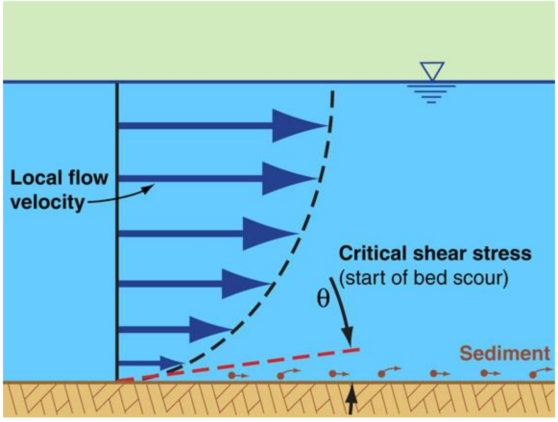
- In creek engineering, flow velocity is considered one of the most important design variables.
- However, when studying bed movement it is the level of *shear stress* that is more important than the flow velocity.
- We use flow velocity as a design parameter because it is a term that is easy to calculate, and it is a term that most people can readily understand.



Defining shear stress

What is shear stress

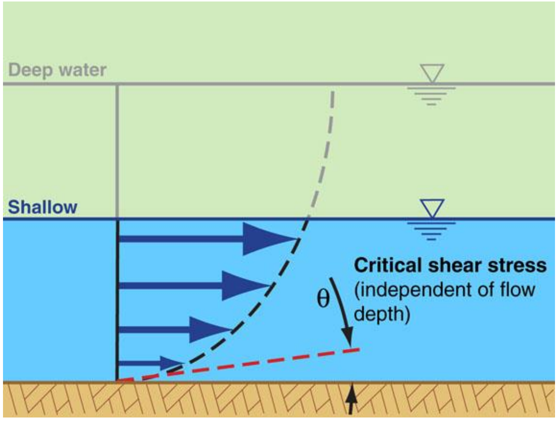
- Shear stress is defined as the rate of change of the <u>local</u> flow velocity immediately adjacent a fixed object.
- Some people look upon shear stress as a 'rubbing' force, such as rubbing your left hand over your right forearm, but that implies that shear stress is influenced by the force pushing down on the surface.
- In water, the degree of shear stress is <u>not</u> related to the weight of water above the surface, but only to the rate of change of the flow velocity.



Critical flow conditions in deep water

Deep water conditions

- When water flows over a fixed (i.e. non-eroding) surface, such as a stable creek bed, flow velocity will be greatest on the surface of the water, but zero immediately adjacent the creek bed.
- In deepwater conditions there is a lot more space between the water surface and the creek bed, which means flow velocities can increase at a more gradual rate, which reduces the shear stress.
  - i.e. there is less 'shearing' between the individual layers of water.

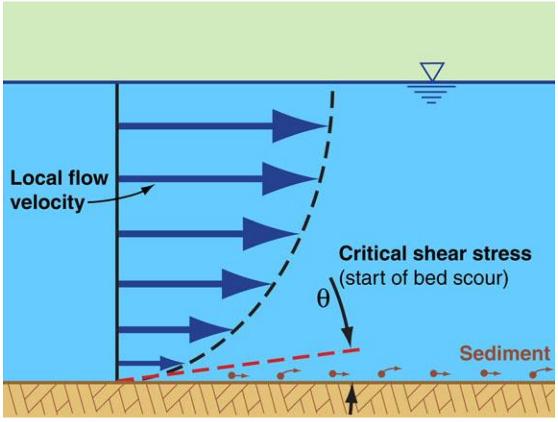


Critical flow conditions in shallow water

Shallow water conditions

- In shallow water conditions, the shear stress that begins to cause soil scour will be identical to that required in deepwater conditions.
  - i.e. the *critical* shear stress is independent of flow depth.
- This means the maximum water velocity at the <u>surface</u> of the water will be <u>less</u> than would be the case for critical flow conditions in deep water.

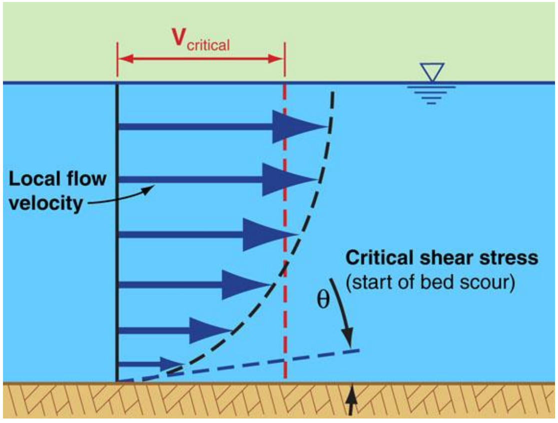
Critical shear stress



Critical shear stress verse particle size

Critical (threshold) shear stress

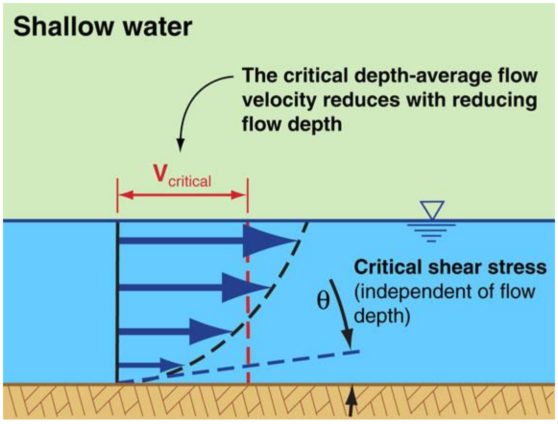
- The critical shear stress is the stress that is required to initiate soil scour, or any other specific form of flood damage.
- Critical shear stress (also known as the threshold shear stress) is most commonly associated with the erosion of non-cohesive, granular substrates (bed material):
  - such as sand, gravel and cobbles
  - but not cohesive, clayey soil.



Critical scour velocity in deep water

Critical scour velocity in deep water

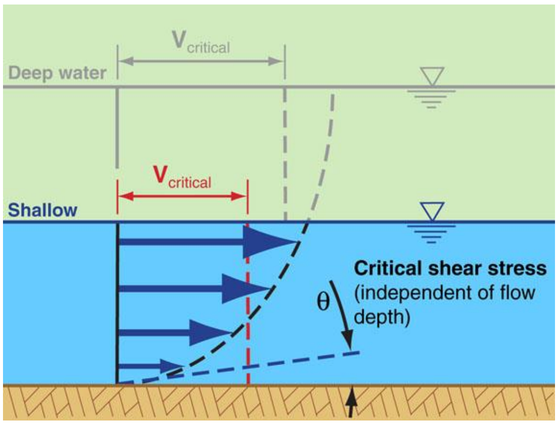
- As the flow depth increases, the maximum flow velocity (at the water surface) increases, even though the critical shear stress remains unchanged.
- This means the *critical depth-average scour velocity* also increases with flow depth.
- This is why flow velocities on the surface of a major river in flood can reach speeds of 3 to 5 m/s without there being major soil scour occurring along the river bed.



Critical scour velocity in shallow water

Critical scour velocity in shallow water

- As water depths reduce from a deepwater condition to a shallow water condition, the critical scour velocity will also reduce.
- This means:
  - the critical average flow velocity in a small drainage channel may be 1.5 m/s
  - while the critical average flow velocity in a creek may be 2.0 m/s
  - and the critical average flow velocity in a deep river may be 3.0 m/s.



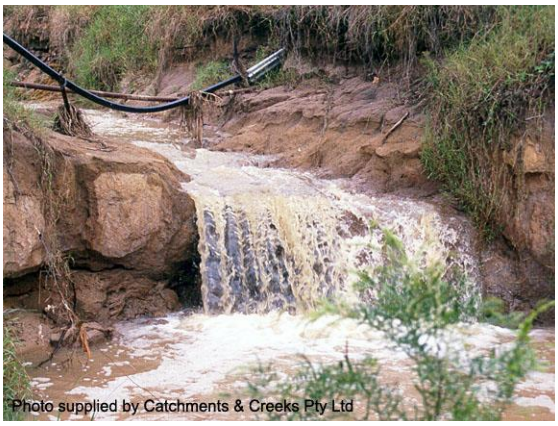
Comparing deep and shallow water

Comparing deep and shallow water conditions

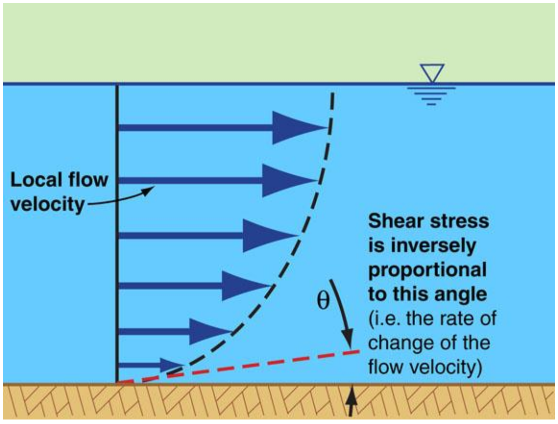
- What the above discussion demonstrates is that the critical scour velocity (and also the allowable flow velocity) of a creek increases with increasing flow depth.
- However, this only applies to the erosion of loose granular material, such as sediment, sand and gravels.
- The reverse rule usually applies in regard to flood damage to trees where the overall force on the tree increases with increasing flow velocity and flow depth.

Critical shear stress

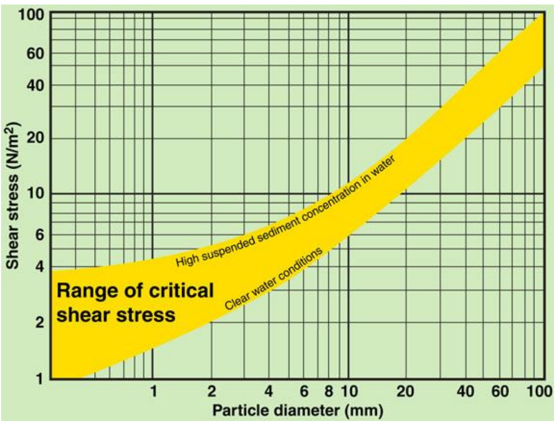
Wawirra Creek (SA)



Soil scour (Qld)



Defining shear stress



Critical shear stress vs particle size

River morphology

- Within the science of river morphology, there is understandably a focus on sediment transport, because this is a major component of river erosion, and the analysis of flood impacts on rivers.
- This means there is also a focus on *shear stress* and *stream power*.
- However, as previously discussed, sediment transport may not be the primary concern in the management of creek erosion.

Tractive force

- Shear stress can be presented in two forms:
  - Tractive force (kg/m^2)
  - Shear stress (N/m^2)
- The tractive force of water flow is given by the following formula:

$$T_F = 1000 \times R \times S$$

where:

- T_F = tractive force (kg/m^2)
- R = hydraulic radius (m)
- S = energy slope (m/m)

Shear stress

- The shear stress of water flow is given by the formula:

$$\tau = \rho \times g \times R \times S = T_F \times g$$

where:

- τ = shear stress (N/m^2)
- ρ = water density (kg/m^3)
- g = gravity (m/s^2)
- R = hydraulic radius (m)
- S = energy slope (m/m)

Critical shear stress for non-cohesive bed material

- The critical shear stress that initiates sediment movement also depends on the sediment concentration within the water.
- Clear water is more 'erosive' than sediment laden water—which means clean water 'wants' to get dirty!
- As an approximation:
  - critical tractive force = particle size (cm)
  - critical shear stress (N/m^2) = particle size (in units of mm).

Critical shear stress

Clayey soil

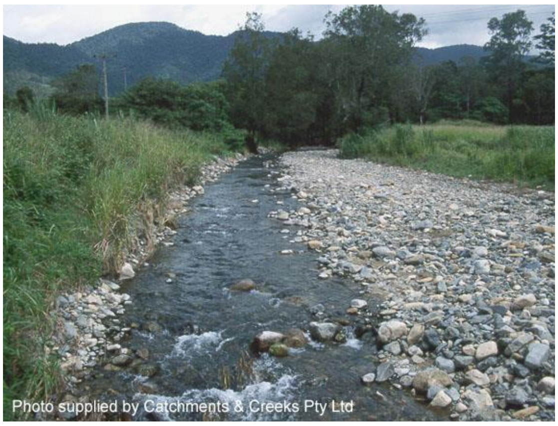
Critical shear stress of cohesive (clayey) soils

- The previous discussion focused on the erosion of non-cohesive bed material, such as sand and gravel.
- Clayey soils have the added strength of sticky 'cohesion'.
- The critical shear stress for this material is no longer linked to the particle size, but to other factors such as:
  - clay content
  - soil texture and organic content.

Sediment deposit (NSW)

The transport and deposition of bed material

- Once bed material has been disturbed by stream flows, the material is either transported as suspended sediment, or it tumbles (saltates) along the bed.
- In general, shear stress decreases as flows move down the waterway, so the larger gravels are deposited further upstream from the smaller gravels, then the sands, and finally the silts are deposited along with much of the organic matter in the tidal reaches of rivers.



Gravel-based waterway (Qld)

Critical (threshold) scour velocity

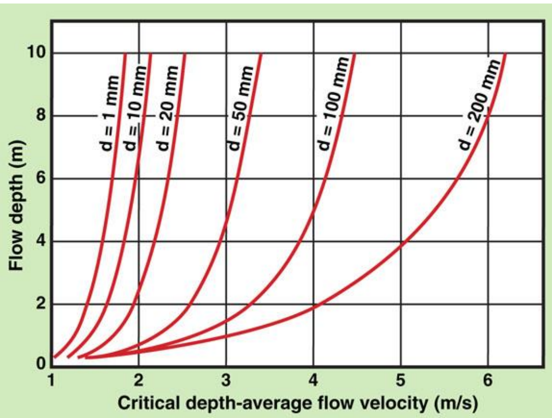
- The *critical scour velocity* is the water velocity that initiates channel erosion, either in the form of soil scour or permanent damage to vegetation.
- The Manning's equation tells us that the average velocity is given by:

$$V_{ave} = (1/n)\ R^{2/3}\ S^{1/2}$$

- The depth-average velocity is given by:

$$V_{depth\text{-}ave} = (1/n)\ y^{2/3}\ S^{1/2}$$

where: y = the local flow depth (m)



Critical scour velocity vs flow depth

Critical shear stress vs critical velocity

- A relationship can be developed between shear stress and flow velocity (also critical shear stress and critical scour velocity).

Shear stress = 1000.g.R.S

Thus: S = shear stress / (1000.g.R)

(R = hydraulic radius, and S = channel slope)

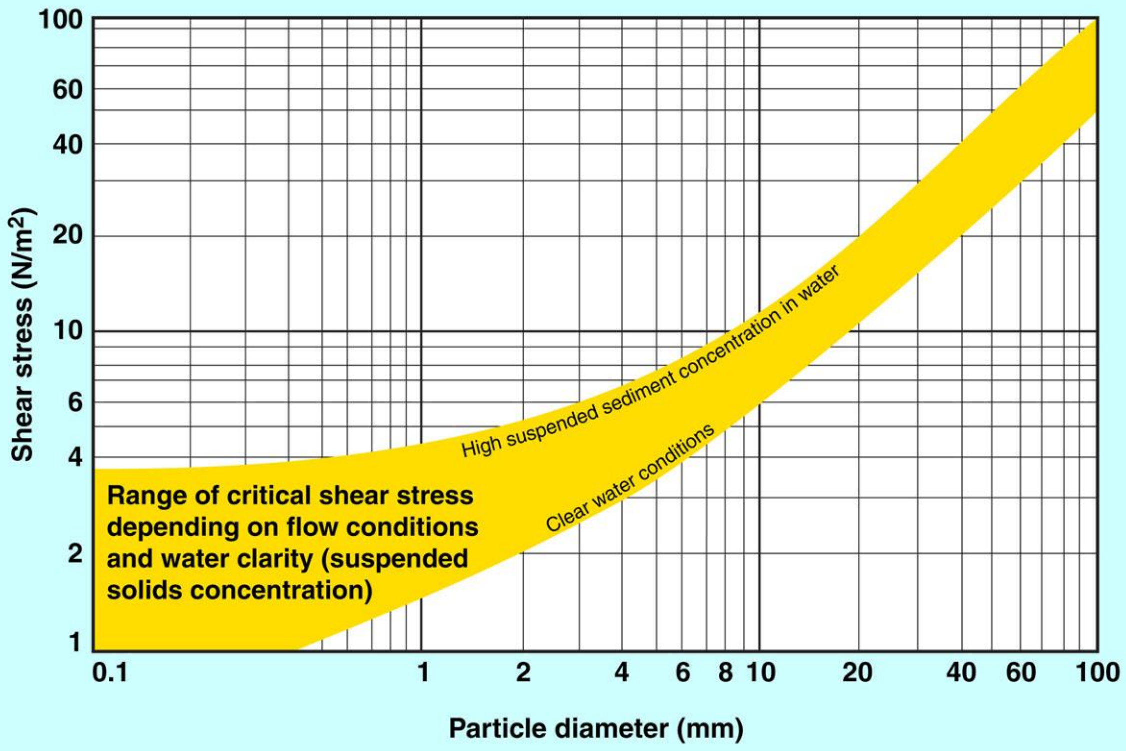
From Manning's equation: $V = (1/n)\ R^{2/3}\ S^{1/2}$

Thus: $V = (1/n).(\text{shear stress}/(1000.g))^{1/2}.R^{1/6}$

For a wide rectangular channel, let R = y

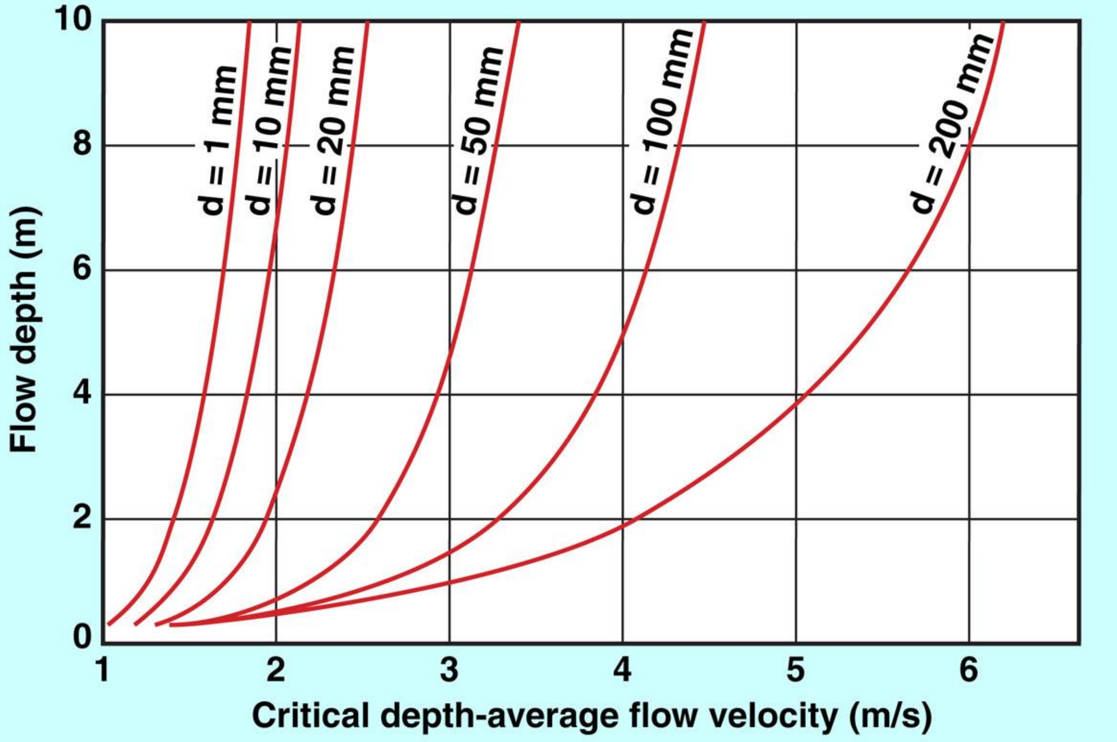
$$V = (1/n).(\text{shear stress}/1000/g)^{1/2}.y^{1/6}$$

Critical shear stress and critical scour velocity



Critical (threshold) shear stress vs creek bed particle size (Not for design)

d = d_{50} = mean gravel/rock size on creek bed; and d_{50}/d_{90} = 0.5
Manning's roughness of the rock-lined channel is based on the mean rock size (d_{50}), the size range (d_{50}/d_{90}), and the flow depth.



Critical depth-average velocity vs flow depth for a rock-lined channel (Not for design)

Reasons why flow velocity is used in design instead of shear stress

Design procedures

Introduction

- There will always be those designers that choose to use shear stress as their key design parameter, and those that prefer to use flow velocity.
- If your focus is on sediment transport in large rivers, then shear stress is likely to be a useful design parameter.
- However, in general creek engineering, flow velocity has proven over time to be a very capable design tool, for the following reasons . . . (see below)

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)

A commonly used rock sizing equation

Allowable velocity vs scour velocity

- In creek engineering we do not design our instream measures to operate near the point of failure.
- This means we design drainage channels to operate at an *allowable flow velocity* that is less than the scour velocity.
- Alternatively, we use rock sizing equations that avoid critical flow conditions—for example, compare the commonly used design equation (left) with the scour velocities presented in the previous graph.

Flood damage to riparian vegetation (Qld)

Vegetation damage

- In creek engineering, our focus is not solely on the movement of bed material during flood events.
- Instead, our focus is often on the bank erosion and vegetation damage caused by a flood.
- For such flood damage, shear stress is generally not a good indicator or design tool; instead, flow velocity is a better measure of the drag forces exerted on the vegetation (particularly, shrubs and trees).

Erosion of bridge pier foundations (Qld)

Erosion around waterway structures

- Soil erosion around the foundations of many engineered structures is more closely linked to the flow velocity than it is to the bed shear stress, including:
  - bridge abutments
  - bridge piers
  - culvert outlets
  - grade control structures.
- Shear stress may be the cause of the erosion, but flow velocity is a more accurate measure of the erosion risk.

Lesson 3: The importance of bankfull discharge

River flooding

Introduction

- It should be obvious to most people that there is likely to be a mathematical relationship between the size of a waterway and the discharge passing down that reach of the waterway.
- The question is: which flow rate is the dominant discharge?
- Is it the:
  - 1 in 100 year discharge
  - most frequent discharge, or
  - bankfull discharge?

Sediment transported by a flood (Qld)

The dominant discharge

- It is only through the detailed comparison of many waterways, i.e. the science of river morphology, that an answer can be found to the above question.
- In large, alluvial rivers, the dominant discharge is claimed to be the flow that yields the *maximum sediment transport*.
- However for most waterways, the discharge that is likely to strongly influence the *size of the channel* is the bankfull discharge.

Bankfull flow (Qld)

Treating the bankfull discharge as the dominant discharge

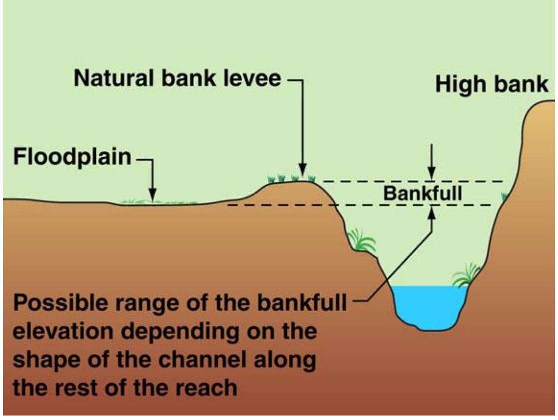
- Several studies have suggested that the bankfull discharge is the flow that yields the maximum sediment transport.
- However, in creek engineering, sediment transport may not be the primary concern, and in many clay-based waterways there may be minimal sediment transport.
- In such cases the focus returns to the flow condition that most strongly influences the size of the channel, which is likely to be the bankfull discharge.

Urban waterway (NSW)

The most frequent discharge

- Several publication focus on the importance of the *most frequent event* as being the dominant discharge.
- In heavily wooded, natural catchments, stream flows may not be affected by minor storms because all of the rainfall is captured by the vegetation and soil.
- This means the most frequent event is likely to be around the 1 in 1 year to the 1 in 2 year flow.
- However this does not apply to most urban catchments.

Bankfull discharge (warning; this discussion may cause your brain to explode)



Elevation of bankfull flow

Bankfull flow conditions (Qld)

Flow conditions just below the bridge deck

Backwater effects of a culvert crossing

Defining bankfull flow conditions

- Often the top of the left and right banks of a waterway are at different elevations, so the bankfull condition is usually defined by the lowest bank that allows water to spill onto an adjacent floodplain.
- If the elevation of the bank varies significantly along a given reach of a waterway, then the bankfull flow condition is defined by the lowest bank height (within that reach) that allows water to spill onto the adjacent floodplain.

Why bankfull flow is so important

- In the previous discussion about *shear stress* it was noted that the scour velocity increases with increasing flow depth.
- This means that higher than normal velocities can exist during bankfull flow before soil erosion begins to occur.
- So why does bankfull flow represent the flow condition of greatest shear stress?
- The answer is all in the mathematics of water flow.
- We know from the Manning's equation that the average velocity in a channel is proportional to the water depth (y) to the power of two-thirds:

$$V = (1/n)\ y^{2/3}\ S^{1/2}$$

- We also known from our discussion about shear stress that the critical depth-average flow velocity is proportional to the water depth to the power of one-sixth.

$$V_c = (1/n).(\text{critical shear}/1000.g)^{1/2}.y^{1/6}$$

- Which means that even though the threshold velocity (V_c) increases with flow depth, the actual velocity (V) increases at a greater rate, meaning erosion is more likely to occur during bankfull flows.

The frequency of bankfull flows

- It is often claimed that bankfull flows occur at a frequency of one to two years.
- Some studies have shown that the frequency of bankfull flows varies according to the type of waterway.
- Many incised urban creeks have a bankfull flow capacity close to the 10 year flow.
- Also, in urban waterways the bankfull flow may be affected by the afflux from downstream bridges, which can alter the frequency and erosive power of these events.

The importance of rare floods

Colorado River (USA)

Flood gauge, Rockhampton (Qld)

Flood stage, Louisville, Kentucky (USA)

Extensive channel erosion, Buaraba Ck

Introduction

- Few people would suggest that the Grand Canyon and the greater Colorado River valley were shaped by the bankfull flow.
- There is the strongly held position that many waterways experience continuous minor changes over decades, or centuries, interlaced with dramatic changes that occur on rare occasions.
- Look for the largest rounded boulder in a valley, and ask yourself what flood event would it take to cause such a boulder to move.

What is classified as a rare flood

- What defines a rare flood depends on the purpose of your study.
- With respect to the possible occurrence of major changes to the planform of a waterway, a rare flood may be defined as a flood with a return period greater than 1 in 200 years.
- The following is a generalisation:

(i) 1 in 1 yr to 1 in 10 yr; minor floods

(ii) 1 in 10 yr to 1 in 200 yr; major floods

(iii) > 1 in 200 year; rare floods.

Reasons why rare floods are so important

- One of the problems with using stream power or bankfull discharge as the key channel-forming parameters is that neither of these terms incorporates ‘duration’.
- Discharge (m^3/s) times duration (seconds) gives you units of volume (m^3), and the volume of water within a given flood can influence the volume of sediment transported by the flood, as well as the degree of erosion.
- Rare floods not only have high discharges, they usually have very large volumes.

The potential impact of rare floods on gravel, cobble and boulder-based channels

- Some cobble and boulder-based waterways can have relatively stable beds that experience very little disturbance during most flood events.
- However, these waterways can be ‘sleeping giants’ that can be awakened by extreme floods, which can commence movement of the cobbles causing extensive damage to both the channel and any adjacent engineering structures.

Lesson 4: The hydraulic roughness of vegetation

Grasses flattened by floodwater (Qld)

Flood damage to shrubs (Qld)

Flood damage to recently planted trees

Post bushfire riparian vegetation (Qld)

Introduction

- It has long been understood that the Manning's roughness of some surfaces varies with flow depth, i.e. Manning's roughness is not a constant.
- However, what is possibly less well appreciated is that the hydraulic roughness of vegetation can vary not only with flow depth, but also over time during a flood.
- This means that channel roughness can be different during the 'rising' and 'falling' limbs of a flood.

Variations in roughness with flow depth

- As the flow depth increases, the hydraulic drag force on the plant increases, which causes the plant to bend with the flow.
- Ultimately the plant will either:
  - bend until the point of breaking
  - fold flat over the ground
  - fold flat to form a hydraulically-smooth 'mat' (typical for grasses).
- For grasses, this change in roughness also depends on the height of the grass prior to the flood.

Variations in roughness over time

- During the initial stages of a flood (i.e. the rising limb of the flood hydrograph), most of the vegetation will remain near vertical resulting in high channel roughness.
- At various stages during a flood different plants will either fold flat, or break, resulting in a significant reduction in the hydraulic roughness of the channel.
- During the falling limb of a flood, much of the vegetation will remain bent, or laying flat over the ground, resulting in continued low roughness values.

Variations in roughness with seasons

- In some regions, the density, and therefore the hydraulic roughness of vegetation, can vary from season to season.
- This means the peak flow velocities during a winter flood can be different from those experienced during a summer flood.
- In addition, the hydraulic roughness of riparian vegetation can significantly reduce for several years following a major bushfire.

The domino effect

Flow just submerging a Lomandra plant

Introduction

- Even while plants are bending with the flow, they can still provide significant flow resistance.

Flood damage to Lockyer Creek, 2011

The domino effect

- However, once the plants break, or fold flat over the soil, their hydraulic roughness can suddenly reduce.
- This sudden reduction in channel roughness can result in a rush of floodwater that damages both upstream and downstream plants.
- Under certain conditions, in-bank plants can fold flat like dominos.

Vegetation damage, Brisbane River, 2011

Flash floods

- It seems that almost every flood these days is called a *flash flood*.
- But a flood that has a very ‘aggressive’ rising limb (i.e. a flood that has a sudden and rapid rise in water levels), can result from the following circumstances:
  - a severe thunder storm over a small drainage catchment, or
  - a flood wave being formed during a flood as a result of a sudden mass failure of in-bank plants.

Vegetation damage, Lockyer Creek, 2011

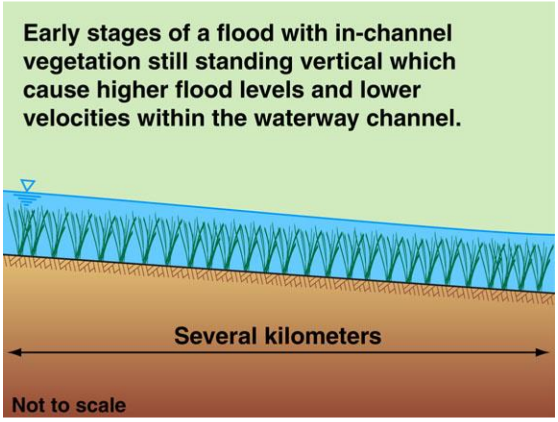
A flood wave

- Flood waves are rare, but many residents have reported seeing a ‘wall’ of water passing down a flooded waterway.
- The hydraulic conditions that produce a flood wave are similar to the conditions that cause river bores—high velocity floodwater catching up with lower velocity floodwater further down the catchment, ultimately causing the formation of a wave-like flood event.

Flash floods and visible flood waves

Introduction

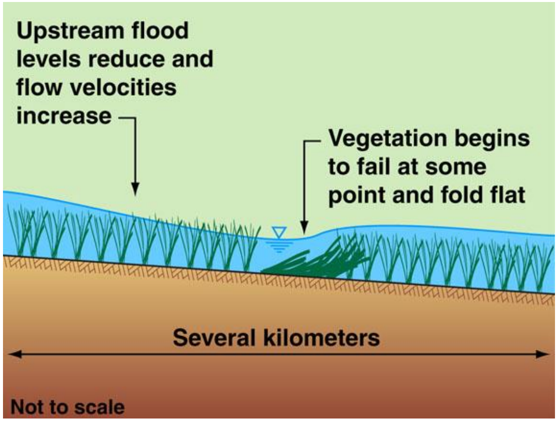
- First of all it is important to note that the following discussion refers to a very rare type of flood event.
- It is likely that very few people will ever witness such a flood condition.
- This discussion is being presented simply to demonstrate one of the potential effects caused by changes in vegetation roughness during a flood.



Waterway conditions prior to failure

Initial failure of in-bank plants

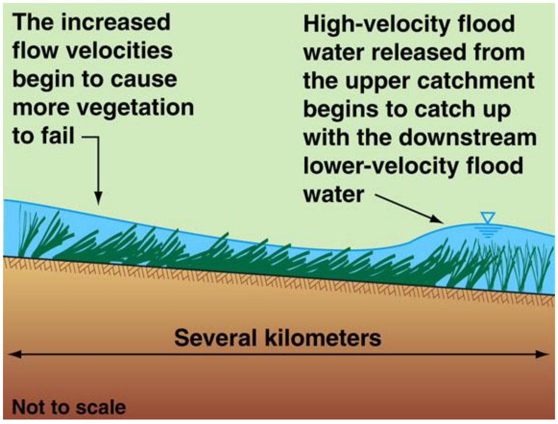
- As flood flows increase, in-bank plants will begin to bend in the direction of the flow.
- However, at a certain velocity, some branches will begin to snap, and some plants will fold flat over the bed and banks.
- I have used the term 'in-bank' (in-channel) to mean all plants located along the bed and banks of a waterway channel, as opposed to *instream* vegetation, which normally refers only to aquatic plants.



Initial failure of some in-bank vegetation

Mass failure of in-bank plants

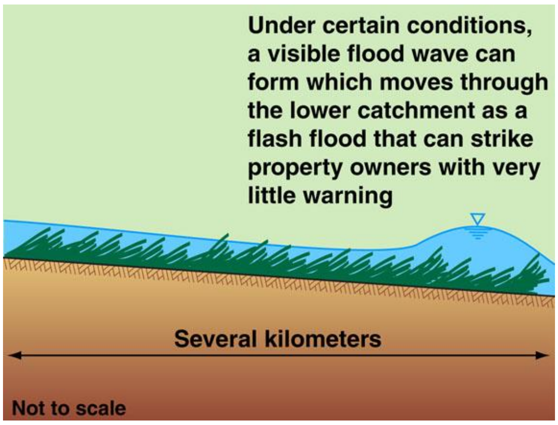
- As flow velocities continue to increase, eventually large sections of the channel will experience the flattening of plants.
- This sudden reduction in channel roughness will cause a rapid lowering of upstream flood levels, and a resulting increase in flow velocities.
- The increase in flow velocities will further damage in-bank plants, and changes in the hydraulic properties of the channel will begin to accelerate.



Stream flows increase in velocity

Creation of a flood wave

- The acceleration of velocities in the upper catchment causes this floodwater to catch-up with the slower moving floodwater in the lower reaches of the waterway.
- In a *'perfect storm'*, these conditions can result in a visible flood wave forming within the waterway.
- Such flood waves can be very difficult to reproduce in numerical flood models because these models do not take account of the changing roughness of in-bank vegetation.



A visible flood wave is formed

5. Causes of Creek Erosion

Introduction

Looking for the *cause*

High-velocity flow (Qld)

Bank slump in an unmodified waterway

Gully erosion investigation (Qld)

Who is to blame for creek erosion?

- If I were to summarise the conversations I have had over the past 30 years I would reach two overwhelming conclusions:
  - all creek erosion is caused by high velocity flow, and
  - all creek erosion is either caused by something the council did, or a development the council approved.
- My response to these enthusiastically expressed opinions is that I only wish it were that simple.

Is flow velocity always the cause of creek erosion?

- Excessive flow velocities are certainly the most common cause of creek erosion, but:
  - what caused the flow velocities to be high, and
  - what was the condition of the creek prior to these high velocity flows.
- The real cause of the creek erosion is often the action that caused the flow velocities to be excessively high.

In the end, isn't creek erosion always the fault of some government body?

- In many cases creek erosion is the fault of no one, it is just a natural process that must occur from time to time within waterways in order to maintain waterway health.
- In some cases the erosion is the fault of people living upstream of the site, in other cases it is caused by the actions of people downstream of your property, and sometimes it is the fault of the landowner at the point of the erosion.

Is there any value in finding the actual cause of the erosion?

- Yes.
- Understanding the cause of the erosion can help in determining:
  - the best treatment measures
  - which land management practices could help to minimise the risk of further erosion
  - what parts of the creek will need the most attention (which is where rock may need to be placed).

Identifying the cause of the erosion

Failed rock stabilisation (Qld)

Dispersive soil creek bank (Qld)

Erosion caused by aggressive weed control

Bank slumping due to bed instability

What could go wrong if you treat an erosion problem without knowing the cause of the erosion?

- Knowing the cause of the erosion helps you to develop treatment measures that have a greater chance of success.
- However, robust treatment measures can sometimes be developed without knowing the cause of the erosion.
- In any case, if your first treatment measure fails, then you would have learnt something, and learning is always a good outcome.

Often there is a chain of events (*causes*) that led to the current erosion problem

- It can be misleading to assume that the cause of the erosion was just high flow velocities, because:
  - what caused the flow velocity to be excessive, and
  - does that cause still exist, and
  - will this mean that the erosion problem will simply re-occur next flood.
- Another problem that may result from assuming that flow velocity is the cause of all creek erosion is that it usually results in people using rock to stabilise everything:
  - but what if the exposed soil is dispersive—rock may not be needed, and may fail if incorrectly placed on such a soil
  - and what if the dispersive soils were exposed to the stream flow because a community group had just completed an aggressive weed removal program
  - or what if the dispersive soils were exposed to the stream flow because a large tree had fallen during a recent wind storm, etc.

Bank erosion vs bed erosion problems

- Bank erosion problems can sometimes be caused by a sudden lowering of the channel bed.
- In such cases, there can be little value in fixing the bank erosion unless knowledge is obtained on whether or not the bed erosion issues have been resolved.
- The first priority is normally to resolve any bed erosion problems before treating any associated bank erosion issues.

Identifying the primary force causing the erosion

Bank scour (Qld)

Soil pinnacles (Qld)

Bank slump (SA)

Dispersive soil erosion (NSW)

Primary erosive force

- The first step in finding the cause of the erosion is to identify the *type of erosion* and the *primary force* that initiated the erosion.
- There are four forces that cause water-induced soil erosion:
  - direct impact (e.g. raindrop impact)
  - scour (resulting from flow velocity)
  - gravity (i.e. bank slips)
  - electro-magnetic dispersion (soil chemistry).

Raindrop impact erosion

- Raindrops can exert significant force upon any exposed soil.
- If vertical columns of soil exist, often with a pebble on the top, then raindrop impact could be the dominant force. Note:
  - the pebble is shielding the soil from the erosive effects of the rainfall, and
  - stream velocities must be low in this area otherwise the soil pinnacle would have been washed away, and
  - the soils are probably dispersive or slaking.

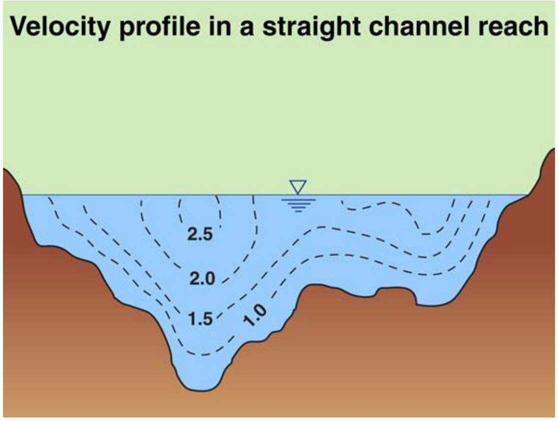
The force of gravity

- Gravity is the primary force which causes a bank to slump.
- Vertical marks (scour lines) observed in the soil immediately after the erosion has occurred usually indicates a gravity issue.
- This means the cause is likely to be too much weight in, or on, the creek bank, or the loss of material from the bed or lower bank.
- These vertical scour marks should not be confused with 'fluting', which is associated with the erosion of dispersive soils.

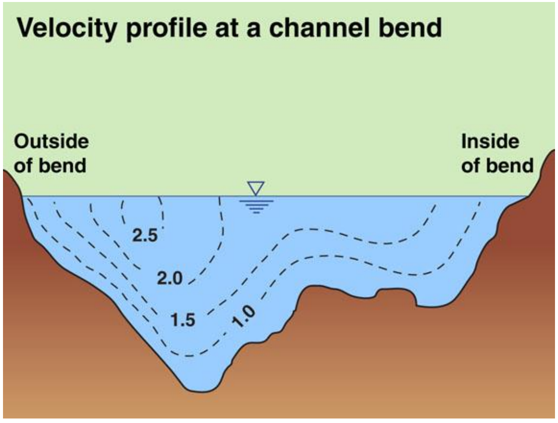
Soil structure and chemistry

- Very often the primary cause of the erosion is the exposure of a weak or unstable soil.
- In some cases it can be the structure of the soil (slaking soils), in other cases it is the soil chemistry (dispersive soils).
- It is not that these soils suddenly became dispersive—the cause is usually the exposure of a dispersive subsoil to stream flows as a result of bank erosion, or the felling of a large tree and rootball.

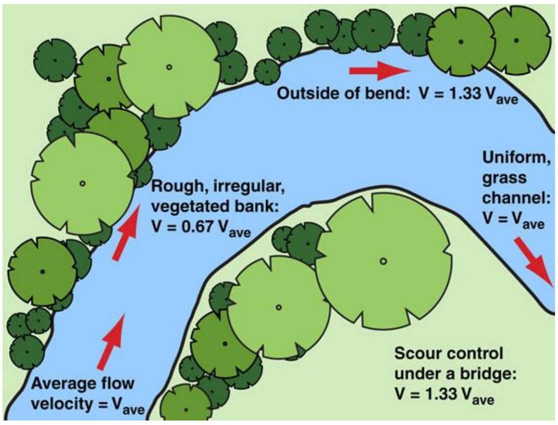
Velocity-induced soil scour



Velocity profile within a straight channel



Velocity profile at a channel bend



Velocity multipliers used in design work

Bed erosion around the base of a tree

Variation in velocity across the channel

- Hydraulic investigations often report on the average flow velocity within a creek, but it should not be assumed that all of the water is flowing at this velocity.
- Flow velocities are faster near the water surface, and in the centre of the channel, or on the outside of channel bends.
- Flow velocities are normally relatively slow adjacent to the bed and banks.
- Further discussion on flow velocities is provided in Chapter 4.

What flow velocity is critical in creek erosion?

- It is the *shear stress* that ultimately causes the erosion, and shear stress is related to the *rate of change in velocity* immediately adjacent to the bed or banks.
- In the diagrams shown left, the shear stress is related to the spacing of the velocity contours—the closer they are together, the higher the shear stress.
- At a channel bend the velocity contours move closer together near the bank on the outside of the bend.

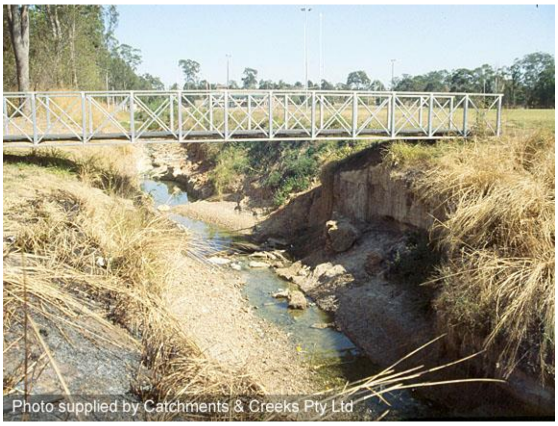
Why are we interested in the 'average' flow velocity?

- The *average flow velocity* is a useful design parameter because it is easy to calculate.
- Unfortunately, it is difficult to measure the average velocity in the field.
- We can use the average velocity to estimate the erosion potential at various locations within a creek by multiplying the average velocity by *multipliers* specified for different locations within a waterway channel.

The importance of the 'local' flow velocity

- There are occasions when creek erosion is dominated by localised issues, such as when erosion is caused by an isolated tree or by fallen branches.
- In such cases, it is the *local velocity* at the obstruction that is more important, not the average velocity of the channel cross-section.
- In most cases, however, we do not need to know the exact local velocity in order to design suitable treatment measures.

Linking the erosion cause to the erosion type



Bed scour (Qld)

Bed scour

Common causes of bed scour include:

- severe flooding, or prolonged bankfull flow
- increased flow velocities resulting from excessive vegetation removal (e.g. weed removal) from the waterway
- changes in catchment hydrology (e.g. urbanisation, land clearing, or severe bushfires), and
- the exposure of weak (dispersive) subsoils to stream flows.

Bank scour (Qld)

Bank scour

Common causes of bank scour include:

- severe floods, or prolonged bankfull flow
- high velocity stream flows, which often occur at channel bends
- poor vegetation cover, or excessive vegetation (weed) removal
- excessive or inappropriate plant growth on the bed of the channel (e.g. reeds)
- turbulence caused by fallen trees, and
- high velocity discharges from stormwater pipes and culverts.

Bank slumping (Qld)

Bank slumping

Common causes of bank slumping include:

- an unusual or rapid lowering of floodwaters within the channel
- inappropriate planting (e.g. insufficient use of deep-rooted plants)
- the removal of trees from the upper bank or overbank area
- deepening of the channel by bed erosion or dredging, and
- the placement of excessive earth fill, or heavy objects, placed on a creek bank.

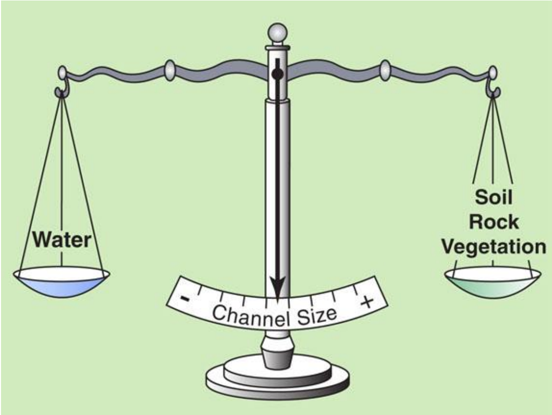
Bank undercutting (Qld)

Bank undercutting

Common causes of bank undercutting include:

- the natural migration of the low-flow channel
- frequent or prolonged, high-velocity stream flows
- the exposure of a weak layer of soil within the lower bank
- changes in catchment hydrology (e.g. urbanisation, land clearing, or severe bushfires), and
- the removal of essential bank vegetation.

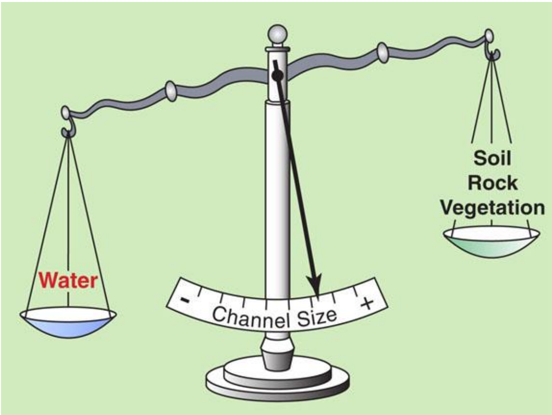
Creeks try to find a balance among competing forces



Finding a channel equilibrium

Introduction

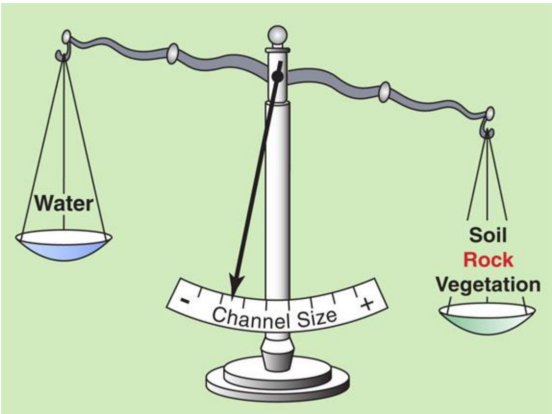
- Creek erosion is often linked to either short or long-term changes in the size of the channel.
- The primary factors that determine the size of a waterway channel are:
  - the catchment hydrology (water), which acts to increase the channel size, and
  - the erosion resistance of the soil, the existence of natural or introduced rock, and the type of vegetation, which can all act to decrease the channel size.



Changes in creek flow

Changes in catchment hydrology

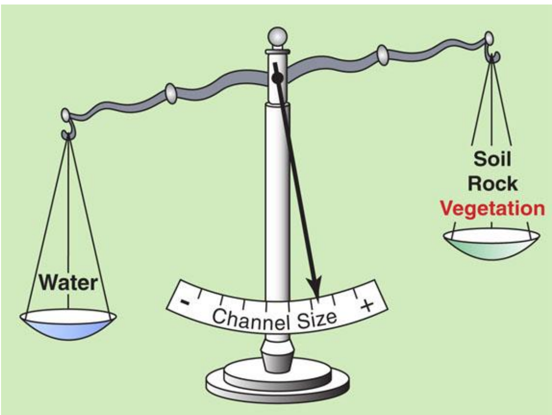
- Creeks exist solely as a response to the existence of a drainage catchment.
- Creeks are in effect a component of nature's drainage system.
- If you alter the hydrology of the catchment, for example through urbanisation, or as a result of severe bushfires, then the volume, velocity and peak discharge of flows down the creek will change.
- If the creek's hydrology changes, then the size of the channel will likely also change.



Introducing rock to stabilise a creek

The effects of rock placement or rock exposure

- If creek erosion exposes natural bed rock, then this will generally dictate the maximum depth of the channel, which may cause the channel to be wider than would normally be expected.
- If the creek's bed or banks are stabilised with introduced rock, then this can mean that the creek will be stable with a smaller channel size, even though this will result in higher flow velocities.



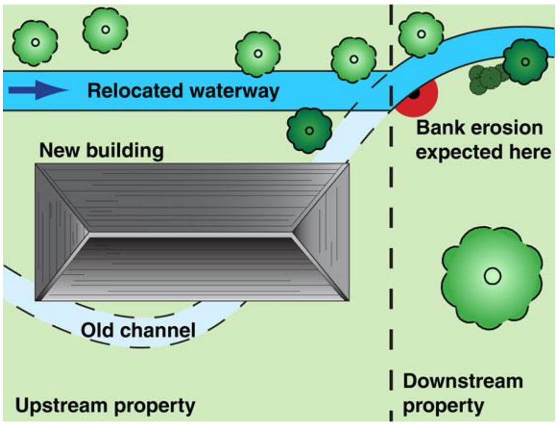
The effect of reduced vegetation cover

Changes in vegetation conditions

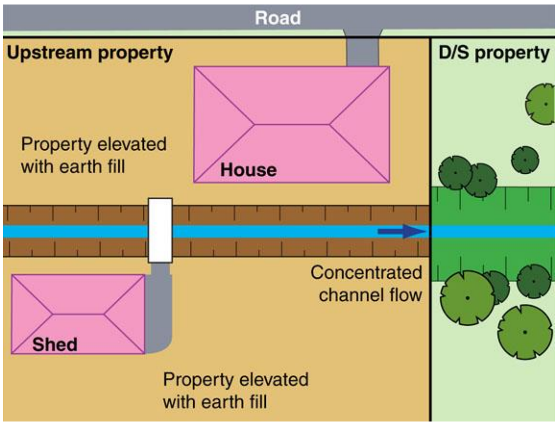
- As a general rule, the smaller the waterway, the greater the role vegetation plays in determining the size of the channel.
- If the in-bank vegetation has been damaged by a severe drought, or a recent flood, then increased channel erosion should be expected.
- If the creek was heavily overrun with weeds, and these weeds were removed leaving the channel poorly vegetated, then increased erosion should be expected.

Upstream activities that can cause downstream erosion

Gully erosion along a property boundary



Relocated waterway channel



Concentration of channel flow

Urbanisation within the upper catchment

Introduction

- It is a common human response to look for someone to blame for any erosion found on your property.
- In some cases the erosion will have resulted from activities upstream of your property.
- In some cases the cause of the erosion problems will be downstream.
- But the erosion may also be a result of your actions, or just a form of natural erosion.

Realignment of the upstream channel

- Channel erosion can occur within a downstream property if the upstream property realigns, or re-positions, the channel passing through their upstream property.
- In most cases, any modifications to a recognised (i.e. mapped) waterway will require the approval of the state government (your local government may not wish, or need, to get involved in such issues).

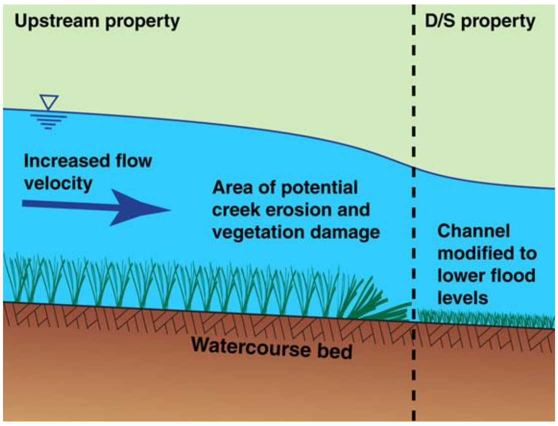
Concentration of flows into the downstream property

- Channel erosion can occur within a downstream property if the upstream property alters the flow conditions at the property boundary by:
  - concentrating the flows by raising or modifying land levels, thus increasing the bankfull flow capacity and/or flow velocity, or
  - reducing the flood storage capacity of the upstream floodplains (i.e. land filling within the floodplains).

Changes to the catchment hydrology

- Channel erosion can also result from an increase in the runoff characteristics of the upstream drainage catchment by:
  - urbanising the catchment without employing adequate stormwater management
  - deforestation (land clearing) within the upper catchment
  - reducing the flood storage capacity of floodplains, or any water storages, such as dams, lakes and wetlands.

<u>Downstream</u> activities that can cause upstream erosion



Reduced downstream flood levels

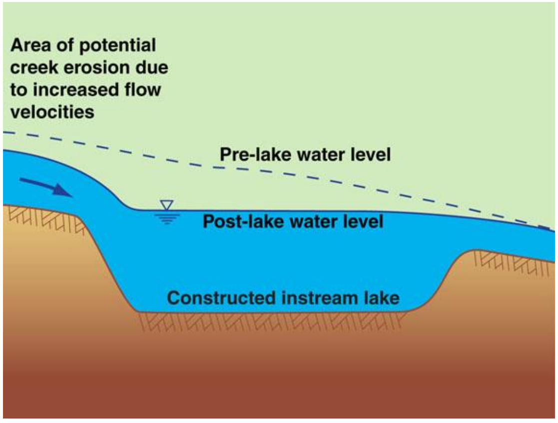
Reducing downstream flood levels

- Channel erosion can occur within an upstream property if flood mitigation works are conducted within the downstream channel in a manner that:
  - lowers flood levels at the property boundary, and as a result . . .
  - increases flow velocities within the upstream channel.
- This outcome can be a negative consequence of some council flood mitigation projects.

Constructed drainage channel (NSW)

Increasing the flow capacity of the downstream channel

- Channel erosion can occur within an upstream property if the immediate downstream channel is:
  - straightened, or
  - modified to increase its flow capacity.
- Improvements in the flow capacity of drainage channels are often carried out for the purpose of reducing flood risks along the channel, but these activities can aggravate erosion problems within the upstream channel.



Hydraulic effects on instream lake

The creation of instream or off-stream lakes or wetlands

- Instream or off-stream lakes and wetlands can be created for the following reasons:
  - urban water features
  - stormwater treatment
  - rehabilitation of extractive industry land.
- Channel erosion can occur within an upstream property if the construction of these water features increases flow velocities at the property boundary.

Weed removal from a creek bank (Qld)

Extensive vegetation removal within the downstream channel

- Vegetation removal from waterways can occur for the following reasons:
  - weed removal
  - flood mitigation works
  - removal of dead trees (this may occur if these trees could cause a risk to property during the next flood).
- Erosion can occur within an upstream property if the vegetation removal lowers flood levels at the property boundary.

<u>On-site</u> activities that can result in local creek erosion

Trees toppled by a recent flood (Qld)

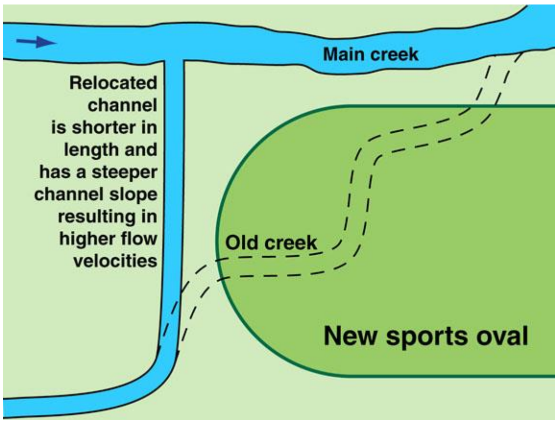
Excessive vegetation removal

- Vegetation removal from waterways can occur for the following reasons:
  - weed removal
  - flood mitigation works
  - snag removal.
- Reducing the vegetation roughness of the waterway on your property can increase flow velocities, and thus increase the risk of channel erosion.

Excessive weed removal from a creek

Extensive weed removal without adequate revegetation

- Removing weeds from your waterway is an admirable activity; however, if this activity is poorly planned or executed, then it can result in channel erosion.
- As a general rule; never remove a weed from a waterway unless you have a plan to immediately replace the weed with a native plant that will be able to provide the waterway with the same erosion control benefits that the weed was previously providing.



Reduction in channel length

Reductions in the channel length

- Property owners often express a desire to:
  - straighten a creek to allow paddock or farm improvements, or
  - relocate a creek to allow construction of a road, building, or park.
- It is important to note that reducing the 'length' of a waterway channel can have the same hydraulic effects as increasing the channel's hydraulic capacity, which ultimately can increase the risk of channel erosion.

Stock access to a creek (NSW)

Creation of channel access paths

- The risk of bank erosion can be increased by:
  - allowing stock to form well-worn tracks down the sides of creek banks
  - forming vehicle access ramps down to a ford or causeway crossing
  - allowing stormwater runoff from paddocks to spill as concentrated flow down creek banks.
- Each of these activities can be performed with or without increasing the erosion risk.

Natural causes of creek erosion

Bushfire (NSW)

Bushfires

- Studies (Melbourne Water and others) have shown how stormwater runoff from bushland first increases, then decreases in the years following a major bushfire.
- It takes a significant volume of rainwater to 'wet' the surface of trees (including their leaves) and the leaf litter and mulch that rests on the ground.
- Once this matter has been burnt, that volume of rainwater is not held back by the forest, but allowed to flow into streams.

2011 flood, Gowrie Creek, Toowoomba

Large or rare floods

- Over my career I have had many people tell me that they have lived next to a creek all their life, but they have never seen this level of flood damage.
- Their comments suggest that something else must have contributed to the creek erosion, and that 'something' must be some type of human activity.
- But that is the thing about rare floods, they occur so rarely that our life's memories cannot reconcile the level of damage they cause.

Fallen tree with adjacent bank damage

Natural loss of in-bank vegetation

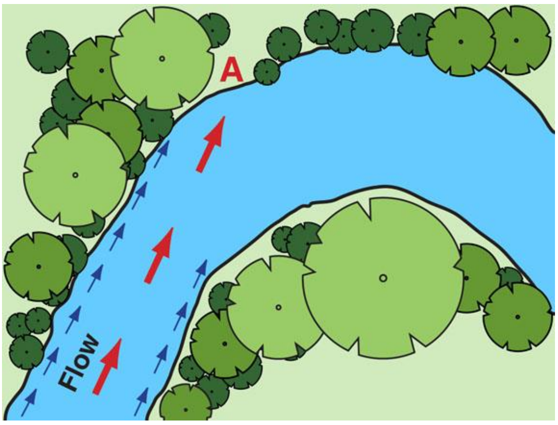
- Trees do eventually die, and some middle storey species die at an increased frequency.
- Dead trees can provide valuable habitat for wildlife, and thus should remain in place wherever possible.
- However, some dead trees can be toppled by strong winds, and the rotation of their rootball can expose parts of a creek bank to soil erosion.

Meandering channel in open farmland

Natural channel meandering

- Waterways generally don't like travelling in a straight line for any significant distance.
- Natural waterways tend to 'meander'.
- Over time these meander patterns can change, and these changes generally occur through a process of natural erosion and accretion (sedimentation).
- Of course this erosion process can be accelerated by human activities, but it can also be simply a natural process.

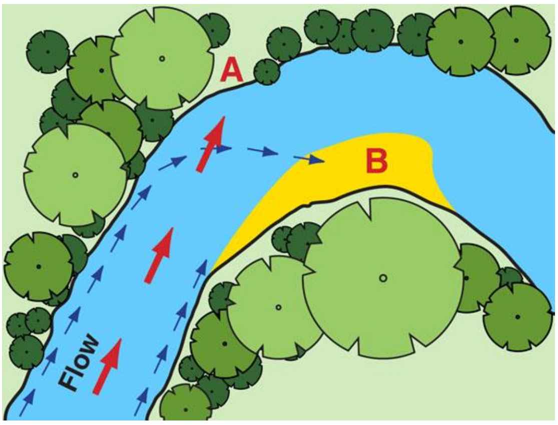
Bank erosion at channel bends



Stream flows approaching a channel bend

Introduction

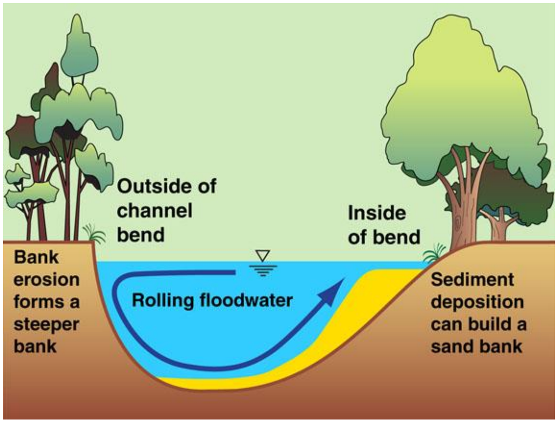
- The creek erosion that occurs at a channel bend could be referred to as 'bend erosion', but it is more commonly discussed in terms of the type of erosion that is occurring at the bend:
  - bank scour
  - bank undercutting
  - bank slumping
  - soil dispersion.
- But at channel bends there is not just soil erosion, there is also soil deposition.



Typical flow patterns at a channel bend

Flow patterns around channel bends

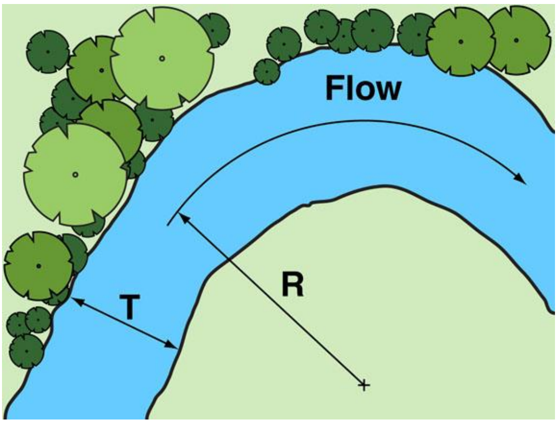
- Because the flow in the centre of a channel has more energy, when this flow reaches a channel bend, it pushes the water that was previously near the bank, out of its way.
- This central flow now moves towards the outside of the bend, and hits somewhere around Point A (causing soil scour).
- The water that was previously near the bank, now 'rolls' under the central flow, and this flow often deposits bed sediment on the inside bank (Point B).



Flow hydraulics at a channel bend

Hydraulics at channel bends

- The actual flow patterns that exist at channel bends are complex, and unsteady (i.e. change from instant to instant as a result of the random effects of turbulence).
- These flow patterns also vary depending on the 'tightness' of the channel bend.
- The severity or tightness of a channel bend depends on the relationship between the top width of the channel (T) and the radius of the bend (R).
  - T = channel top width [m]
  - R = bend radius [m]



Definition of terms

What is seen as a 'tight' channel bend

- At channel bends, a relationship develops between:
  - the hydraulics of the bend
  - the 'rolling' action of the flow
  - the ratio of the channel's top width (T) and the radius of the bend (R).
- In natural channels, and in the absence of rock, bends will normally reach a minimum radius of approximately three times the channel's top width.

$$R_{(Min)} = 3T \text{ (approx.)} \qquad 5.1$$

Creek erosion resulting from variations in catchment hydrology

Flooded creek (Qld)

Flood damage to bank vegetation (Qld)

Flood damage to bank vegetation (Qld)

Grass stripped off a gravel floodplain

Flow conditions within a creek

- Stream power can be an effective measure of the erosion potential of a flood.
- However, stream power does not incorporate three critical hydrology parameters:
  - flood duration
  - flood frequency
  - flood volume.
- Refer to Chapter 4 for further discussion on stream power.

The importance of flood duration

- Flood duration is important because:
  - the volume of bed sediments moved during a flood depends on the duration of the critical flows, and
  - the damage to some in-bank vegetation will be dependent on the duration of the flood, and
  - for small waterways, such as creeks, the stability of the waterway greatly depends on the stability of the in-bank vegetation, which can be impacted by flow duration.

The importance of flood frequency

- Flood frequency is important because:
  - the strength of some in-bank vegetation will be dependent on how much time has passed since the vegetation was last damaged (i.e. the vegetation repair time), and
  - for small waterways, like creeks, the stability of the waterway greatly depends on: [1] the strength of the in-bank vegetation, and [2] the density of the branches and leafy matter.

The importance of flood volume

- The volume of a flood is important because it is related to the peak discharge (which is related to the peak flow velocity) and the flood duration.
- The longer the duration of bankfull flows, the greater the:
  - expected damage to plants with low branches
  - loss of soil from around the base of isolated trees, and
  - damage to ground covers.

The effects of urbanisation

Urban creek catchment (Qld)

Urban land clearing (Qld)

A natural gravel-based waterway (Tas)

An urban creek with open floodway (Qld)

Introduction

- For a lot of people, urbanisation is seen as the primary cause of erosion problems in urban creeks.
- And yes; it is true that urbanisation does result in a lot of changes to our urban creeks, but you can still have a very healthy and natural-looking creek in an urban setting.
- Urbanisation will cause a creek to change, but good urbanisation results in a good creek changing into another 'good' creek.

Can you have a 'natural' creek in an urban catchment?

- In the 'chicken and egg' fable we cannot tell which came first; however, with *catchments* and *creeks* we know the catchment came first.
- Creeks exist as a direct response to the existence of a drainage catchment.
- Change the catchment, and you change the creek.
- You cannot have a 'natural' creek in an unnatural catchment, but you can have a creek that has many natural features.

Features of a <u>natural</u> creek

- Natural (undisturbed) creeks often exhibit the following features:
  - good water quality
  - healthy aquatic life
  - healthy terrestrial life, terrestrial habitats and movement corridors
  - healthy and diverse riparian vegetation
  - stable channel bed and banks, with erosion that is in equilibrium with the drainage catchment and vegetation regrowth.

Desirable features of an <u>urban</u> creek

- In a well planned urban catchment, the local creek can have all of the above mentioned features.
- The only differences (if any) that should exist within an urban creek are:
  - usually a larger channel size
  - reduced riparian width, often with an open grassed floodway located outside the riparian zone
  - a change in the dominant fauna species (though undesirable).

The effects of urbanisation

Roadside stormwater treatment (Qld)

Is it possible to have a zero-impact urban catchment?

- Urbanisation can influence creek erosion in many ways: Some impacts can be avoided through appropriate planning and design, while other impacts are simply unavoidable.
- If a natural creek exists downstream of a proposed urban development, then it is misleading for any engineering report to claim that there will be <u>no</u> adverse effects as a result of the development—there will always be some level of impact.

Water Sensitive Urban Design (NSW)

The benefits of *Water Sensitive Urban Design* (WSUD)

- The rules that are applied to new urban developments are constantly changing in order to minimise environmental impacts, and to better integrate attractive creeks into our urban landscapes.
- The principles of *Water Sensitive Urban Design* aim to achieve these benefits.
- BUT, not even these 'modern' rules can avoid <u>all</u> the potential adverse impacts to our urban creeks.

Urban catchment (Qld)

How urbanisation can influence the extent and frequency of creek erosion

- Most of the impacts of urbanisation relate to how the urbanisation will ultimately change to the catchment's hydrology.
- In responding to these changes in flow conditions the creek will try to change its channel size and meander pattern.
- The creek can only make these changes through the effects of channel erosion.

Flood flows in an urban creek (Qld)

Does urbanisation increase flow velocities in creeks?

- One of the most common statements I have heard over the years is that urbanisation increases flow velocities in creeks.
- This is one of those half-truth statements.
- After urbanisation, the <u>maximum</u> flow velocity that a creek will experience is **unlikely** to change, but the **frequency** of these high flow velocities is likely to increase.

The effects of urbanisation

Stormwater detention basin (Qld)

Stormwater retention basin (USA)

Creek flooding (Qld)

Flood damage to vegetation (Qld)

Increases in peak discharge

- If an urban area is developed without adequate stormwater detention and/or retention systems, then there will likely be an increase in the peak discharge during a wide variety of storms.
- Increasing the peak discharge will likely increase the peak velocity for that storm.
- Peak stormwater discharges from urban areas can be managed through the use of <u>detention</u> basins, but unlike <u>retention</u> basins, these systems do not alter the volume of runoff leaving an urban area.

Increases in the volume of storm runoff

- Some parts of a creek are sensitive to changes in peak discharge, while other parts are sensitive to changes in the volume of runoff.
- In some cases the creek will be sensitive to changes in the volume of runoff during a specific storm event, while for other creeks the critical issue will be changes to the annual (yearly) runoff volume.
- The volume of stormwater runoff can be managed through the use of porous pavements and retention basins.

Increases in the duration of storm flows

- Urbanisation can increase the duration of flood events, as well as increasing the duration of the critical bankfull flow.
- Increases in the duration of flows can result from:
  - increases in the volume of runoff
  - the use of detention basins.
- Increases in the duration of runoff can increase the degree of flood damage to some types of riparian and in-bank vegetation.

Increases in the frequency of runoff

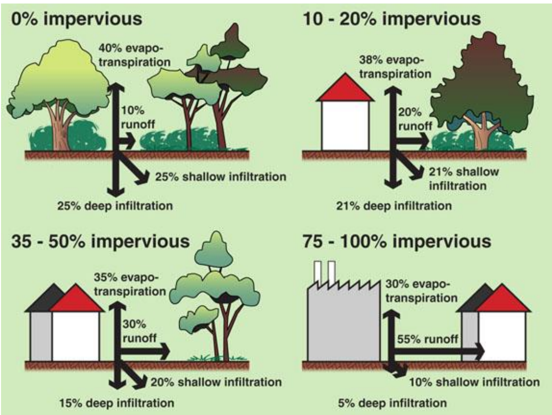
- Most waterways operate under a *damage–repair* cycle; that means, flood damage is expected to occur on a regular basis, but on average, sufficient time will exist between floods to allow the waterway to repair any damage.
- This means most waterways are *dynamic* systems that achieve a form of long-term equilibrium.
- If urbanisation increases the frequency of flood damage, then the creek will experience long-term changes.

The effects of urbanisation

Urban development (Qld)

Full urbanisation of a catchment (Qld)

Community tree planting (Qld)



Changing infiltration rates

When will a creek show signs of stress?

- If urbanisation is initially restricted to the lower catchment, then changes in the creek may be slow to appear.
- Changes to the creek may occur more rapidly once urbanisation reaches the upper half of the catchment.
- In general:
  - significant *physical* changes begin to occur after 50% urbanisation
  - *ecological* changes begin to occur after 10% of the catchment is urbanised.

How long after full urbanisation is achieved will a creek reach a stable condition?

- A waterway will generally need to pass through several damage-repair cycles before a stable channel condition is reached; even then, normal cyclic changes will continue to occur.
- A creek may not reach a stable channel size and meander pattern until some 20 to 50 years after full urbanisation is achieved within the catchment.

Should governments and community groups try to prevent a creek from eroding as a result of urbanisation?

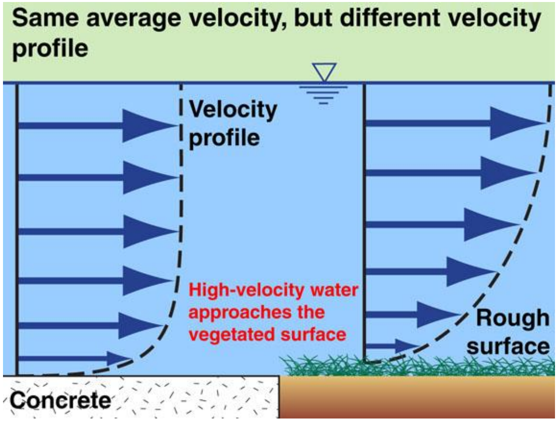
- Yes and no!
- Yes; it is good to monitor any creek erosion, and to assist a creek to find a new equilibrium.
- No; it is wrong to try and force a creek to stay in its original (natural) condition if the catchment hydrology is in fact changing—the creek should be allowed to find a new form that is in equilibrium with the new catchment.

How do the soil properties of the catchment affect the potential impacts of urbanisation?

- In general, urbanisation increases runoff rates and volumes because of the increase in impervious surface areas.
- However, if the catchment contains a very clayey soil with low infiltration rates, then the change in hydrology may be minor.
- The expected impact on a creek is related to the overall change in stormwater ‘infiltration and retention’ across the drainage catchment.

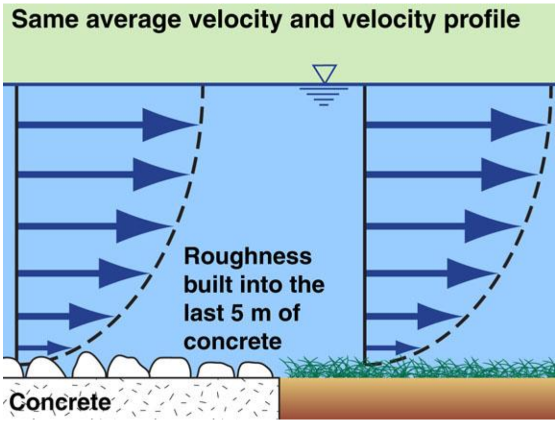
The erosive effects of concrete drains

Channel erosion adjacent a concrete drain



Changing flow conditions

Rock displaced at end of concrete channel



Roughness added to concrete surfaces

Introduction

- Flow velocity is obviously a major cause of soil scour, but flow velocity can arrive at a creek is many forms.
- The most important variables that can alter the form of the approaching flow are:
  - flow depth, and
  - surface roughness.
- If a concrete drain exists immediately upstream of a creek, then soil scour is often observed at the end of the concrete, and even along the edges of the concrete.

Changes in bed roughness

- Variations in flow depth and surface roughness cause variations in:
  - the velocity profile (i.e. changes in flow velocity with depth) and
  - the boundary layer thickness.
- When stormwater runoff leaves a concrete drain and enters a vegetated creek, it must slow the water that is close to the bed—this requires energy—and the effects of this energy loss is an increase in soil scour at the end of the concrete.

Rock placed downstream of concrete

- Most of the rock sizing equations presented within this field guide are based on the following assumptions:
  - the surface immediately upstream of the rock has approximately the same roughness as the rock-lined surface
  - the Manning's roughness of the rock-lined surface is given by Equation 10.4 (Part 2, Chapter 10).
- Therefore, the rock placed downstream of concrete needs to be increased in size.

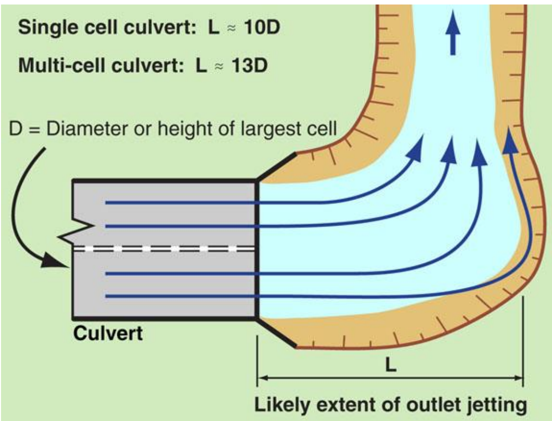
Modifying the roughness of concrete surfaces

- In circumstances where a concrete-lined stormwater drain suddenly ends, and releases its water into a vegetated creek, soil scour can often occur immediately downstream of the concrete.
- To reduce the risk of this erosion, artificial roughness can be introduced to the final 5 metres (or so) of the concrete (usually by embedding rocks into the concrete) in order to develop an appropriate boundary layer and velocity profile.

The potential impact of waterway crossings on creek erosion

Outlet of a pipe culvert (NSW)

Localised bed scour around bridge piers



Outlet jetting causing bank erosion

Scour hole downstream of a causeway

Introduction

- Waterway crossings can consist of:
  - bridges
  - arch structures
  - culverts
  - causeways (elevated embankments)
  - fords (bed level crossings)
- In some cases these structures can initiate channel erosion, in other cases they can arrest some forms of migrating bed erosion.

Erosion caused by bridges

- Major bridges potentially have the least impact on creek and river erosion.
- Localised bed erosion can occur around the bridge piers.
- Unlike a culvert crossing, any bed erosion that is migrating up the waterway towards the bridge (e.g. a head-cut), can readily pass under a bridge and continue its migration up the waterway.

Erosion caused by culverts

- Outlet 'jetting' from an culvert can cause bank erosion if the jet travels less than 13 times the jet diameter before striking a waterway bank.
- Bed erosion that is migrating up the waterway may terminate at the culvert, which may help to prevent bed erosion upstream of the culvert.
- A scour hole can form at the outlet of the culvert if the culvert's floor is elevated above the downstream bed.

Erosion caused by causeways and ford crossings

- A relatively stable scour hole can form downstream of a causeway crossing.
- In general, these scour holes aid in energy dissipation, and therefore should not be reduced in size by filling them with rock.
- Bed-level (ford) crossings generally do not initiate creek erosion unless the road crossing is stabilised with concrete (or other materials) that restrict or prevent the normal migration of bed material.

The importance of vegetation in controlling creek erosion

Riparian vegetation (Qld)

Introduction

- In the early days of waterway assessment, waterway health was judged solely on water quality outcomes—this meant a glass of pure water could have technically been classified as a Class A waterway!
- Obviously there is more to waterway values than just water quality.
- A key component of most non-arid waterways is *vegetation*, including lower storey, middle storey and upper storey plants.

Ground covers (NSW)

The role of groundcovers

- With respect to erosion control, groundcovers are the primary plants used to control soil 'scour'.
- Groundcovers can also reduce local erosion around the base of isolated trees.
- Besides their erosion control benefits, groundcovers provide:
  - a food source for wildlife
  - shelter for small ground-dwelling fauna
  - boundary layer development that aids fish passage during floods.

Middle storey shrubs on a river bank

The role of middle storey plants

- In my opinion, middle storey plants are often the forgotten heroes of our riparian landscape.
- Yes they make it difficult for humans to walk along a creek (which can be a good thing for the creek and wildlife), and they can have an adverse effect on flood levels, but their slowing of water velocities can help to reduce the degree of flood damage to many trees.
- They also provide food and shelter for many birds.

Upper storey trees with minimal shrubs

The role of upper storey plants (trees)

- Tree roots provide the primary anchoring system for the soil, which allows creeks to have steep and/or high banks.
- The upper canopy can help control temperatures, shade the stream, help to control weed growth (through shading), and in some cases help to form a micro-climate within the riparian zone.
- Besides their erosion control benefits, trees provide a source of food, habitat, shelter and movement corridors for wildlife.

Creek erosion caused by changes to riparian vegetation

Weed removal from riparian areas

Land cleared of natural bushland (Qld)

Removal of middle storey plants (Qld)

Creek on left, floodway on right (Qld)

Introduction

- As discussed several times so far, vegetation plays a major role in the stability of most waterways.
- Different plants have different hydraulic properties, and so a change in plant species or plant density along a creek will almost certainly cause some type of change in the dynamic stability of the waterway.
- In creeks, native vegetation is better than weeds, but weeds are better than bare soil.

The effects of land clearing

- Vegetation removal outside the riparian zone can still adversely impact a local waterway.
- Land clearing:
  - reduces stormwater infiltration
  - reduces rainwater capture and storage over the land surface
  - reduces plant evapo-transpiration
  - reduces evaporation from wetted plants and groundcover surfaces
  - increases stormwater runoff.

Changes to the density of overbank vegetation

- Reducing the vegetation density within floodplains and floodways reduces their hydraulic resistance:
  - which can increase the volume of floodwater passing through these areas
  - which can reduce the shear stress and flow velocity within the adjacent creek.
- Conversely, increasing the hydraulic roughness of floodplains can increase the erosion potential within the creek.

The benefits of creating open floodways

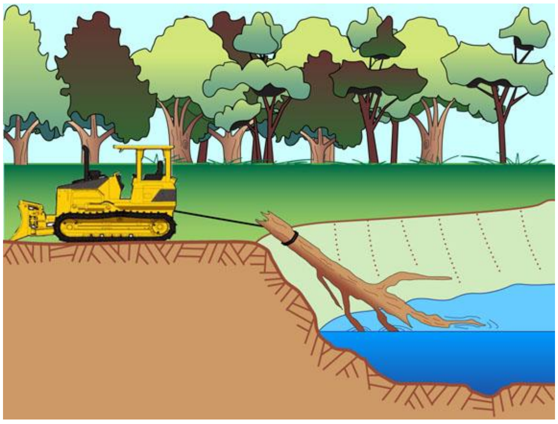
- In urban areas, open *floodways* are often set aside as parkland between the riparian zone and the residential properties.
- These floodways can:
  - reduce local flood levels
  - reduce the erosion potential within the adjacent creek
  - reduce wildlife (snake) movement from the creek into adjacent homes
  - provide fire control and maintenance access.

The impact of fallen trees on bank erosion

Fallen tree (Qld)

Bank erosion (Qld)

Heavily blocked waterway (Qld)



Snag removal

Introduction

- Trees do die from time to time.
- And trees, living or dead, do fall from time to time.
- When trees fall within the riparian zone they can increase the hydraulic roughness of these areas.
- When trees fall into the waterway channel, they not only increase the roughness of the channel, they also capture leafy debris, and can generate large-scale eddies that cause bank erosion.

Local bed and bank scour

- Fallen trees not only disturb the soil through the movement of the rootball, they can also cause:
  - increases in the local flow velocity
  - large-scale turbulence and eddies
  - the re-direction of stream flows (sometimes directing these flows towards the opposite bank)
- However, fallen trees can reduce upstream flow velocities, thus reducing the erosion risk upstream of the debris.

Backwater effects

- In many cases, fallen trees and branches can benefit a waterway; however, they can also adversely affect upstream flood levels (known as the backwater effect).
- If this woody debris is displaced by a flood, it can become trapped against a culvert or bridge, which can further impact the backwater effects of the waterway crossing.

Should fallen trees be removed from creeks?

- Fallen trees (or snags) are a natural part of our landscape, and a natural part of many waterways.
- Ideally, fallen trees should not be removed from waterways.
- However, their removal is usually required if they represent a flood risk, or if they could be dislodged by subsequent floods and subsequently block or damage downstream structures.

Other causes of creek erosion

Off-stream extractive industry (Qld)

Extractive industries

- Instream extractive industries (e.g. sand and gravel extraction from within a waterway channel) can adversely affect the erosion potential upstream of the industry by:
  - initiating head-cut erosion
  - increasing upstream flow velocities.
- Off-stream extractive industries (within the floodplain) can adversely affect the erosion potential of a waterway in a similar manner.

Boat-generated wave (Qld)

Waves generated by boats

- If waves are introduced to a river by boat traffic, and if these waves approach the river bank just above the height of a mangrove bench, then these waves could curl and break just like on a beach.
- After breaking, wave energy is transferred into a forward rush of water, which can erode the river bank.
- Waves can also be generated by water skiing activities.

Introduced sediment covered with grass

Inflow of sediment from urban developments

- Excessive sediment runoff (e.g. sand) from urban developments quickly settles on the bed of minor waterways, such as urban creeks.
- Often this sediment can become stabilised by grasses and weeds.
- Excessive sedimentation can cause a creek to become shallower and therefore wider, consequently resulting in bank erosion.

Flood damage to a river bank (Qld)

Flood damage

- Of course floods are a major cause of creek erosion, but in most cases this erosion can be linked back to the key issues of:
  - flow velocity
  - flow duration
  - flood frequency
- Further discussion on how different types of creeks respond to severe flood is the subject of the next chapter.

6. How Creeks Respond to Severe Floods

Introduction

Bank failure, Brisbane River, 2011

River flooding (Qld)

Flood damage to the Burnett River (Qld)

Bank slumping (Qld)

Introduction

- It should not come as a surprise to anyone that creek erosion is often associated with the occurrence of floods.
- For some waterways, both the peak discharge and peak velocity will increase with the severity of the flood, but this is not the case for all waterways.
- In some cases, peak flood levels will be linked to tide levels, or debris blockages, and peak flow velocities may only occur during bankfull conditions.

Types of floods

- A flood is any flow condition that spills over a floodplain (i.e. floods the land).
- Creeks can experience both short duration and long duration floods.
- Short duration floods are generally caused by thunder storms.
- Long duration floods are caused by rainfall depressions or cyclones.
- Rivers generally only experience long duration, slow moving floods.

Types of flood damage

- The most common forms of flood damage to a creek are:
  - vegetation damage
  - vegetation and snag displacement
  - bed and bank scour
  - movement of bed sediments
  - scour around bridges and culverts.
- Less common erosion problems include the relocation of the channel within the floodplain.

Creek erosion that occurs after a flood has passed

- Some forms of creek erosion can continue to occur in the days following a flood event, including:
  - bank slumping
  - the collapse of an undercut bank, and
  - landslides.
- Even though these bank failures may occur well after a flood, they are still considered to be a component of the overall flood damage.

Flood damage to waterways

Natural channel roughness (Qld)

Flood scour of a creek bank (Qld)

Debris blockage of a road culvert (Qld)

Artificial log groynes (NSW)

Introduction

- Prior to a flood, it is typical for the hydraulic roughness of a waterway channel to slowly increases, with increasing vegetation density and snags.
- The term 'hydraulic roughness' incorporates many aspects, including:
  - vegetation roughness
  - landform roughness, and
  - the hydraulic effects of a meandering waterway channel that also helps to slow the passage of floodwater.

Flood clearing of waterways

- During a major flood, the floodwater will try to remove hydraulic roughness from the waterway.
- Soil erosion and hydraulic turbulence will be focused on any irregularities within the channel, and the floodwater will try to remove vegetation and debris.
- As far as the floodwater is concerned, the smoother and more uniform the channel cross-section is, the faster the floodwater can move.

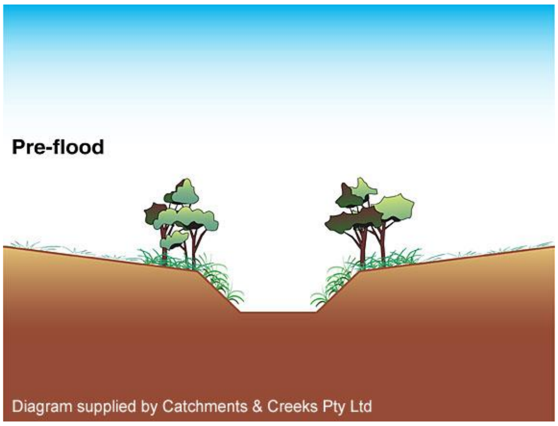
The release of flood debris into waterways

- In natural waterway, floods will typically produce a 'smooth', uniform channel.
- In urbanised waterways the damage caused by the floodwater can actually increase the channel roughness by washing vegetation debris up against bridges and culverts.
- This means the speed of floodwater can begin to slow down during certain stages of a flood.

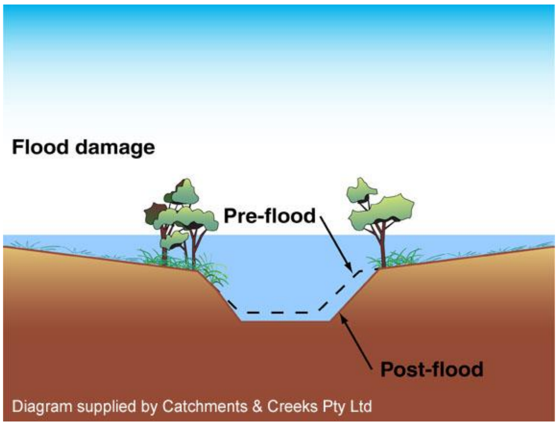
Introducing channel roughness

- Some waterway rehabilitation measures involve introducing additional physical roughness to a waterway channel in order to slow the velocity of floodwater, and thereby reduce flood-induced erosion.
- Extreme care must be taken in the design of such roughness elements because subsequent flood events will focus their energy loss and soil erosion around these elements in an attempt to undermine and remove these roughness units from the channel.

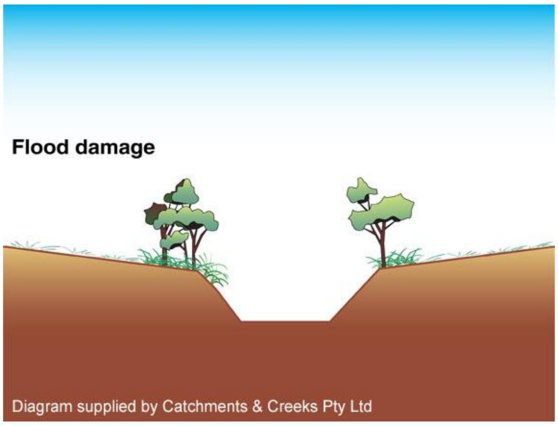
Flood damage to clay-based waterways



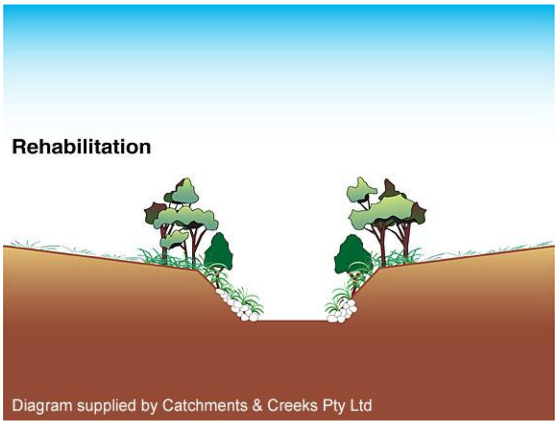
Pre-flood channel condition



Flooded waterway



Enlarged, post-flood channel



Typical post-flood creek rehabilitation

Introduction

- In general, clay-based creeks are more dependent on vegetation for their long-term stability than sand or gravel-based waterways.
- Even though these waterways can be looked upon as 'fixed bed' creeks, they are still dynamic systems that are continually passing through a damage–repair cycle.
- Erosion is often followed by accretion, is followed by erosion, is followed by accretion, etc.

During a flood

- As water levels rise, the soil becomes saturated, and some plants become partially or full submerged.
- Plants that cannot tolerate full or partial submergence will die (natural selection).
- Some plants will bend with the flow, some plants will fold flat on the ground, and some plants will experience fracturing of their branches or trunk.
- Soil scour will occur on the bed and banks.

Post-flood channel condition

- In general, the enlarged, post-flood channel has the same basic shape (i.e. width-to-depth ratio) as its pre-flood condition.
- Some bank slumping may occur in the days following the flood (i.e. while the soil is still saturated).
- Some of the plants that folded flat during the flood will either re-stand, or re-shoot after the flood.

Post-flood channel works

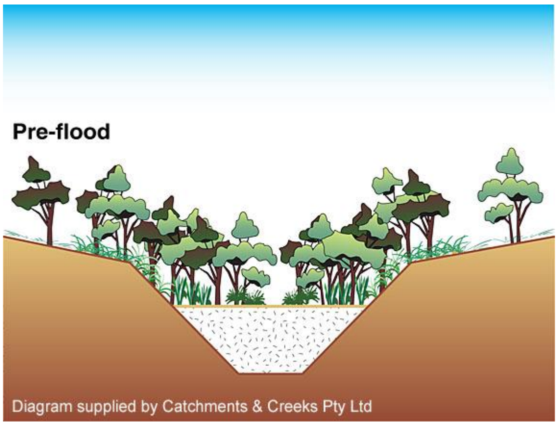
- After the flood, the channel can be left to repair itself if the creek is in equilibrium with its drainage catchment.
- However, if the creek is not in equilibrium with its catchment, then governments or community groups can assist the creek to find a new stable condition.
- Active replanting can reduce short-term erosion problems.
- The placement of rock can reduce the risk of bank slumping.

Flood damage to clay-based waterways

Figtree Creek, Yeppoon, Queensland (2014)

Tenthill Creek, Gatton, Queensland (2011 flood damage)

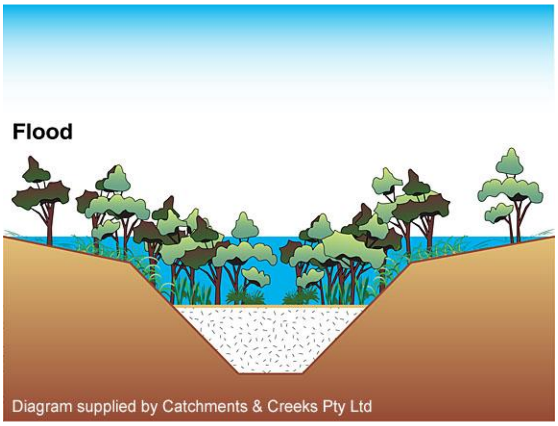
Flood damage to sand-based waterways



Pre-flood channel condition

Introduction

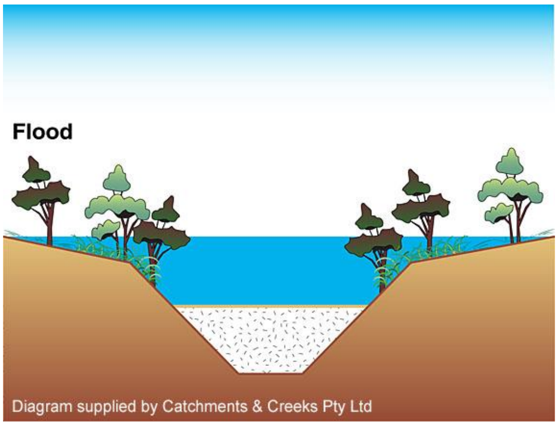
- The behaviour of sand-based waterways during flood events will depend on the depth and extent of the sand layer.
- In some cases, the sand layer can be very deep, and may even be deeper then the root systems of most vegetation.
- In other cases, the bed sand may be relatively shallow, allowing tree roots to pass through the sand and into the underlying clayey soil.



Flooded waterway

During a flood

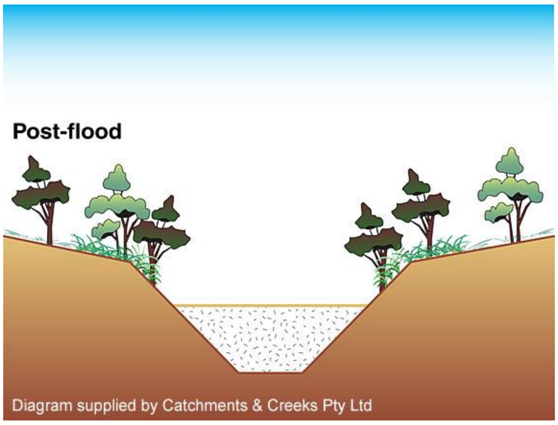
- If the sandy bed was formed by sand depositing in a deeply eroded channel (possibly the result of historical sea level changes), then the depth of the sand may be greater than the root systems of most plants.
- During major floods, the sandy bed can liquefy and begin to ‘flow’ down the channel.



Gross loss of vegetation during the flood

Damage caused by rare floods

- If the sand layer deep, or extends into (or under) the banks, then when the sand liquefies, large areas of riparian vegetation can be washed away.
- During such a flood, the banks may erode, and the channel may become wider.
- However, it is also possible for the flood damage to be limited to just the movement of the sandy bed material.



Enlarged, post-flood channel

Post-flood condition

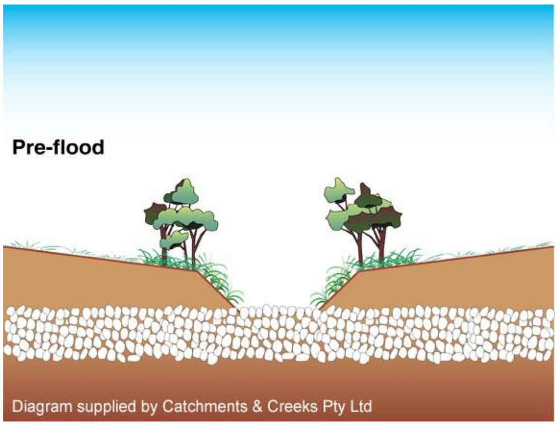
- After the flood the channel bed will generally be near-level from bank to bank, with just minor undulations in the sandy material.
- If such floods are regular events, then the sandy bed will remain relatively free of woody vegetation.
- If such floods are rare events, then mature woody vegetation can re-establish over the sandy bed, with just a small section of the bed exposed in the form of a small creek.

Flood damage to sand-based waterways

Gully formed in a sandy soil during a single storm event (Roma, Queensland)

Significant loss of riparian vegetation, Oxley Creek, Brisbane, Queensland (1996)

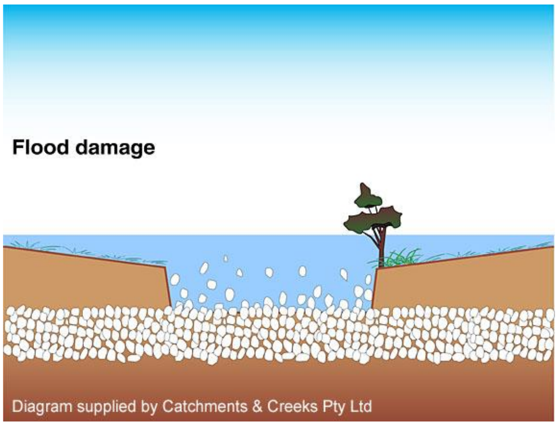
Flood damage to gravel-based waterways



Pre-flood channel condition

Introduction

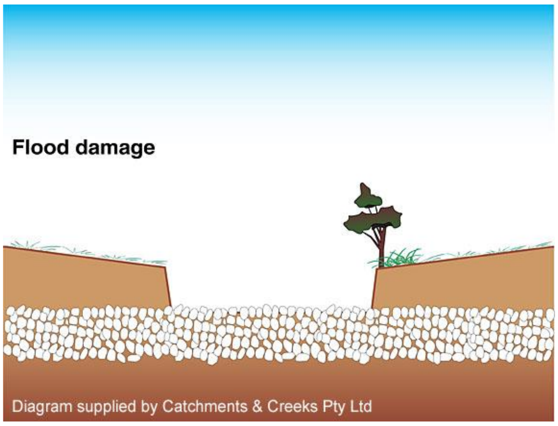
- For the purpose of this discussion, gravel-based waterways will include cobble-based and boulder-based waterways.
- Some gravel-based waterways can experience only minor movement of the bed material during the more frequent flood events.
- However, during major, or even rare floods, these waterways can experience significant bed movement and flood damage.



Flooded waterway

During a flood

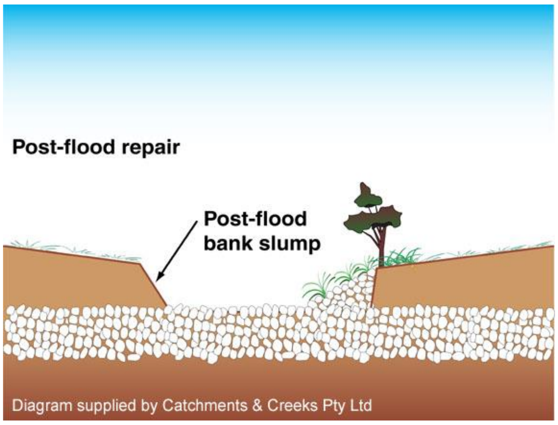
- At a certain stream power (what is termed the critical velocity or critical discharge) the bulk of the bed material will begin to mobilise and move (roll) down the channel.
- Some of the smaller gravels will be lifted up into the main channel flow.
- As this gravel-filled floodwater passes down the waterway, its erosion potential is significant, causing severe damage to any vegetation or engineered structures that may stand in its path.



Enlarged, post-flood channel

Damage caused by rare floods

- After the flood has passed, the channel will often be left with near-vertical banks, and a near-level channel bed with just minor undulations over the surface of the gravel.
- The post-flood channel can be near-rectangular in cross-section, usually much wider than the pre-flood condition.
- Large amounts of riparian vegetation can be damaged and/or removed by the flood.



Possible post-flood creek rehabilitation

Post-flood channel works

- Some mature trees may remain on the inside of some channel bends.
- To save these remaining trees, the bed gravel can be pushed up against the bank, thus reducing the risk of post-flood bank slumping that would remove these remaining, and now highly-valued, trees.
- If left untouched, the near-vertical banks will normally slump over time, and new riparian vegetation will establish over the bank, but this may take decades if left to natural processes.

Flood damage to gravel-based waterways

Blackfellow Creek (tributary of Tenthill Creek) Queensland (Pre 2011 flood)

Tenthill Creek, Tenthill, Queensland (2011 flood damage)

Flood damage to gravel-based waterways

Warrell Creek, Aratula, Queensland (2011 flood damage on a channel bend)

Buaraba Creek, Buaraba, Queensland (2011 flood damage)

Post-flood channel repair

Post-flood creek inspection (Qld)

Introduction

- The various methods available for the repair of bed and bank erosion are discussed in Part 2 of this document, but just because you have the willingness and resources to conduct creek rehabilitation, does that mean you should?
- Creeks have existed on this planet for longer than humans, and during that time they have experienced millions of floods, so do they really need our help?

Natural revegetation of a bank slump (Qld)

The 'do nothing' approach

- Creeks have the natural ability to 'repair' any form of bed or bank erosion.
- The *do nothing approach* is often the best way to deal with creek erosion.
- Of course, this 'do nothing' approach costs less initially, but it can cost more over the long-term.
- Creeks may be able to find their own solution to flood damage, but that outcome may result in long-term damage to private property, or public assets.

In-channel repair works after a flood (Qld)

The protection of public assets

- People can 'assist' a creek to establish a new form of stability when it appears that the creek erosion will:
  - cause the loss of productive farm land
  - threaten the stability of a home
  - cause damage to public assets, such as roads or bikeways
  - result in the formation of a safety hazard, such as an unstable creek bank in a public park.

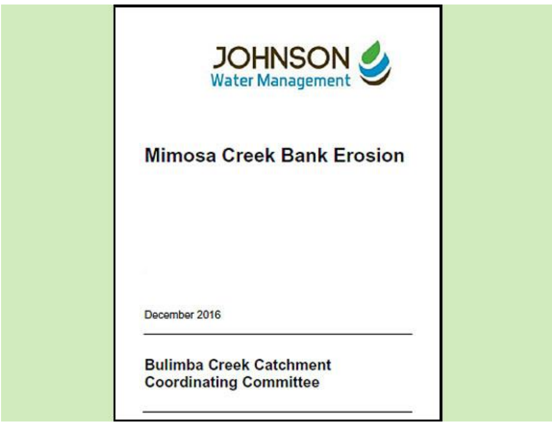
Post-flood bank repairs (Qld)

Helping a creek to accelerate its natural repair cycle

- Ideally, the repairs made to a creek should be consistent with the outcomes the creek would have naturally achieved over the long-term.
- Ideally, creek repairs should utilise only three products: soil, rock and plants.
- Wherever possible, synthetic products should not be used in creek rehabilitation, because such products can present a risk to fauna and fauna habitats.

7. Reading the Land

Introduction



Creek erosion study

Data collection

- Data collection is a very important part of the planning and design phases of creek engineering.
- If you do not have years of experience in dealing with creek erosion, then you may need to rely on creek data collected by others.
- As you gain experience, you will begin to rely more on what your eyes see in the field than on what you gain from reports.

Aerial photography (Qld)

Data collection in the office

- The first data to be collected on a creek includes:
  - the creek's name and location
  - size and shape of the catchment
  - location of the erosion site
  - any previous reports on the site.
- Before or after visiting the site it can be useful to review historical aerial photographs (Internet & Dept of Lands, or DPI) looking for indicators of past erosion and channel migration.

Creek inspection (Qld)

Site inspection

- It has become my preference to visit a creek only when the exposed soils are 'dry'—this is because soils generally reveal more information when they are dry.
- When the soil is wet it can be hard to distinguish the soil layers, the soil type, and any surface markings that may indicate the type of erosion.
- It can be helpful to inspect the creek by walking in an upstream direction—this is because most reaches of a creek will be subject to backwater effects, which means what occurs upstream is often influenced by what is occurring downstream.
- Walking upstream allows you to understand what may be causing the upstream erosion, because you have already inspected the downstream reach.
- When you reach the erosion site, take note of:
  - the location of channel bends
  - the direction of scour marks in the soil
  - any change in plant species that looks unusual.

Creek inspection (NSW)

Identifying problematic 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

Dispersive soil (Port Lincoln, SA)

Water testing

Saline soils (Port Lincoln, SA)

Soil data

- It is not essential to get soil testing at every creek erosion site—in most cases just a visual inspection will provide all the necessary information.
- However, if the site inspection reveals possible 'problematic soils' (such as highly erodible soils, dispersive soils, slaking soils, or acid sulfate soils), then soil testing may be required.
- Some suggest there are no problem soils, just poorly managed landscapes!

Dispersive and slaking soils

- Dispersive soils become unstable when wet, causing clay particles to separate and wash (disperse) from the soil.
- Critical soil tests:
  - exchangeable sodium percentage > 6%
  - Emerson aggregate classes 1 to 5, note classes 3(2), 3(1) and 5 have a slight risk of dispersive problems.
- A simple field test such as the Aggregate Immersion Test (see over page) can be used as an on-site indicator test.

Acid sulfate soils

- Prior to the disturbance of soils below an elevation of 5 m AHD, the soil should be tested for its acid sulfate potential.
- Creek works that disturb acid sulfate soils can result in fish kills.
- Actual and potential acid sulfate soils must be managed in accordance with the state-approved guidelines.

Saline soils

- Saline soils can introduce complex revegetation problems.
- Saline soils can be identified through appropriate soil testing, such as:
  - electrical conductivity (EC) of either a 1:5 extract > 1.5 dS/m, or a saturated extract > 4 dS/m.
- Tree planting in saline soils requires expert advice.

Aggregate Immersion Test

Slightly dispersive soil

Non-dispersive, non-slaking soil

Dispersive soil

Slaking soil

Aggregate Immersion Test

- The ***Aggregate Immersion Test*** can be used as an 'indicator' of dispersive soils.
- The test involves filling a dish with distilled water (generally available at petrol stations and supermarkets) to a depth sufficient to cover the soil sample.
- 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 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 soil clumps are loose or otherwise 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 soils

- If the soil disperses both horizontally and vertically into the water, then the soil could be dispersive.
- Highly dispersive soils 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; hence the need to use distilled water.

Slaking soils

- Slaking soils are soils that readily collapse in water, but do not necessarily 'colour' 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 floodwater.

Identifying dispersive and slaking soils

Fluting erosion (Qld)

Fluting

- In dispersive or sodic soils the rills passing down steep banks and batters are normally deep, narrow and regularly spaced—a form of erosion known as 'fluting'.
- Dispersive soils are sometimes referred to as sodic soil (because of the high sodium content), or 'sugary' soils (because they produce a lot of 'washed' sand when they erode).

Bank not exposed to direct rainfall (Qld)

Textured surface

- Both dispersive and slaking soils can display textured patterns on soil surfaces that are not directly exposed to rainfall.
- These surfaces become textured as a result of raindrop splash bouncing off adjacent soil surfaces.

Deep rilling and tunnel erosion (Qld)

Tunnel erosion

- Tunnel erosion is typically an indicator of dispersive or sodic soils.
- Tunnel erosion can initially appear as just another example of bank rilling, until further investigations discover that tunnel erosion exists further up the bank.

Rilling that extends to top of bank (Qld)

Rilling that extends to the top of the bank

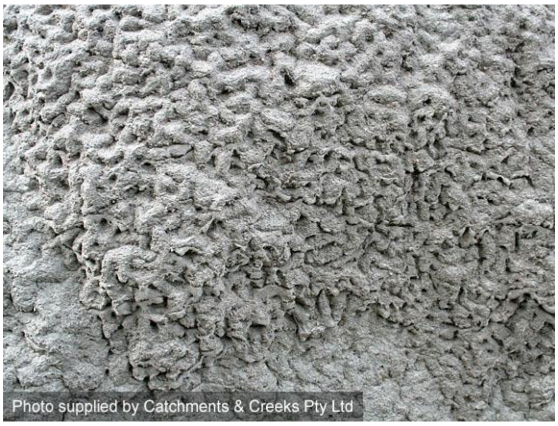
- If the rilling extends to the top of the bank, then this **may** indicate that the erosion is influenced by run-on water.
- In such cases, investigate the drainage conditions coming off the floodplain.
- However, this can also indicate that the soil is dispersive all the way to the top of bank
- If the soils are dispersive (sodic) then they will need to be ameliorated with chemicals, such as gypsum.

Identifying dispersive and slaking soils

Caboolture, Queensland

Visual indicators of dispersive soils

- As previously discussed, dispersive soils can often be identified by the regular-spaced rilling (fluting) and their often textured erosion patterns.
- In Australia, dispersive soils are more commonly associated with examples of gully erosion, but these soils can still be exposed by recent erosion activities on creek banks.



Brisbane, Queensland

Ipswich, Queensland

Springsure, Queensland

Miles, Queensland

Coverty, Queensland

Broken Hill, NSW

Reading the scour marks in the soil

Soil scour caused by high velocity flows

Horizontal scour marks

- Scour marks generally align with the direction of the force that caused the erosion.
- In this case the scour marks indicate high-velocity flood flows.
- Over time these marks can be altered by rainfall or stormwater spilling down the bank.

Bank slump (Qld)

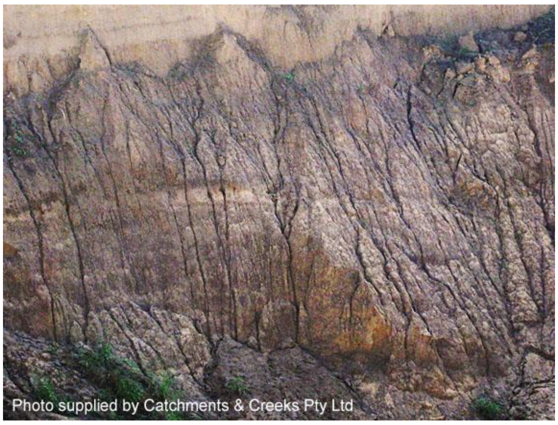
Other horizontal marks

- Near-horizontal marks can appear in a soil as a result of:
  - the different erosion rates of different soil layers (horizons)
  - the bank being constructed through the process of land filling (i.e. a previous bank repair), where different layers of the soil underwent different levels of compaction, or have different erosion properties.

Bank slump (Qld)

Vertical scour marks

- Bank slumping can often leave vertical ‘scratch’ marks in the soil.
- However, care must be taken to avoid confusing such marks with the vertical rilling that is created by minor stormwater flows spilling over the bank after the flood have receded.
- ‘Rills’ can wriggle and meander a bit as they travel down a slope; while slump ‘scratches’ are normally straight and vertical.



Minor runoff rilling (Qld)

Vertical rilling (fluting)

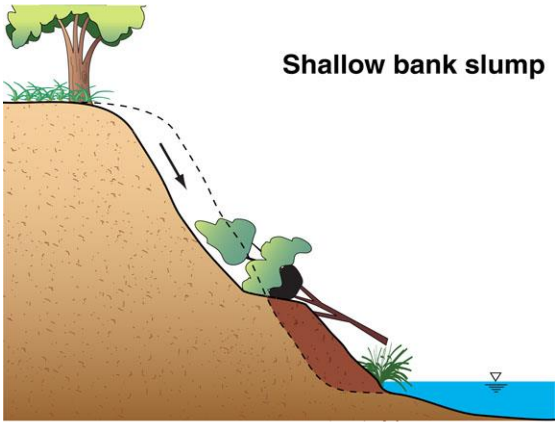
- Vertical rilling can result from:
  - minor stormwater flows spilling down the bank
  - erosion caused by stormwater flowing over a dispersive soil.

Displacement of vegetation by floodwater

Flood damage to riparian vegetation (Qld)

Introduction

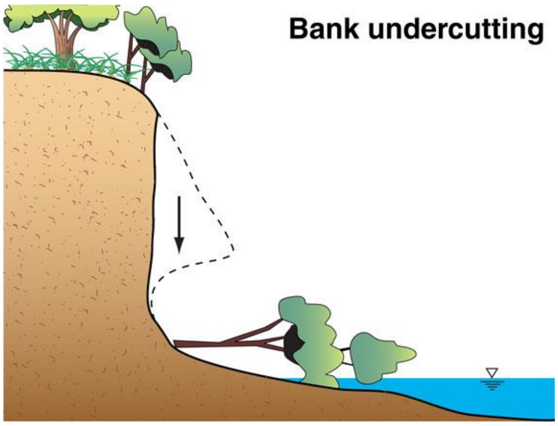
- Observing how certain plants have been disturbed by a flood can <u>sometimes</u> provide useful information about the type of erosion.
- In high velocity flows, trees often fall in the direction of the flow, with the rootball upstream and the branches pointing downstream.



Bank slumping

Bank slumping

- If the bank slumped after the flood has receded, then trees often (not always) rotate such that the branches point up the bank.



Bank undercutting

Bank undercutting

- If an undercut bank collapses (slumps) after a flood has receded, then trees often (not always) rotate such that the branches point into the channel.

Tree that fell in an upstream direction

Sometimes other factors cause a tree to fall in a different direction

- But there are always exceptions, such as:
  - trees felled by strong winds
  - trees that are affected by large eddies that cause a backflow at the location of the tree
  - trees that fall into a scour hole that has formed either side of the tree (i.e. upstream or downstream of the tree).

Other visual indicators

Crack in soil close to a creek bank (Qld)

Cracks near the top of bank

- Cracks in the soil mean 'stress'—the earth is being 'pulled' apart.
- In this case the bank has been undercut by stream flows, and the edge of the bank is close to falling into the creek.

Crack several metres from a creek bank

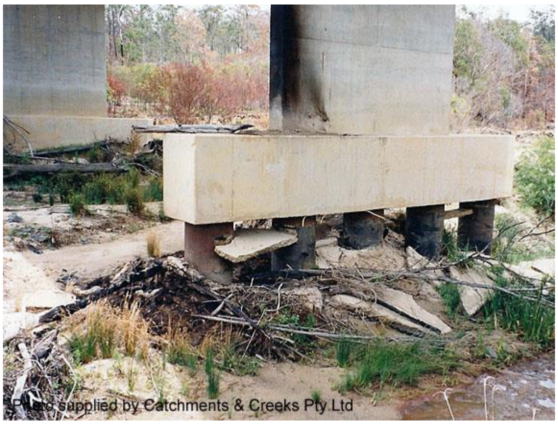
Cracks well away from the top of bank

- Cracks in the earth that are located several metres from the top of bank generally indicate that a slip circle failure is in progress.
- Deep cracks like this can also occur in 'black soils' that experience significant shrink–swell movement as a result of changing soil-moisture conditions.

Heavily 'patched' bitumen road (NSW)

Roads in poor condition near the erosion site

- If soil issues are likely to dominate a particular creek, then you will often find that the roads near the creek also experiences foundation problems, usually resulting in lots of potholes and bitumen repairs.



Lowering of a creek bed under a bridge

Earth shifting around bridge foundations

- The foundations of bridges, culverts and some stormwater outlets can reveal the likely elevation of the creek bed at the time these structures were built.
- This information can give a timeline of bed and bank movement within the waterway.

Other visual indicators

Flood debris (Qld)

Flood debris

- Flood debris caught in trees can provide an indication of:
  - the force of the flow
  - the maximum height of the flood (i.e. flood debris caught in the upper branches of trees).

Bank erosion downstream of a sewer pit

Exposed engineering structures

- Engineering structures, such as stormwater outlets and sewer pits, can provide information on:
  - the extent of bank erosion
  - the effects of eddies formed as floodwater passes these structures
  - the original elevation of the bank (if the structure was originally located within the floodplain)
  - the original elevation of the bed (if located within the channel).

Old fence post exposed by bank erosion

Exposed synthetic materials

- The exposure of made-made (synthetic) products usually indicates that:
  - the site has been ‘filled’ or otherwise modified in the past
  - the site has experienced significant sediment deposition during past floods, and now the site is experiencing significant erosion or channel migration.

Soil pinnacle (Qld)

Soil pinnacles

- Soil pinnacles can indicate:
  - the site is subject to raindrop impact erosion
  - the exposed soil is highly erodable
  - the site has not experienced medium to high-velocity flows in the recent past.

Other visual indicators

Bed erosion around the base of a tree

Scour holes

- Scour holes can indicate:
  - high-velocity flows
  - bank erosion that has caused a tree to now be located within the main channel
  - recent sedimentation; i.e. scour holes were not previously formed because the in-situ bed material (below the sediment) is more erosion resistant.

Scour hole within an overland flow path

Scour hole near a fallen tree

- A scour hole located downstream of a fallen tree located within an overland flow path indicates that:
  - flow velocities where high, and/or
  - the soil is highly erodible, and/or
  - an eddy was formed above the scour hole during a recent flood.

An indicator of severe bank erosion

Exposed tree roots

- Exposed tree roots can indicate:
  - severe bank erosion
  - channel migration
  - the loss of adjacent groundcovers or middle storey plants that previously prevented high-velocity flows from passing around the base of the tree.
- It is noted that for some plant species:
  - exposed tree roots can survive open air exposure, and effectively turn into 'trunk' elements
  - buried parts of a tree trunk can reform into parts of the root system, thus allowing the growth of new lateral roots.
- Partially buried plants indicate that the site has been subjected to significant sedimentation.