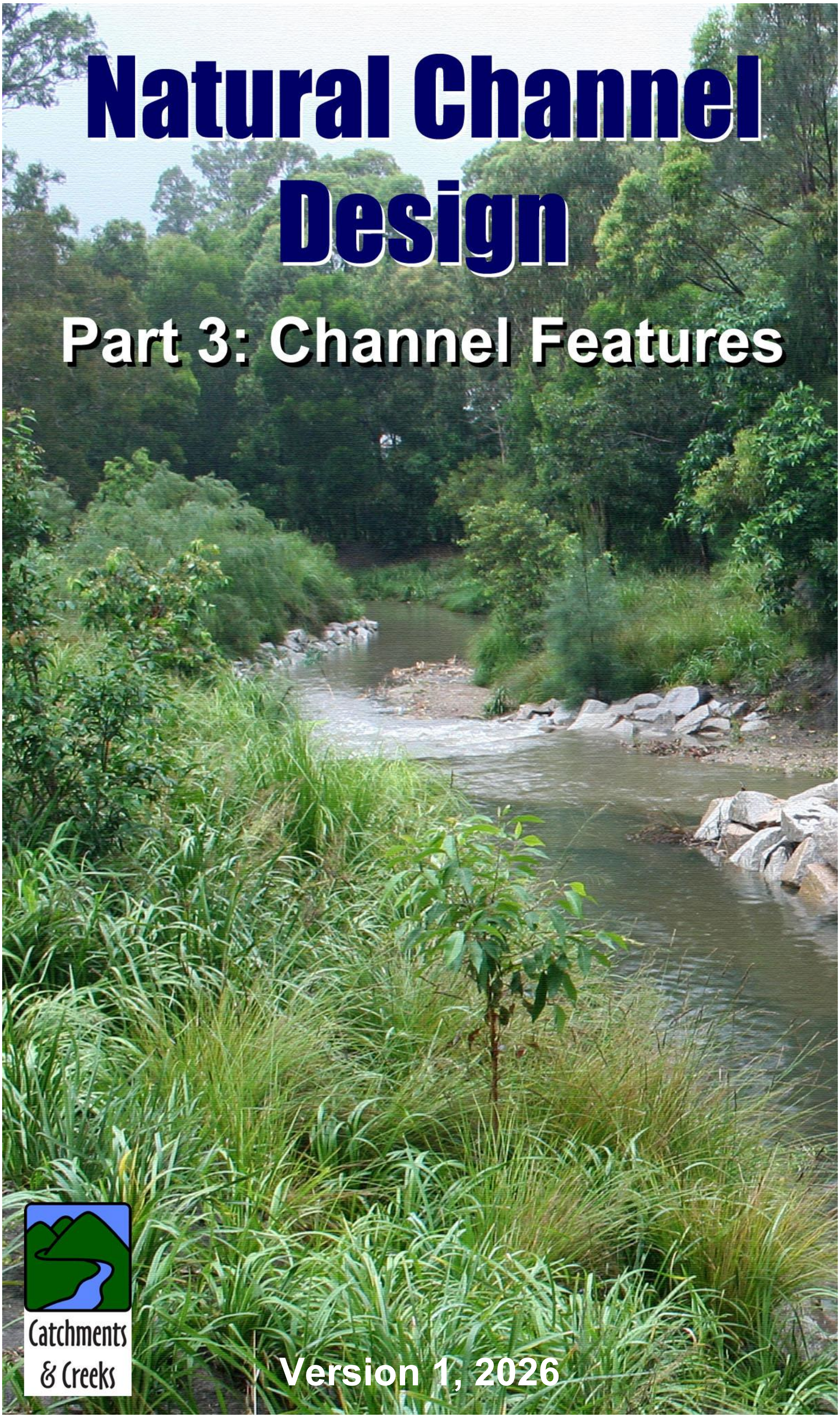
Natural Channel Design

Part 3: Channel Features



Catchments & Creeks

Version 1, 2026

Natural Channel Design
Part 3 – Channel Features

Version 1, April 2026

Prepared and illustrated by: Grant Witheridge, Catchments and Creeks

Published by: Catchments and Creeks, Bargara, Queensland

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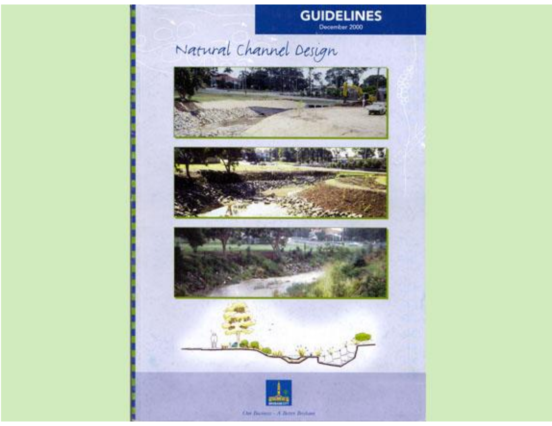
Copies of this document may be downloaded from: www.catchmentsandcreeks.com.au

Cover image: A rehabilitated tributary to Bulimba Creek adjacent Rembrandt Street, Carina, Brisbane, Queensland.

Principal reference documents



Brisbane City Council, 2000

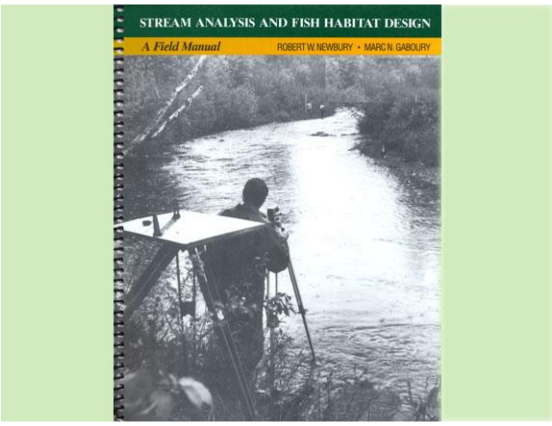
Natural Channel Design Guidelines

Brisbane City Council, 2000, Brisbane, Queensland.

Prepared in association with Catchments and Creeks Pty. Ltd.

152 page colour booklet (out of print).

PDF is/was available from the Council's website.



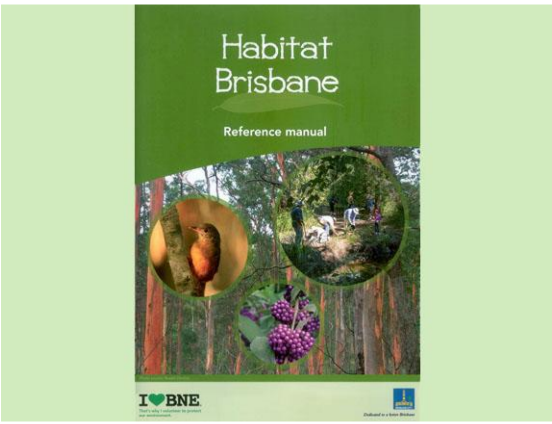
Newbury & Gaboury, 1993

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



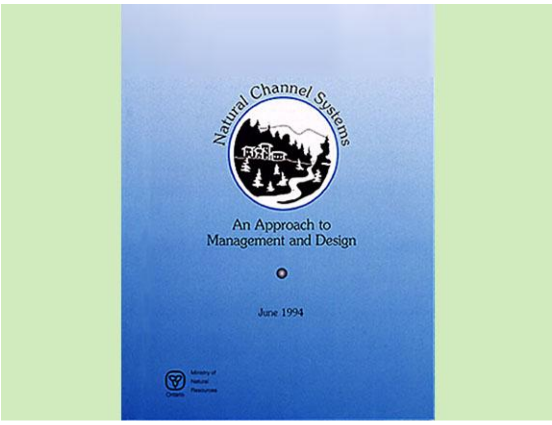
Habitat Brisbane, 2016

Habitat Brisbane – Reference manual

Brisbane City Council, 2016

CA15-454487-01-1500

A colour, hard copy document with limited release—supplied to Brisbane habitat volunteers.



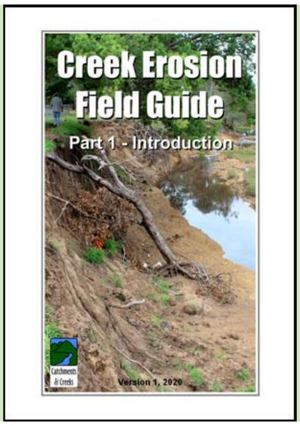
Natural Channel Systems, 1994

Natural Channel Systems – An Approach to Management and Design

Ministry of Natural Resources, Ontario, June 1994.

ISBN 0-7778-2669-0

Related *Catchments and Creeks* publications



Catchments & Creeks Pty Ltd, 2021

Creek Erosion Field Guide

Catchments & Creeks Pty Ltd, 2021, Bargara Queensland.

A four-part PDF document

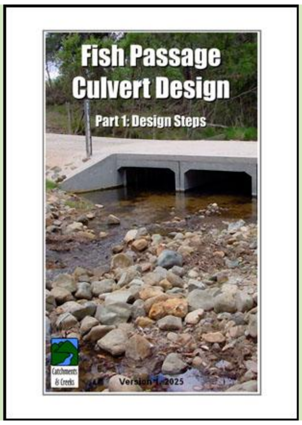
Version 1, April 2021

Part 1: Introduction

Part 2: Bed Stabilisation

Part 3: Bank Stabilisation

Part 4: Bank Treatment Options



Fish Passage Culvert Design, 2026

Fish Passage Culvert Design

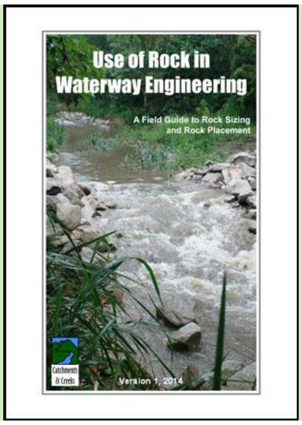
Catchments & Creeks, Version 2, 2026, Bargara Queensland.

A three-part PDF document.

Part 1: Design Steps

Part 2: Appendices A to F

Part 3: Appendices G to M



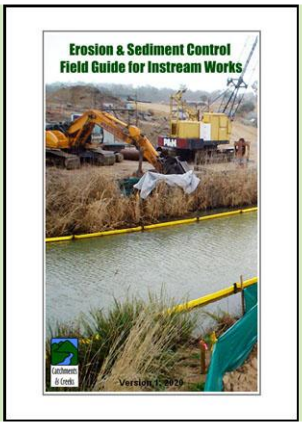
Catchments & Creeks Pty Ltd, 2020

Use of Rock in Waterway Engineering

Catchments & Creeks Pty Ltd, 2020, Brisbane Queensland.

Version 3, 2020

A pictorial guide to the sizing and placement of rock within waterways.



Catchments & Creeks Pty Ltd, 2020

Erosion and Sediment Control Field Guide for Instream Works

Catchments & Creeks Pty Ltd, 2020, Brisbane Queensland.

A pictorial-based guide to erosion and sediment control practices appropriate during the conduction of instream work, such as constructed drainage channels, and creek rehabilitation.

Contents

Page

Purpose of field guide

Part 3 of this four-part document has been prepared specifically to:

- provide general information on creek engineering
- provide this information in a manner that is both visually attractive and easy to understand.

While Part 2 of this document may have focused on the design of drainage channels, Part 3 focuses on the attributes of natural waterways. Some of these attributes may be incorporated into the design of Natural Channel Design projects as outlined in Part 1.

It was not the intension of the author that Part 3 would be read from cover to cover. Part is presented as a series of self-contained 'fact sheets' on the topis presented with the 'title'. However, the author is aware that some readers (those that wish to learn about creek engineering), may choose to read the document from cover to cover. To those readers, I wish to warn you that there is a lot of repetition of key issues from topic to topic, and chapter to chapter.

The photos presented within this document are intended to represent the current topic of discussion. These photos are presented for the purpose of depicting either a preferred or discouraged outcome (as the case may be). In many cases the photos do not represent current best practice, but are simply the best photos available to the author at the time.

The caption and/or associated discussion should **not** imply that the site shown within the photographs represents either good or bad waterway management. The circumstances, site conditions and history of each site are not known to the author, and may not be directly relevant to the current discussion. This means that the designer may have had a completely valid reason for the design presented within the photo.

About the author

Grant Witheridge is a retired civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has over 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.

Introduction

Nobody should ever judge the 'health' of a waterway solely on its water quality. If such a standard were used, then a glass of pure water would be classified as a health waterway. An ephemeral waterway does not even need flowing water in order to be classified as a healthy.

Natural Channel Design is not just the combined ecological and hydraulic design of a channel. It is an urban drainage philosophy that must integrate a wide range of principles and ideals into a functional, affordable, and aesthetically pleasing outcome that incorporates appropriate natural features.

Natural Channel Design not only has to integrate well with a catchment's hydrology and ecology, but it must also integrate well with the local community and the values the community places on their waterways.

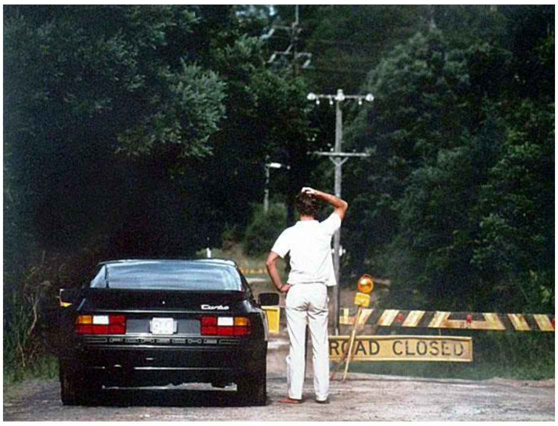
The list of channel features that are discussed within this Part 3 have been divided into five categories:

- Human Access and Usage (Chapter 11)
- Pathways and Watercourse Crossings (Chapter 12)
- Aquatic Habitats (Chapter 13)
- Terrestrial Habitats (Chapter 14)
- Riparian Zones. (Chapter 15)

Readers are reminded that this document has been prepared by a 'civil engineer' who specialised in creek engineering. The author is not a wildlife biologist, nor a bushland officer.

11. Human Access and Usage

Introduction



Access to waterway closed (the author)

Introduction

- A waterway does not need to support human usage in order to be a valued part of our landscape, in the same way that a wilderness does not need human access in order to be valued by humans.
- A waterway that does not have public access is NOT a 'wasted' asset.
- Public access to waterways is important, but too much access can be worse than not enough—the key is finding the right balance.

Recreational activity (Qld)

Key channel features

- Issues discussed in this chapter include:
  - Accessibility (public access)
  - Adjacent land usage
  - Aesthetics
  - Cultural values
  - Drainage
  - Open space management
  - Pedestrian crossings
  - Recreation
  - Safety.

A 'Mowit' in its natural environment

Active and non-active open space

- While working for a council, the author was introduced to the term: 'Mowits and Growits'.
- The expression comes from the idea that there are some people in councils that focus on the cutting of vegetation (on public land), and others that focus on growing vegetation.
- Our society needs both the 'Mowits' and the 'Growits'—it is all about finding the right balance.

A 'Growit' inside a protective fence

Legal issues

- Wherever there is human interaction with our landscapes, there will be safety risks, and there will be legal issues.
- There is NO legal requirement for water authorities to make all waters 'safe'.
- Natural Channel Design adds further complexity to this issue because the 'designer' of the waterway project holds a professional responsibility that is linked back to the designer's code of practice.

Accessibility (public access)

Public access to a waterway

Restricting public access to a track (Qld)

Area closed for revegetation (Qld)

Public access to a beach (Qld)

Introduction

- How much access should the public have to a waterway?
- There are many functions and values of a waterway that are enhanced through public usage, and just as many functions and values that can be damaged by public access.
- It is not a question about whether the public has the right to access waterways; instead, it is a question of whether the public should access waterways.

Consider the following analogy:

- In regards to our freedom of speech, we have the power to say what we want, but it is a measure of our strength that we choose to restrict our speech at certain times so we don't offend people.
- In regards our physical strength, we may have the power to force our will over others, but we show our strength by resisting the use of violence.
- In regards to a power of attorney, we may have the power, or legal right, to utilise the money owned by the person that we are caring for, but we show our strength by only using that person's money for the direct benefit of that person, and not for our own benefit.
- Similarly, when it comes to managing our waterways, the public may have the 'right' to access and utilise all areas of lands declared as 'open space', but the question is:
  - Is the public willing to demonstrate their strength by limiting their access to waterways for the benefit of the community and the waterway?

Limiting public access to open space

- In coastal regions, we limit public access through the sand dunes in order to protect the sand dunes, which ultimately helps to protect our coastline.
- At waterways, we should also limit public access through the riparian zone, within the waters, and across the waters, in order to protect the 'values' we assign to these waters.
- The 'key' is to have clearly-defined waterway values.

Adjacent land usage

An urban waterway corridor (Qld)

Junction between parkland and riparian

Bushfire risk

Creek passing through a golf course

Introduction

- In an ideal world, the properties of a natural or constructed watercourse would be independent of the adjacent land use; however in the real world, conflicts can occur.
- These conflicts are typically linked to:
  - aesthetics
  - vegetation management
  - perceived safety risks
  - the control of 'vermin'
  - golf courses.

Aesthetics

- By their very nature, waterways can appear 'messy' or 'poorly-maintained' if they are positioned next to well-maintained park.
- But this observation does NOT mean the waterway is poorly maintained—it is just a perception.
- Such aesthetic issues can be addressed with intelligent landscaping—even something as simple as a line of *Lomandra* planted along the border between the waterway and the park.

Perceived safety risks

- In an urban environment, the term 'safety risk' is often used as an excuse to remove something that someone doesn't like, for example:
  - the bush must be cleared because it encourages 'snakes'
  - rock stabilisation of a creek bank cannot occur because it may encourage 'vermin'
  - trees must be cleared from the creek because of the 'bushfire' risk.

Golf courses

- The author has had a long history of dealing with conflicts between golf courses and waterways.
- In the author's opinion, a creek can pass along the side of a golf course, but town planners should NEVER allow a golf course to straddle a waterway.
- Conflicts include:
  - excess fertiliser runoff
  - removal of riparian vegetation
  - the hard engineering of eroding bank.

Aesthetics

Storm drain without riparian vegetation

Introduction

- The aesthetics of a waterway is largely governed by three factors:
  - landscaping
  - the observer's view point
  - the contrast between the waterway and the adjacent land.
- With appropriate landscaping, a storm drain can look like a natural waterway, as the example presented below demonstrates.

Recently constructed storm drain (2000)

Same storm drain (left) in 2014

Edge planting (Qld)

Edge planting

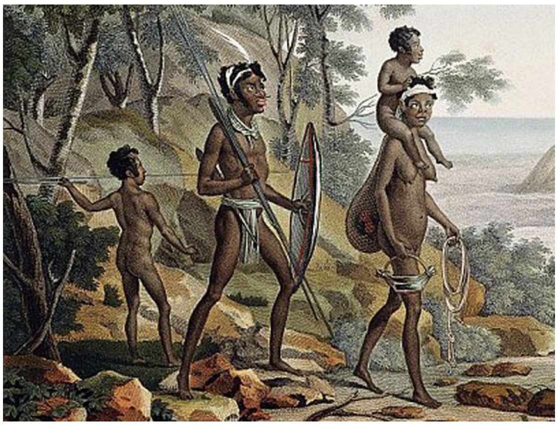
- Edge planting can be applied to a narrow riparian zone to:
  - reduce the side-entry of sunlight, which can reduce weed growth
  - reduce the risk of grass mowing operations damaging riparian plants
  - help form a visual barrier between a high-maintenance park, and a low-maintenance riparian zone.

Vegetated minor storm drain (Qld)

Vegetated storm drains

- The introduction of woody vegetation to a storm drain can have both positive and negative outcomes.
- On the positive; a canopy can improve the aesthetics of the drain, and can even hide litter released from the storm drain.
- On the negative; if the drain requires maintenance, such as de-silting, then such works may require the removal of established vegetation, which increases the cost of the maintenance work, and creates an aesthetics problem.

Cultural values



Indigenous culture

Introduction

- As a second generation Australian of British migrates, the author does not feel worthy to discuss the cultural values of our waterways.
- Instead, readers should seek advice on this topic from better qualified authors.

Meeting place

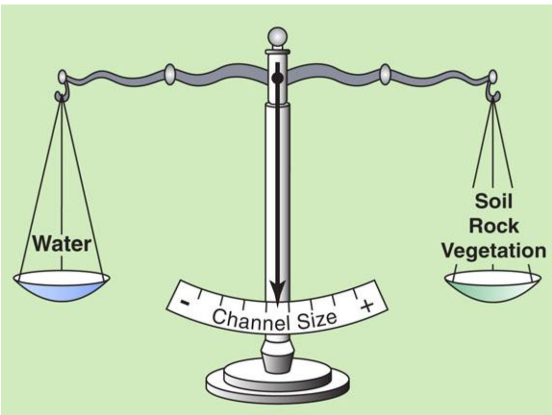
On-site recognition of cultural values

- Project planning and design should respect the traditional cultural values of the waterways, which may include:
  - a point of gathering
  - fishing ponds.

Sign post

Recognition of the traditional name of the watercourse and land

- The traditional name of the location and/or waterway can be included in new signage.
- Public information boards can be used to tell the traditional stories associated with the land and its waters.



Balanced geomorphology

Always recognising the needs of the waterway

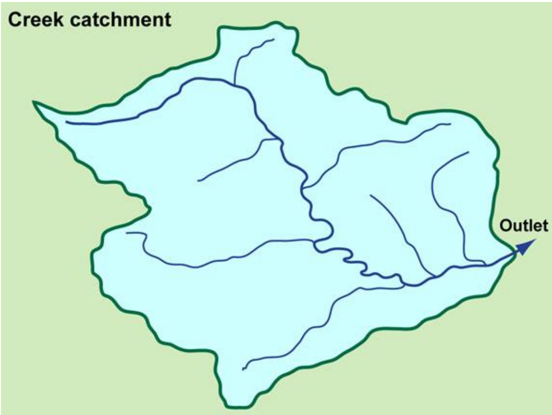
- In the author's opinion, current and past values placed on a waterway should always come second to the current needs of the waterways.
- Honouring the cultural values of a waterway should not involve the formation of a swimming hole, or fishing hole, if such a water feature is inconsistent with the current geomorphology of the waterway.
- The 'needs' of the waterway should exceed the 'wants' of humans.

Drainage and flood control

Stormwater outlet into a creek (Qld)

Introduction

- **True story:** The author once attended a public seminar in which a person announced the disgust they felt when they had discovered that the council was releasing stormwater into their creek.
- It is statements like this that make you realise how easy it is for people to forget what the primary function of a waterway is.
- The primary reason why 'nature' creates a waterway, is to drain the land of excess stormwater runoff.



Drainage catchment

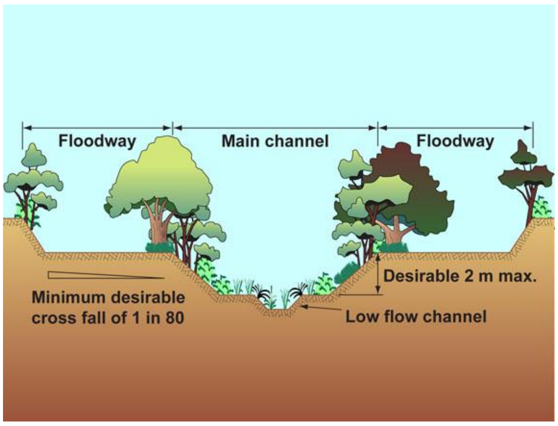
Catchment drainage

- There are two types of drainage that waterways perform:
  - drainage of excess stormwater from the catchment surface
  - drainage of sub-surface water (groundwater and spring flows).
- The retention, and protection, of both of these functions is important.

Low-flow channel on the right-hand side

The use of low-flow channels

- Only the smallest of channels is often required in order to achieve effective drainage, which is a task that is often performed by a low-flow channel.
- If a wide drainage channel is being rehabilitated, then consideration should be given to the formation of a narrow low-flow channel, with the remainder of the channel bed being benched to form a floodway (or the like).

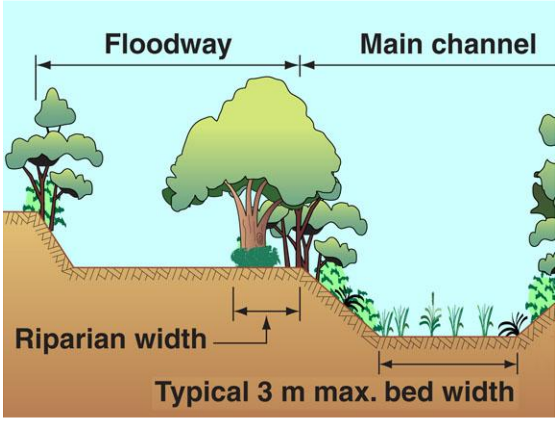


Main channel and floodways

Flood control

- In constructed drainage channels it is the capacity of the channel that provides flood control.
- In waterways, it is the floodplains and floodways that provide flood control.
- In waterways, flood control is usually linked to vegetation management, the landscaping of channel modifications, and the grouping of floodplain trees to form areas of bushland (riparian zones) adjacent to areas of open grassed floodways.

Floodways



Low-level floodways

Introduction

- Open grassed floodways can perform several functions, including:
  - increased flow conveyance
  - public access, footpaths, bikeways
  - maintenance access
  - fire breaks and fire trails.
- Floodways typically form part of the floodplains, but are generally free of woody vegetation, which allows flood flows to occur without vegetation damage.

Fire trail and maintenance berm (Qld)

High-level floodways

- The primary purpose of a high-level floodway is not flood conveyance (this is because the floodway is too close to the elevation of the adjacent properties).
- Instead, these floodways primarily act as fire trails, maintenance access, and pedestrian movement corridors.
- These areas of open grass also help to discourage terrestrial wildlife (snakes) moving from the riparian zone and then into residential properties.

Benched floodway (Qld)

Benched floodways

- Benching a waterway bank can increase the stability of the channel bank, and its resilience to flood damage.
- If this benched area is left as a grassed floodway, then the area can act as:
  - maintenance access
  - a floodway
  - pedestrian movement corridor.
- The benched area must be regularly mown in order to maintain these benefits.

Low-level floodway (Qld)

Low-level floodways

- Floodways are most commonly located on low-level floodplains.
- These floodways can significantly increase the flow conveyance of a waterway, while also providing maintenance access and pedestrian pathways.
- Bikeways are typically located above the 1-in-2 year flood level.

Golf courses

Old golf course buggy on creek bank!

Introduction

- Most waterways have floodplains, and these floodplains have limited uses.
- A golf course is one of the acceptable uses of flood-prone land.
- Golf course owners may welcome access to cheap and wide expanses of land, but they are unlikely to welcome the existence of the adjacent watercourse.
- The fact is, golf courses need to follow the same waterway regulations that the rest of the community must follow.

Nutrient-rich water (not a golf course)

Excess nutrient runoff

- Most golf courses employ ground managers (or similar), to manage the greens and fairways of the golf course.
- These managers take pride in presenting to their members and visitors the best possible greens.
- Unfortunately, the fertiliser that is used to maintain the 'greens' in a healthy green condition, is likely to cause harm to any waterway passing through, or near, the golf course.

Fairway with minimal riparian vegetation

Loss of natural riparian vegetation

- If the golf course owns land on both sides of a watercourse, then it is likely that some fairways will cross over the watercourse, making the watercourse just one of the 'hazards' of the hole.
- Inevitably this can lead to the total removal of the natural riparian vegetation.
- Such vegetation clearing would require State Government approval, including Fisheries approval.

Rock-lined creek without riparian zone

Use of hard engineering bank stabilisation

- Without the stabilising benefits of natural vegetation, creek banks can become unstable and subjected to increased flow velocities, and bank erosion.
- In the author's opinion, golf course managers generally prefer hard engineering solutions that do not introduce tall vegetation to the fairways.
- Such bank stabilisation measures would require State Government approval, including Fisheries approval.

Open space management

Open space corridors (Qld)

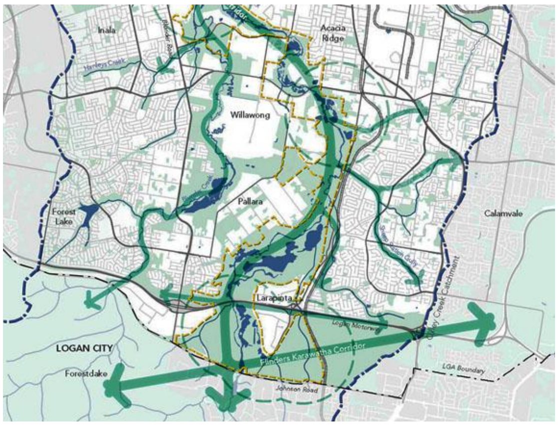
Introduction

- In an urban environment, areas classified as 'open space' can include:
  - open plan parks
  - sports ovals
  - public-entry gardens
  - bushland reserves
  - waterway corridors
  - National Parks.

Public usage of a waterway (SA)

The open space benefits of waterway corridors

- Waterway corridors can contribute to a region's open space by providing:
  - pedestrian pathways
  - bikeways
  - quiet and peaceful surroundings
  - bird and nature watching
  - recreational fishing
  - swimming and bathing
  - gathering of friends.



Wildlife corridor map (Qld)

The importance of connectivity

- There is no denying that the need for open space is primarily linked to human's needs and wants; however, areas of open space also provide significant benefits to wildlife.
- A critical attribute of open space is the connectivity between areas of bushland and waterway corridors, which allows some animals to move between different areas to avoid long-term interbreeding problems that can occur within isolated areas of bushland.

Wildlife interaction (Qld)

Potential conflicts with fauna needs

- It could be stated that there are four key aspects of open space management:
  - bushland management
  - wildlife management
  - fire management, and
  - people management.
- Many people visit areas of open space to enjoy encounters with native wildlife; however, such encounters are rarely enjoyed by the wildlife.

Recreation – finding the right balance

Controlling pedestrian movement (Qld)

Introduction

- Power is a measure of a person's potential political, economic, or social influence.
- Control is a measure of how much a person chooses to exercise their power.
- Public rights is a measure of the public's political, economic and social influence and access, as provided by legislation.
- Public control is a measure of how much the public chooses to exercise their public rights.

Controlling pedestrian movement (Qld)

Controlling public access to waterways

- The public has the 'power' (right) to access public open space, such as waterways that pass through Crown land.
- However, it is the task of land managers to 'control' the extent and type of public access for the overall benefit of the public and the asset.
- This control can exist through the use of rules and regulations, sign posts, and areas marked-off by fencing.

Goldfish released into a creek (Qld)

Interaction with aquatic environment

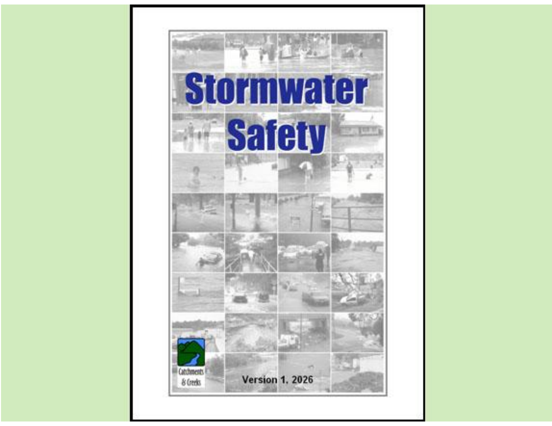
- Potential adverse effects on the aquatic environment can include:
  - the release of non-native (fish tank) species
  - the removal of native wildlife for private fish tanks
  - excessive fishing
  - barriers to fish passage caused by waterway crossings.

Meeting of domestic and wild fauna

Interaction with terrestrial environment

- Potential adverse effects on the terrestrial wildlife can include:
  - disturbance to wildlife during their morning feeding by early morning joggers and cyclists
  - disturbance to wildlife by domestic pets (dog walking)
  - loss of wildlife by domestic cats
  - removal of wildlife from waterway corridors as domestic pets.

Safety



Stormwater Safety (expected late 2026)

Introduction

- Safety is a major issue of consideration when managing stormwater, waterways, and areas of open space.
- Aspects of stormwater safety will (possibly) be addressed in new *Catchments and Creeks* document which very much in a draft form as of April 2026.

Law courts (Qld)

Legal issues and the ownership of the watercourse

- The responsibility for managing the safety risks are often shared between:
  - owner of the land
  - manager of the land
  - the individual.
- Many waterway corridors exist within privately owned land; however, the ownership of land zoned 'open space' typically rests with the State, even though it may be managed by the local government.

Closure of a waterway crossing (Qld)

A focus on providing easy egress rather than preventing access

- There are three key aspects of safety management:
  - minimising safety risks
  - the posting of warning signs
  - controlling public access
  - allowing easy egress from dangerous waters/locations.
- Designers should remember that there is no type of fence or sign that will stop a determined trespasser.

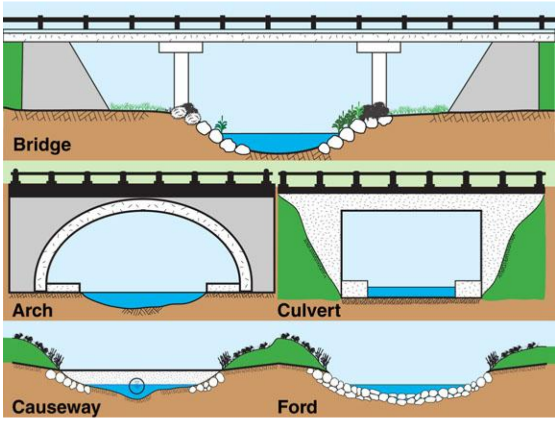
Warning sign (SA)

Safety issues associated with waterways

- Safety risks are normally associated with:
  - an unexpected slip or fall
  - an unexpected change in velocity
  - an unexpected change in depth
  - an unexpected flow of water
  - an unexpected encounter with wildlife.
- The key to managing safety risks is to remove the 'unexpected' aspect of a waterway experience through education and signage.

12. Pathways and Watercourse Crossings

Introduction



Bridge, arch, culvert, causeway and ford

Bridge crossing (NSW)

Twin arch bridge (Penrith, NSW)

Meeting room

Introduction

- An important part of human access and usage of a waterway is our access into, along, and across the waterway.
- Movement along a waterway corridor can be on:
  - pathways
  - bikeways
  - maintenance berms and fire trails.
- Movement across a waterway can be on:
  - elevated crossings (footbridge)
  - stepping stones.

Types of vehicular crossings

- Public access across a waterway can also occur at road crossings.
- The types of road crossings include:
  - bridges
  - arch bridges
  - culverts
  - ford crossings
  - causeways.

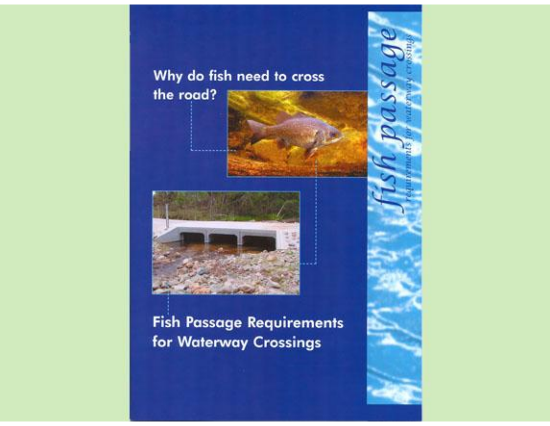
Preferred use of bridge and arch bridge

- The use of bridge and arch crossings is typically preferred in the following cases:
  - major waterways
  - crossing the habitat of a threatened fish species
  - named waterways with semi-permanent to permanent water in pools, or connected wetland areas
  - waterways containing marine or freshwater aquatic vegetation.

The need for 'common sense' and 'compromise'

- If you were to take every fish passage requirement literally, and without compromise, then we would never be able to construct any crossing of a waterway.
- We cannot walk away from the fact that everything we do in and along a waterway has the potential to interfere with fish habitats and fish passage.
- The key is to manage these impacts in a way that does not limit the aquatic values of a waterway.

Selecting the preferred type of crossing



NSW Fisheries, 2003

Preferred type of crossings

- The following table was extracted from:
  - Fairfull and Witheridge, 2003, '*Why do fish need to cross the road? – Fish Passage Requirements for Waterway Crossings',* NSW Fisheries, Cronulla.
- Application of this table is not mandatory.
- Designers need to refer to their local State or Territory policies (refer to Part 2 of the field guide: *'Fish Passage Culvert Design'*).

Table 12.1 – Preferred crossing type (Fairfull and Witheridge, 2003)

Classification	Characteristics of waterway type	Minimum [1] recommended crossing type
Major fish habitat **Class 1 (NSW)** **Purple Zone (Qld)**	Major permanently or intermittently flowing waterway (e.g. river or major creek), habitat of a threatened fish species.	Bridge, arch structure or tunnel
Moderate fish habitat **Class 2 (NSW)** **Red Zone (Qld)**	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.	Bridge, arch structure, culvert [2] or ford
Minimal fish habitat **Class 3 (NSW)** **Amber Zone (Qld)**	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (e.g. fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.	Culvert [3], or ford
Unlikely fish habitat **Class 4 (NSW)** **Green Zone (Qld)**	Named or unnamed waterway with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (e.g. dry gullies or shallow floodplain depressions with no permanent aquatic flora present).	Culvert [4], causeway or ford

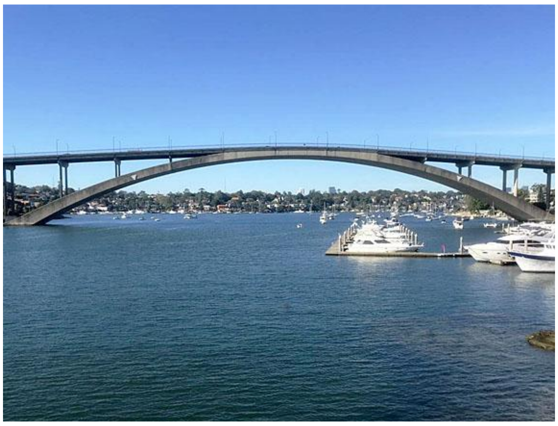
[1] In all cases bridges are preferred to arch structures, culverts, fords and causeways (in that order).

[2] High priority given to the High Flow Design procedures presented for the design of these culverts - refer to Design Considerations section of this document, or engineering guidelines.

[3] Minimum culvert design using the Low Flow Design procedures; however, High Flow Design and Medium Flow Design should be given priority where affordable.

[4] Fish friendly waterway crossing designs possibly unwarranted. Fish passage requirements should be confirmed with the local fisheries department/authority.

Arch structures



Gladesville Bridge, Sydney, NSW

Introduction

- An arch structure is often incorrectly referred to as a 'culvert', when in fact it should be treated as a bridge.
- By definition, a culvert is an enclosed conduit, meaning that it has a structural based, even if the based is buried under a layer of natural bed material.
- The arch design is even used in large bridge construction, such as the Gladesville Bridge, Sydney.

Arched footbridge (Qld)

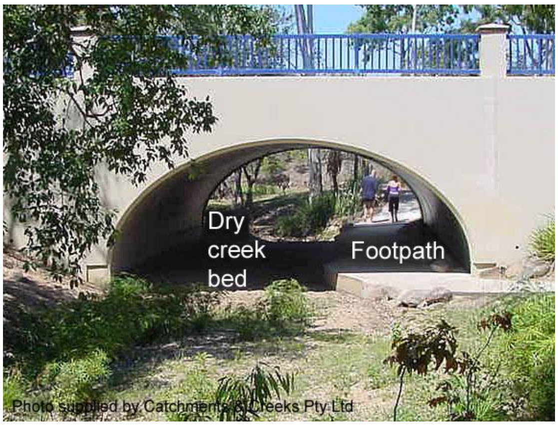
Impact on aquatic life

- Arch structures can benefit aquatic habitat in the following ways:
  - good sunlight conditions
  - natural bed conditions
  - good boundary layer flow conditions
  - opportunities for resting areas
  - shading of the water that helps control water temperatures
  - opportunity for both 'pool' and 'riffle' conditions under the arch.

Terrestrial pathway under an arch (NSW)

Impact on terrestrial passage

- Arch structures can benefit terrestrial passage in the following ways:
  - good sunlight conditions
  - opportunity for an elevated dry pathway to be formed adjacent the abutments
  - opportunity for a natural dry pathway located adjacent to a low-flow channel
  - good visibility, making it harder for predators.

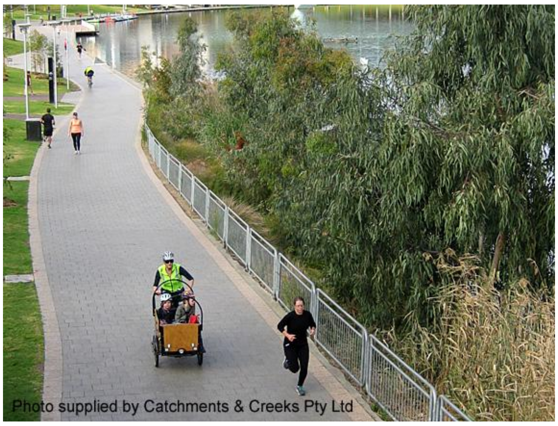


Arch bridge over ephemeral creek (Qld)

Impact on waterway

- Arch structures can affect a waterway in the following ways:
  - allow free movement of bed material
  - allow the free formation, and reformation, of pools and riffles
  - allow minor lateral movement of the low-flow channel
  - <u>not</u> allow meandering of the main channel
  - <u>not</u> slow or stop the progression of head-cut erosion.

Bikeways



Combined pedestrian and bikeway (SA)

Combined pedestrian and bikeway (Qld)

Limited line-of-sight at tunnel exit

Insufficient head room below the arch

Potential conflict of interest

- I need to declare that I love bikeways.
- I love using bikeways.
- I love being on a bikeway next to a creek.

However;

- I also love creeks.
- I respect the need to protect wildlife from unnecessary disturbances.
- I believe that if an alternative route can be found, then we should move the bikeway.

Potential impact of bikeways on wildlife

- Bikes typically pass along a bikeway at moderate speeds, which can startle wildlife, especially reptiles that are using the heat of the bikeway to warm their bodies.
- Bike bells can startle wildlife, especially wildlife that are resting.
- Safety concerns associated with bikeways can result in a wider clearing of riparian vegetation in comparison to pedestrian pathways.

Bikeways passing under waterway crossings

- It is an important safety requirement that bikeway tunnels have a clear-site exit in both directions.
- This requirement is important to both the cyclist and other users of the tunnel.

Bikeways passing under arch bridges

- On arch bridges, it is important to ensure that the arch does not limit headroom at critical locations.

Boardwalks and elevated pathways

Elevated pathway (SA)

Elevated pathways

- The term 'elevated pathway' could refer to:
  - a pathway that is positioned well-above most flood levels
  - a pathway that is suspended above natural ground level
  - a boardwalk suspended above natural ground level.
- The primary purpose of a 'pathway' is to accommodate pedestrian movement, but it may include the use of bikes.

Elevated pathway (SA)

Wetland boardwalk (Qld)

Wetland boardwalk (Qld)

Boardwalks

- In the author's opinion, boardwalks should not be located close to a waterway, but instead should only be placed in areas of low flow-velocity, such as wetlands.
- High-velocity flows can cause turbulence as the water passes around the support posts, which can cause soil erosion, which can cause failure of the boardwalk (see below).
- Flood debris can also wrap around the boardwalk increasing the lateral forces generated by the floodwater.

Boardwalk formed from recycled goods

Flood damage to creek boardwalk

Bridges – <u>fish</u> passage issues

Bridge (Qld)

Introduction

- Bridges and arch structures are generally the preferred means of crossing waterways such as:
  - permanently flowing rivers
  - permanent or ephemeral streams containing threatened fish species
  - water bodies containing aquatic vegetation.

Twin bridges with good light penetration

Divided bridges

- Twin bridges improve sunlight penetration passing under the bridge, which provides the following benefits:
  - assists vegetation growth along the river banks
  - assists fish passage along the vegetated stream banks
  - provides cover for terrestrial movement
  - helps stabilise the stream banks from the effects of soil scour.

Plants shaded from rainfall under a bridge

The need for water supply

- In order to achieve successful long-term vegetation cover under bridges, it will be necessary to ensure that the plants will receive enough water.
- The bridge deck can shade these plants from rainfall.
- If possible, stormwater runoff from the bridge deck should be channelled under the bridge deck, and then filtered through this riparian vegetation before entering the waterway.

Piers located within the waterway

Ideally, bridge piers should not be placed in the waterway

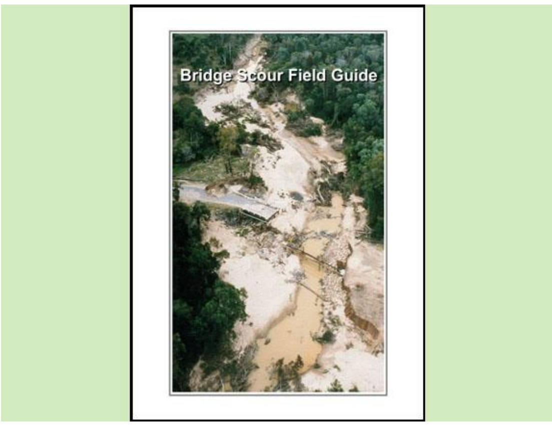
- The bridge pier issues is not a strict rule!
- If it is possible, then the number of bridge piers located within the main channel should be minimised because these piers can generate large-scale eddies, which can interfere with natural fish passage.
- What is needed most of all is common sense, and good judgement.

Bridges – fish passage issues

Bridge piers placed near a stream bank

Benched river bank (Qld)

Hard engineering scour protection



Bridge Scour Field Guide, 2020

Bridge piers located close to the bank

- Bridge piers should be located away from stream banks for these reasons:
  - eddies generated by the pier can cause bank erosion for a distance of at least five (5) time the pier diameter downstream of the pier
  - stream banks often need hard engineering scour protection, which can slow fish passage
  - many fish migrate along stream banks, and can find it difficult to pass around a bridge pier during a flood event.

Bridge abutments

- Ideally, bridge abutments should be set-bank from the top of bank, if:
  - the abutment would cause a significant break in the terrestrial movement corridor (i.e. vegetation cover)
  - the abutment could cause bank scour that could expose the abutment's foundations.
- If practical, the upper bank should be benched to recess the abutment and increase the effective flow area.

The use of non-fish-friendly scour protection measures

- Designs should minimise the use and extent of any scour control measures that may:
  - damage aquatic habitats
  - interfere with fish passage
  - restrict vegetation cover.
- Wherever possible, scour protection measures should allow full bank revegetation, and bed planting wherever possible.

Scour control under bridges

Reference document:

- *Bridge Scour Field Guide*, Catchments & Creeks Pty Ltd, 2020, Bargara Queensland.
- This field guide provides an overview of current design guidelines for scour control under bridges, with a focus on the use of rock.
- A key recommendation is the integration of vegetation into the rock protection.

Bridges – terrestrial passage issues

Bridge with minimal 'dry' passage

Introduction

- Bridge design should consider both fish passage and terrestrial passage.
- Terrestrial passage typically requires:
  - a 'dry' surface
  - either a near-flat surface, or a sloping surface with sufficient surface friction.
- Smooth, steep, concrete abutments can be impossible for some mammals to negotiate.

Low-noise asphalt placed over the bridge

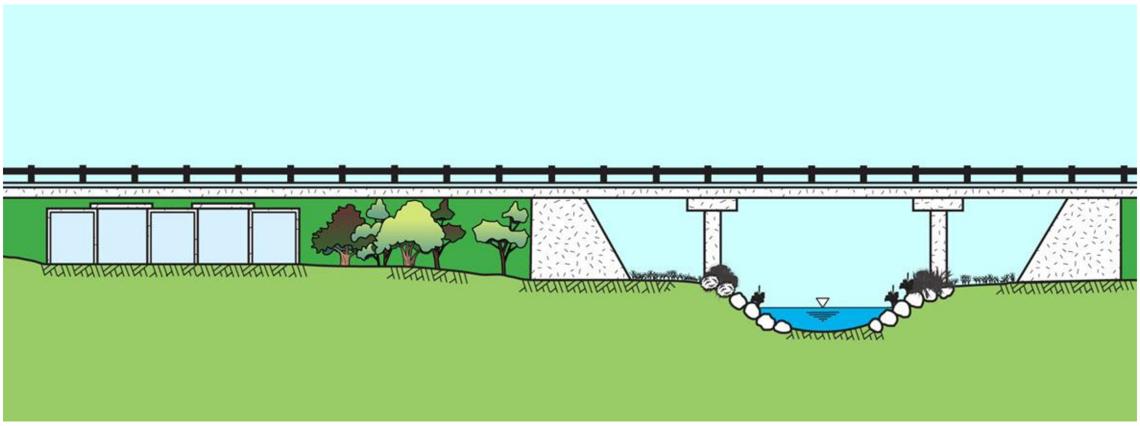
Noise control under a bridge

- The author encourages bridge designers to experience:
  - standing on a bridge deck when a heavy truck passes over the bridge a speed
  - standing under a bridge to hear the noise generated by normal traffic.
- Noise-suppressing asphalt can be placed over the bridge deck to significantly reduce traffic noise.

Floodplain culverts (Qld)

Floodplain culverts

- Consider the use of floodplain culverts in areas where:
  - fish migration is likely to occur along floodplains during flood events
  - terrestrial fauna live on, or traverse the floodplain.
- It is a common misunderstanding that fish do not swim through floodplain culverts, and therefore these culverts do not need to be fish friendly—**in most cases this is not true**—it all depends on the fish species (seek expert advice).



Floodplain culvert adjacent to a bridge crossing of the waterway

Bridges – the advantages of a single span bridge

Single span concrete bridge (NSW)

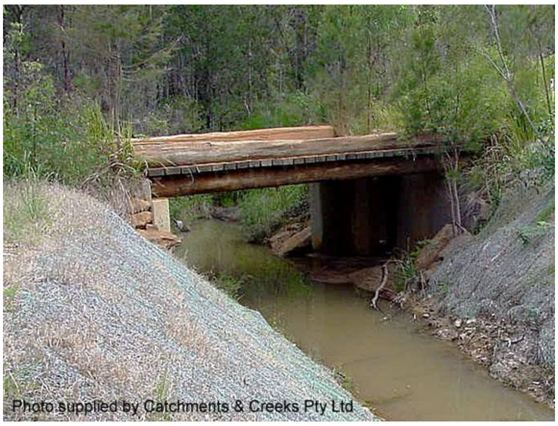
Single span bridges

- Where practical use single span bridges to cross small streams.
- Simple single span bridges can be used on minor waterways, and can be a useful option on private roads, access tracks, and driveways.

Arch bridge (NSW)

A single span arch bridge

- Arch bridges can provide ideal fish passage, as well as terrestrial passage.
- Arch bridges usually provide good lighting conditions, which is favourable for fish passage.
- Arch bridges can only be used when the ground conditions can support the required foundations.



Single span log bridge (NSW)

Single span log bridge (Tas)

Small bridge formed from a 'bridging slab'

Small steel bridge (USA)

Causeways

Stream flow just overtopping a causeway

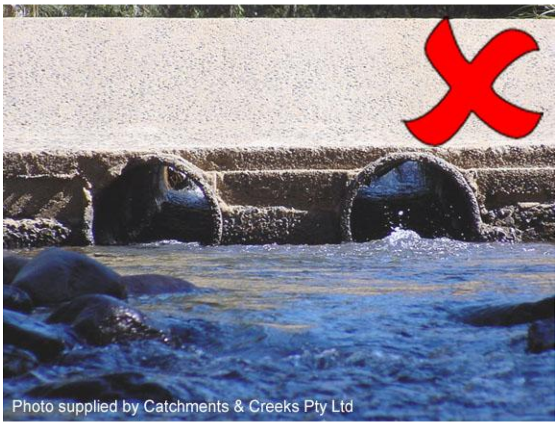
Introduction

- A causeway is a raised carriageway constructed across a watercourse.
- The term most commonly refers to a watercourse crossing where:
  - the low-flow pipe (i.e. the culvert) has a relatively small cross-sectional area compared to that of the embankment
  - the culvert is abutted on one, or both sides, by a roadway embankment of significant length that is frequently overtopped by flood water.

Causeway with minor overflow (NSW)

Design issues

- The hydraulics is normally analysed using broad-crested weir formulas.
- A maximum depth*velocity product (D*V) of 0.3, and a maximum flow depth of 200 mm is required to allow trafficable conditions across 'urban' causeways.
- Warning signs should clearly indicate likely trafficable hazards.



High-velocity, low-flow pipes

Potential impacts on fish passage

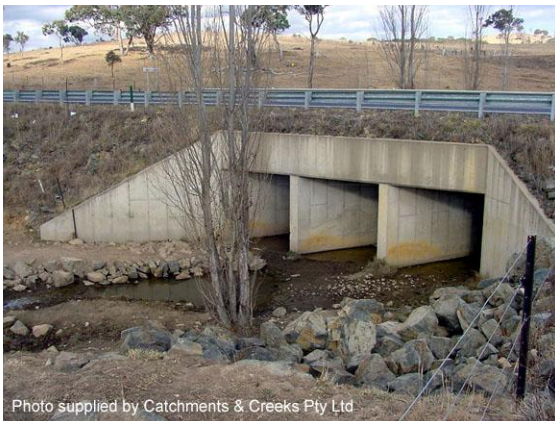
- Causeways have a high potential to adversely affect fish passage, and are generally considered the least desirable crossing option.
- Issues include:
  - excessive flow velocities
  - hydraulic step (waterfall) formed along the downstream edge of the causeway
  - inadequate flow depth
  - long, dark, high-velocity low-flow pipes.

Bed gravel upstream of a causeway

Potential impacts on the waterway

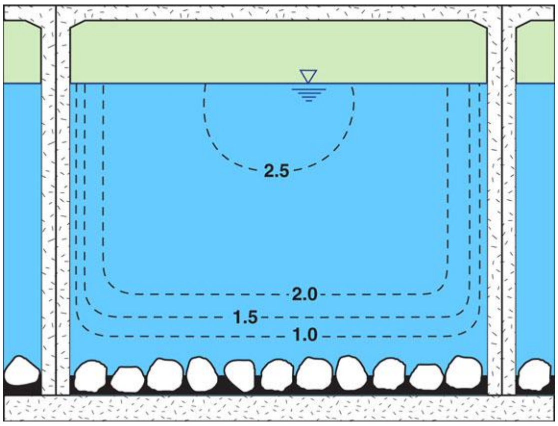
- Alluvial waterways typically experience significant annual movement of bed material (either sand or gravel).
- **Causeways should NOT be constructed across alluvial waterways.**
- Building a causeway across an alluvial waterway will result in a build-up of sand or gravel upstream of the causeway, and the formation of a scour hole downstream of the crossing, which further adds to the difficulties of fish passage.

Culverts



Rural culvert with stock underpass (NSW)

Box culvert (Qld)



Velocity profile in a rough-bed culvert

Flood overtopping road culvert (Qld)

Introduction

- The term: 'culvert' can refer to:
  - each individual conduit
  - the collective term for the entire waterway crossing consisting of one or more conduits.
- Technically, a culvert is a sub-category of the more general term 'causeway'.
- By definition a culvert is a fully enclosed conduit; however, fish-friendly culverts are normally recessed into the channel bed, which results in an earth-like bed.

Preferred use of culvert crossings

- The use of culvert crossings is typically preferred in the following cases:
  - waterways with intermittent flow, and waterways that offer potential refuge, breeding zones, or feeding areas for aquatic life
  - minor waterways containing semi-permanent pools that form after rainfall
  - waterways experiencing significant bed erosion (head-cuts), which can be arrested by the culvert.

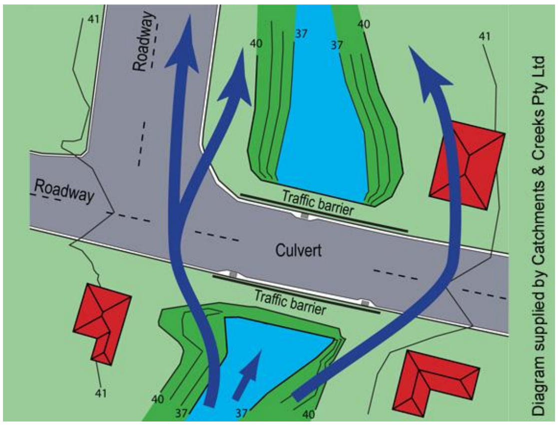
Types of culverts

- Pipe culverts are generally cheaper to install than box culverts.
- Box culverts allow better (fish friendly) boundary layer conditions to exist within the corners of the conduit.
- Both pipe and box culverts can be designed to be fish friendly.
- Once a culvert cell becomes large enough for maintenance equipment to enter the culvert, then box culverts should be used.

Choice of design storm

- Some authorities may require flood-free access to residential areas during the nominated major storm in order to allow safe access for emergency vehicles.
- If a residential area is linked only by waterway crossings, then at least one of these crossings may be required to be flood free during the design storm.
- Consideration must be given to the consequences of flows in excess of the major storm for the remaining flood affected culverts.

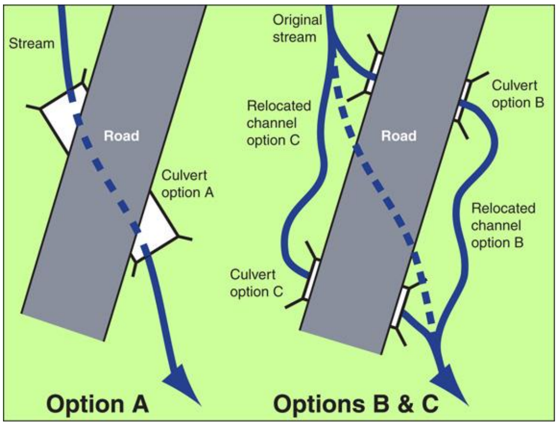
Culverts



Flows bypassing around traffic barriers

Consideration of flows in excess of design storms

- Consideration should be given to the likely effects of channel flows in excess of the design ARI storm event including:
  - likelihood of significant debris blockage
  - relative elevation of adjacent floor levels
  - the damaging travels of bypass flows.



Options for the alignment of culverts

Location and alignment of culverts

- Ideal locations include:
  - straight sections of the waterway
  - well-downstream of sharp bends
  - on a stable channel cross-section
  - upstream of a channel riffle.
- Ideally, culverts should be aligned with the <u>downstream</u> channel (options A or C).
- Avoid realigning the waterway channel to match the culvert; instead, align the culvert to match the channel.

Maximum height culverts should be used

Culvert sizing considerations

- Minimum 375 mm diameter/height.
- A diagonal greater than 6 m significantly reduces the risk of 100% blockage.
- Maximum use should be made of the available height to reduce the risk of blockage, and to improve safety for persons swept through the culvert.
- Culvert sizing may also be controlled by fish passage requirements—refer to the relevant State's Fisheries guidelines.

Box culvert (Qld)

Preliminary sizing of culverts

- For 'outlet controlled' culverts, a first estimate of the culvert size may be obtained from:

$$\text{Head loss} = C\,(V^2/2g)$$

- Typically the constant 'C' equals 1.5 for large culverts, and 1.7 for small culverts.

Culverts

Culvert with sunken invert)NSW)

Culvert elevation and gradient

- Generally the gradient of the culvert should match that of the streambed; however, flat gradient culverts are sometimes used to improve fish passage.
- In fish habitats, the invert of at least one cell should be set below normal bed level to allow the deposition of natural bed sediments over the culvert floor, while also retaining a minimum 0.2 to 0.5 m flow depth during periods of low flow.

Thin deck box culvert (NSW)

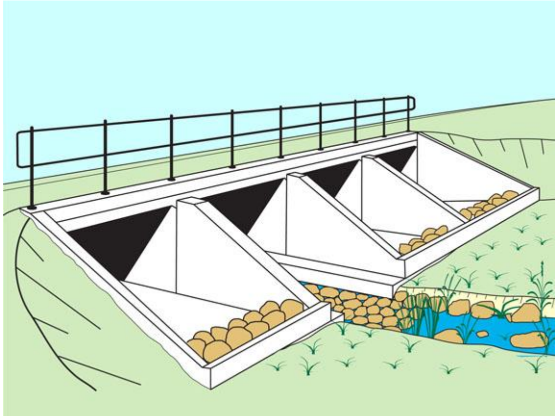
Minimum cover

- Minimum cover over cells should be:
  - 300 mm over concrete pipes
  - 100 mm over reinforced concrete culverts, slab link box culverts, and reinforced concrete slab deck culverts
  - 600 mm over corrugated metal pipes.
- Designers should refer to the latest recommendations from the Concrete Pipe Association of Australasia to confirm desirable minimum cover requirements.

Debris deflector walls (NSW)

Debris deflector walls

- Adopted blockage conditions should reflect both the likelihood of occurrence and the consequences of such blockage.
- Typical blockage allowance of 10% to 20% of the culvert flow area, but if the height < 3 m, or width < 5 m, the risk of 100% blockage becomes significant.
- Typical assume 100% blockage of handrails and traffic barriers.
- Debris deflector walls (left) can help to reduce the risk of debris blockage.

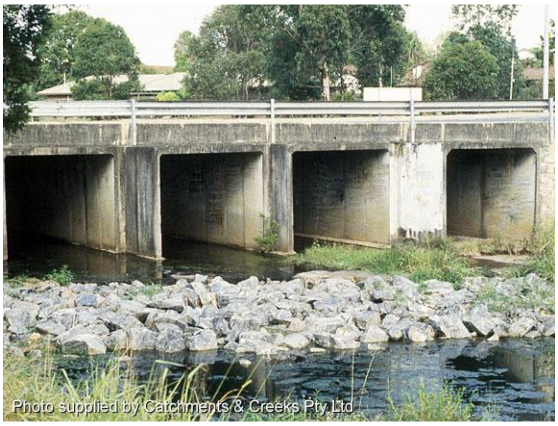


Culvert with sediment training wall

Sediment control measures

- Sedimentation can be managed using one or more of the following:
  - formation of an upstream sediment extraction pond
  - formation of multi-cell culverts with variable inverts
  - installation of sediment training walls (left) to restrict low flows to just one cell—thus helping to keep sediment moving through the culvert during periods of low flow.

Culverts



Rock pad outlet protection (Qld)

Outlet scour control

- Refer to the *Catchments and Creeks* field guide: *'Use of Rock in Waterway Engineering'* for the sizing of rock.
- Extreme care must be taken in regards potential safety risks to persons, or aquatic life, swept through the culvert and then impacting upon sharp rocks.
- Minimum 0.6 m depth of cut-off wall at end of the concrete apron (if any), or otherwise at the end of the culvert cells.

Fish friendly rural culvert (NSW)

Fish passage requirements

- Fish passage requirements generally apply if permanent water exists upstream of the culvert.
- Fish passage requirements may also apply to floodplain culverts through which fish may pass during flood events.
- The culvert flow area should mimic the natural channel flow area.
- Ideally, minimum flow depths of 200 to 500 mm should exist during periods of low flow.

Terrestrial passage through culvert (Qld)

Terrestrial passage requirements

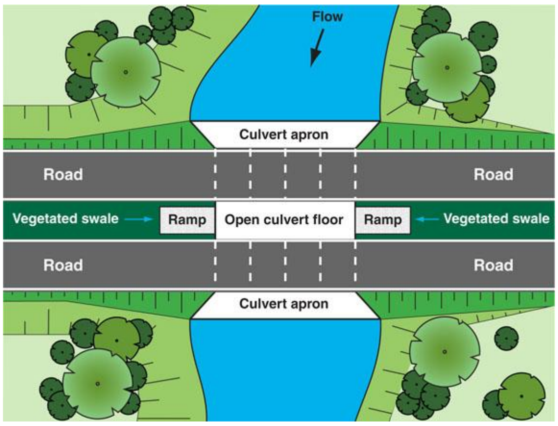
- Terrestrial passage considerations are required when the road crosses a fauna corridor, and traffic conditions on the road are such that unacceptable road kills are likely to occur.
- Dry passage should extend through the culvert along one or both sides of the waterway channel, as required.
- Designers could refer to AustRoads' *'Road Design Part 5B'* guidelines.

Box culvert with terrestrial pathways (Qld)

Accommodation of terrestrial passage needs

- The selection of the type of culvert must consider the terrestrial passage requirements of the crossing.
- Even Fisheries officers (charged with the protection of fish passage) must consider the potential impacts of their fish passage requirements on terrestrial passage as part of their overall environmental duty.
- Terrestrial passage needs are generally easier to accommodate within box culverts.

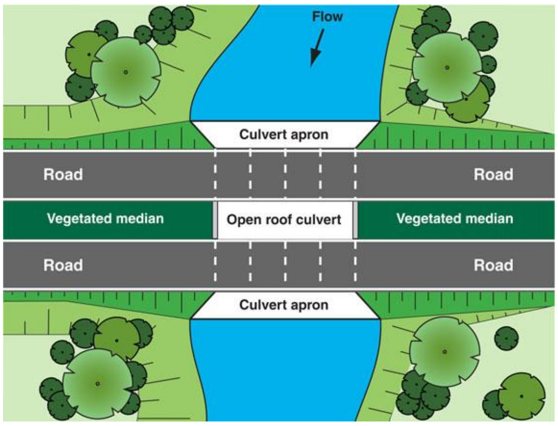
Culverts – fish passage issue



Trapezoidal channel formed in median

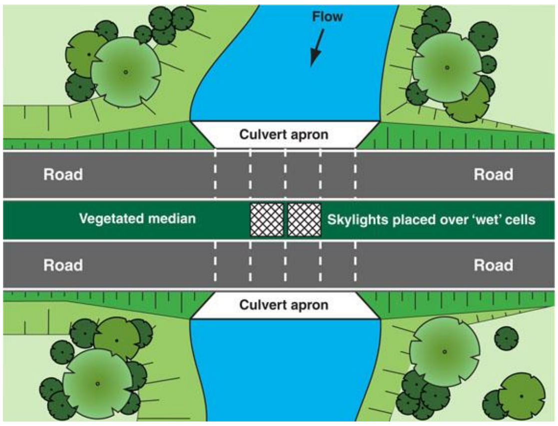
Dual carriageway roads

- In general, the wider the road, the longer the culvert; however, dual carriageways provide us with the opportunity to introduce 'resting' areas for fish.
- These resting areas can also help to improve lighting conditions within the culvert.
- The difficulty for designers is to achieve these outcomes without introducing excessive energy loss within the culvert, which would reduce the culverts flow capacity.



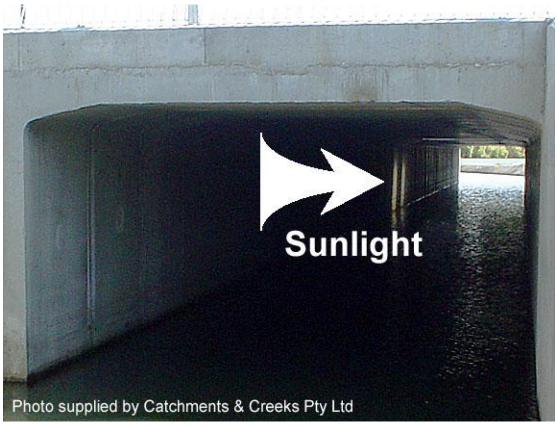
Open roof section within a long culvert

Open roof section within a long culvert



Skylights placed within the median

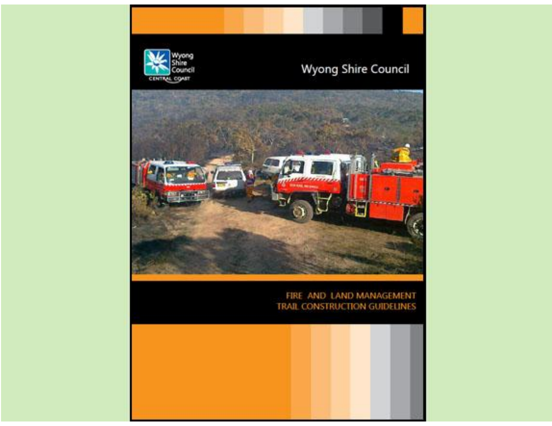
Skylights placed within the median (Qld)



Light entering the culvert (Qld)

Skylights placed within the median (Qld)

Fire trails and access roads



Wyong Fire Trail guidelines, 2012

Reference document:

'Fire and Land Management Trail Construction Guidelines'

Wyong Shire Council, Wyong, NSW, 2012.

Also refer to various NSW Rural Fire Service (RFS) publications.

Infall trail drainage

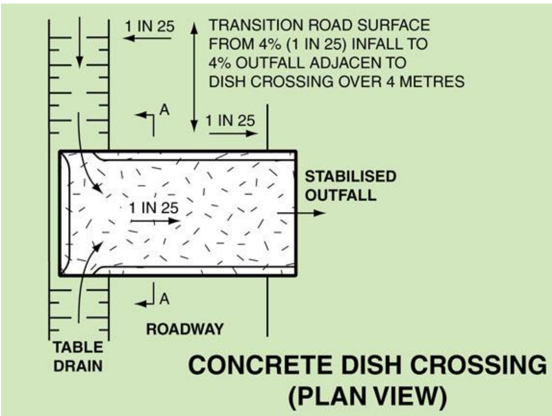
Fire trails

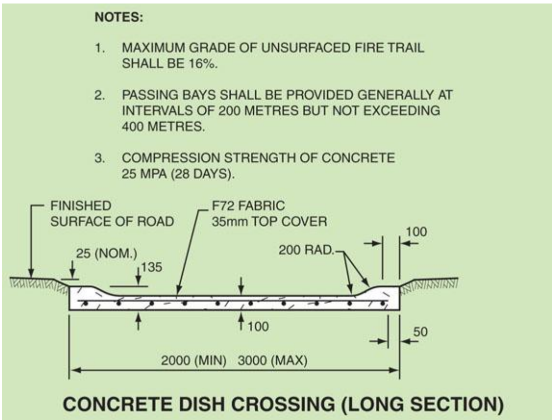
- Fire trails should not be grassed.
- Where possible, the trails should be graded with infall drainage that directs stormwater runoff inwards (i.e. towards the hill slope).
- If the trail is graded with outfall drainage, then the earth windrows, which will form with time along the edge of the trail, will interfere with the free flow of stormwater runoff (i.e. problems will occur).

Crossing of a drainage swale (NT)

Trafficable cross drainage

- At locations where the fire trail crosses a drainage line, such as:
  - overland flow path
  - cross drain
  - spoon drain, etc.
- The road surface needs to be stabilised, otherwise, deep rutting can occur, which can undermine the fire trail.





Concrete dish crossing (NSW Rural Fire Service design details)

Fire trails and access roads

Fire trail and maintenance access (Qld)

Introduction

- Vehicular access along a waterway corridor may be required for various reasons, including:
  - maintenance access (for channel repairs and the removal of flood debris)
  - fire fighting access
  - emergency vehicles.
- Access roads/tracks can be:
  - grassed floodways
  - unsealed (dirt or gravel).

Gravel-grass access road (NSW)

Gravel-grass surfaces (structural soil)

- Gravel-grass is a concept of integrating vegetation over a deep gravel bed.
- These surfaces have proven to be more resilient to occasional heavy traffic than traditional gravel roads.
- Similar surface conditions have been used to stabilise overflow car parking on park-land that surrounds sporting centres.
- A 200 mm deep cover of uniform-sized 50–100 mm aggregate is mixed with topsoil and grass seeded (not turfed).

Bikeway and maintenance access (Qld)

Concrete bikeways

- Some stormwater treatment systems require regular maintenance (i.e. clean out), which will require regular visits by heavy vehicles.
- A high strength access pathway is therefore required in order to avoid long-term damage to the park or waterway corridor.
- Intelligent design can see these access roads being disguised as a bikeway.

Concrete cross drain on a walking track

Cross drainage at overland flow paths

- At low points in a fire trail, stormwater runoff will be expected to spill across the fire trail as overland flow (i.e. shallow, wide-spread, medium-velocity water flow).
- Given the weight of fire trucks, and given the fact that these low points can become ‘muddy’, it is desirable to stabilise these cross drains with concrete.

Fire trails and access roads – drainage

Water damage to an access road

Erosion control

- Access roads can be subjected to erosion problems originating from:
  - vehicular traffic
  - stormwater runoff
  - flood damage.
- Vehicular damage can be controlled by the selection of an appropriate road surface.
- Stormwater runoff can be controlled by directing the water off the roadway at regular intervals.

Cross bank drainage (USA)

Road drainage

- Cross banks can be used to direct stormwater runoff across the road.
- The typical spacing of cross banks on unsealed roads is:
  - 120 m for road grades less than 2%
  - 60 m for road grades of 2 to 4%
  - 30 m for road grades of 4 to 8%
  - 15 m for road grades greater than 8%
- The occurrence of erosion on the road is a indicator of insufficient drainage control.

Outfall drainage of a fire trail (Qld)

Outfall drainage

- Outfall drainage involves sloping the road surface towards the waterway to allow stormwater to discharge evenly off the road.
- Outfall drainage is used on grassed floodways / fire trails / access roads.
- Outfall drainage can cause erosion problems if:
  - the road surface needs regular grading
  - adjacent riparian vegetation causes water to pool on the floodway.

Dirt road with infall drainage

Infall drainage

- Infall drainage is generally the preferred drainage system when:
  - the road surface is earth or gravel, or
  - an earth windrow is likely to form along the outer edge of the road as a result of road grading.
- The use of infall drainage means that cross banks and/or drainage pipes will be required to carry water from the table drain, across the roadway, and to a stable discharge point (that spreads the released water).

Fire trails and access roads – cross drainage

Cross banks on a gravel access road

Rock check dam (Qld)

Dirt access road with cross bank (NSW)

Combined cross bank and cross drain

Introduction

- Cross drainage involves the movement of stormwater runoff from a table drain, across the road, and the release of this water in a manner that does not cause ongoing erosion issues.
- On walking tracks, this cross drainage can be performed in a variety of ways.
- On dirt and gravel roads, this drainage system normally involves the use of 'cross banks', which also function as a 'speed bumps'.

Table drains

- A table drain is the shallow drainage channel that is formed on the side of a roadway.
- On these fire trails, a table drain is formed when the road surface is sloped into the hill slope (i.e. infall drainage).
- Significant erosion can occur within these table drains, and is erosion can be controlled with the use of 'check dams' made from sandbags, rocks, or small logs.

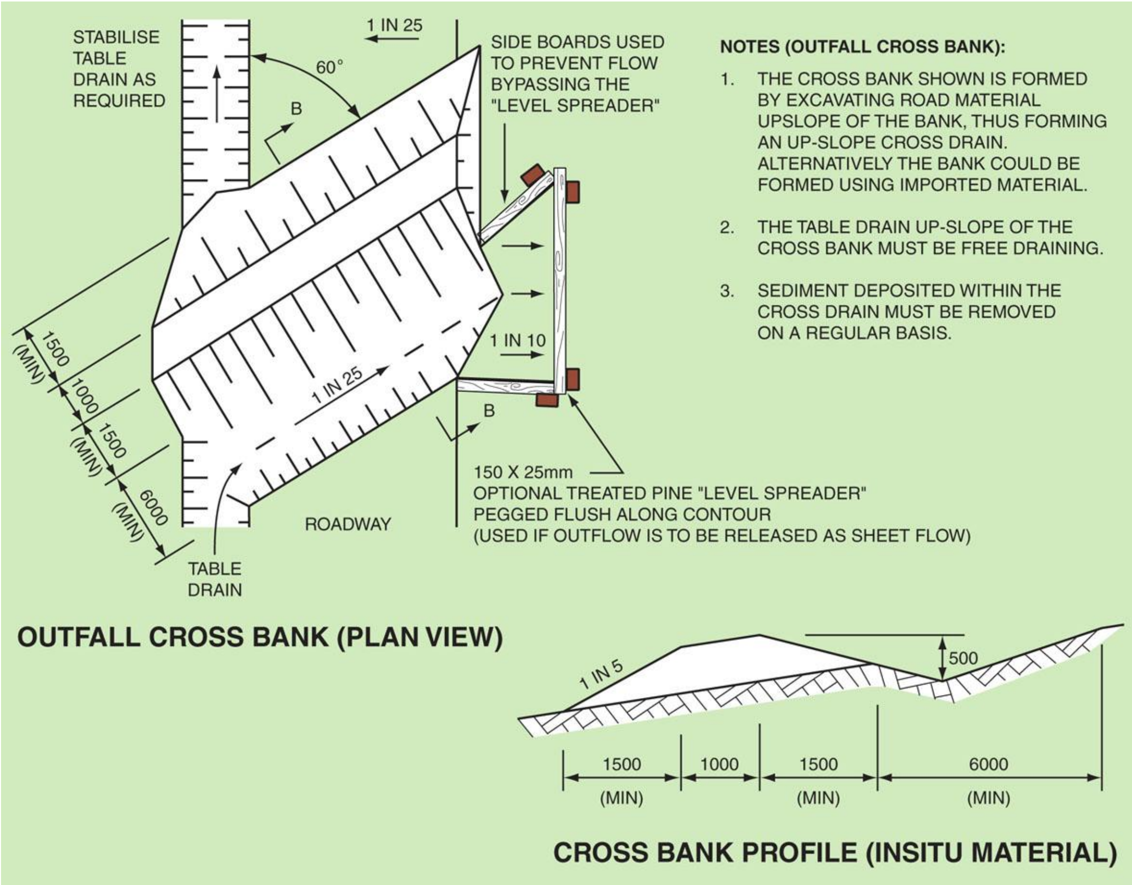
Cross banks (outfall bank)

- Cross banks can be referred to under various names, including 'cross drainage' 'speed bumps' and 'whoa-boys'.
- The banks can be used to:
  - off the road, or
  - inward towards a table drain.
- The height and width of the raised banks depends on the expected speed of the vehicular traffic—caution the use of cross banks on high-speed access roads and fire trails.

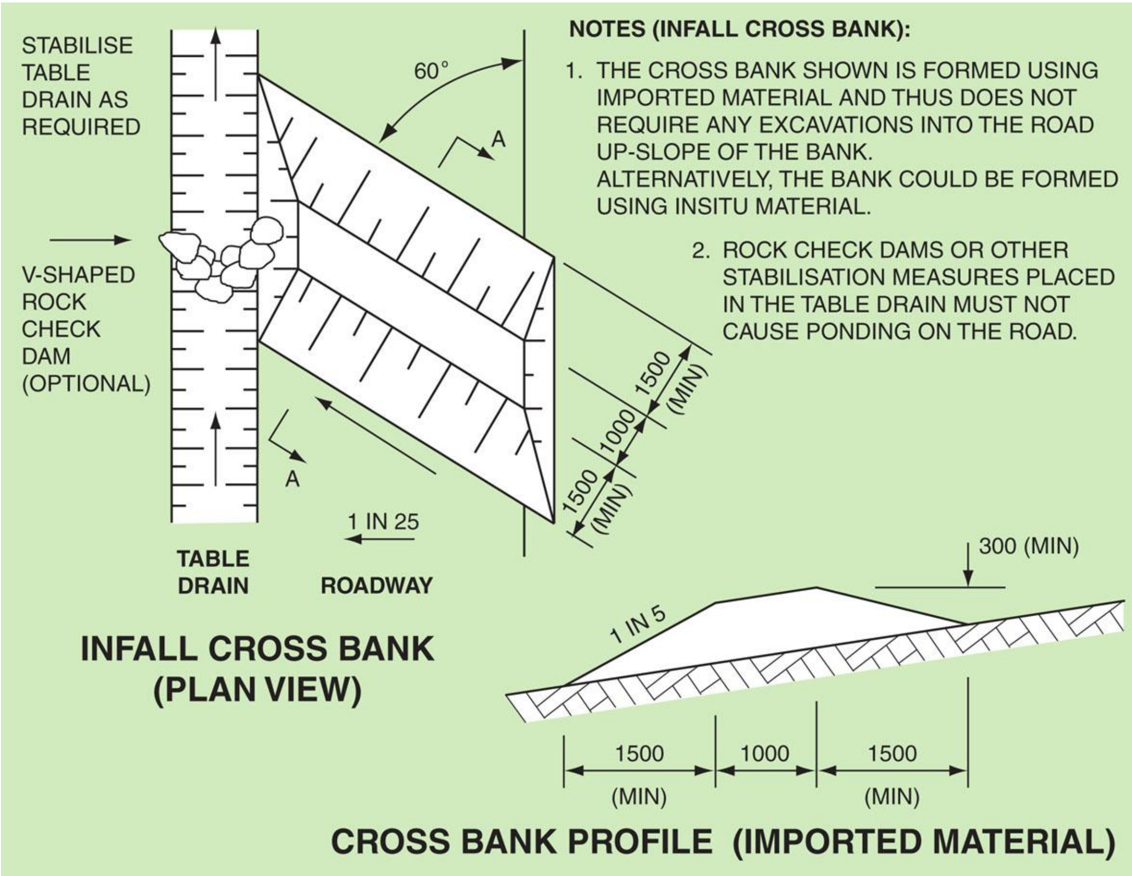
Cross drains (infall cross bank directing flows to piped drainage)

- Piped drainage can be used to carry stormwater runoff:
  - across the road to an outlet structure
  - down the road in a formal piped drainage system.
- Infall cross banks may be used to direct road runoff inwards towards the table drain, or may be avoided altogether due to the type of vehicular traffic.

Fire trails and access roads – cross drainage



Cross bank which directs flows off the road and down the hill slope (most common)



Cross bank which directs flows inward towards a table drain

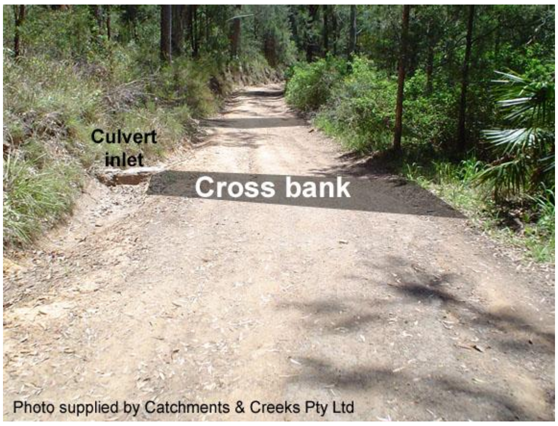
Fire trails – cross drainage examples

Gravel access road (USA)

Gravel access road with cross bank

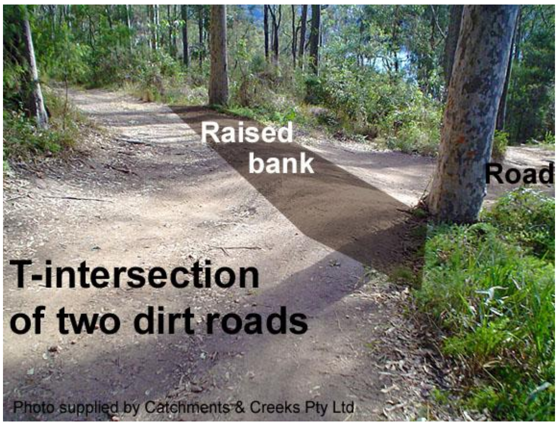
Dirt access road with cross bank (NSW)

Dirt access road with cross bank (NSW)



Cross banks and culvert drain (NSW)

Cross banks and culvert drain (NSW)

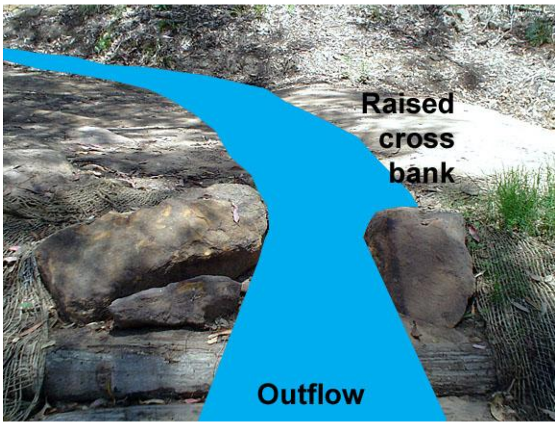


T-junction with cross bank (NSW)

T-junction with cross bank (NSW)

Fire trails – cross drain outflow examples

Discharge end of a cross bank (NSW)



Discharge end of a cross bank (NSW)

Discharge from a cross bank (NSW)

Discharge from a cross bank (NSW)

Discharge end of a cross bank (NSW)

Discharge end of a cross bank (NSW)

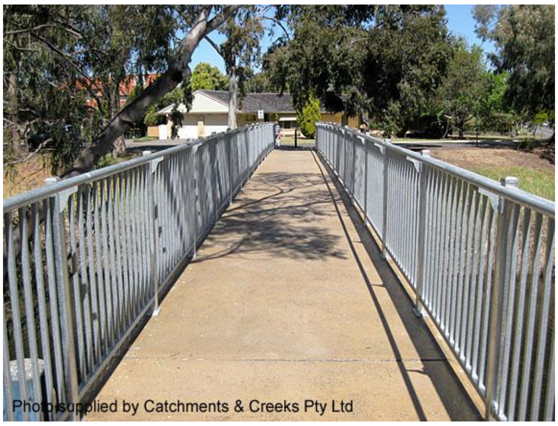
Outfall cross bank, which releases the flow down a stabilised rock-lined chute (NSW)

Footbridges

Suspended footbridge (SA)

Introduction

- Footbridges are typically used as a pedestrian crossing when:
  - crossing from top-of-bank to top-of-bank
  - crossing a waterway at an elevation that is likely to be flood free
  - crossing a waterway in a manner that minimises interference to the channel and potential fish passage.



High-level footbridge (SA)

Impact on aquatic life

- In order to minimise adverse impacts on fish passage, the preferred types of pedestrian crossings are:
  - footbridge
  - ford crossing
  - stepping stones
  - culvert
  - causeway.
- Obviously there are exceptions to this general classification based on local conditions.

Low-level footbridge with railings (Qld)

Impact on terrestrial life

- Footbridges can provide several benefits to terrestrial fauna, including:
  - a 'dry' passageway across a permanently-flowing channel
  - habitat in and around the structure
  - shelter under the footbridge
  - provide shading.

Low-level footbridge without railings (SA)

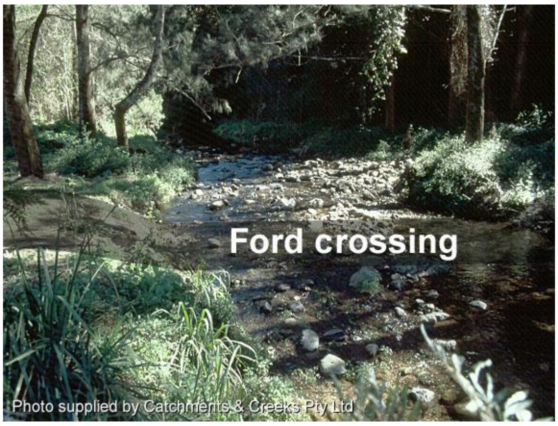
Impact on waterway

- The potential impacts a footbridge can have on a waterway channel include:
  - bed erosion (head-cut) can progress under the footbridge without being arrested (unlike culvert crossings)
  - the solid bridge abutments can resist the natural meandering of the waterway channel (which can be a positive attribute).

Ford crossings

Ford crossing of sand-based creek (Qld)

Ford crossing of a sandy bed (NSW)



Ford crossing of a gravel bed (NSW)

Concrete-lined ford crossing

Introduction

- A shallow place in a stream where the bed may be crossed by traffic. [Australian Standard, AS1348-2002]
- A shallow place where a river or other body of water may be crossed by wading or otherwise passing through the water.
- A carriageway formed directly on the channel bed in a shallow section of a watercourse.

Preferred use of ford crossings

- Unsealed bed-level ford crossings are only suitable for low traffic movement across alluvial (i.e. sand or gravel-based) streams.
- Ford crossings that have been stabilised with rock (say greater than 150 mm) are likely to experience regular displacement, or loss of the rocks during flood events.
- Sandy bed crossings that are normally very stable, can become very unstable (boggy) immediately after a flood event.

Impact on aquatic life

- Fixed bed crossings can be a problem in moving bed sand and gravel-based streams.
- High sediment inflow from the approach roads.
- Disturbance of the aquatic life (invertebrates) that life within riffles.

Potential problem

- Do NOT seal a ford crossing of an alluvial waterway with a concrete causeway.
- Fixed bed ford crossings (e.g. concrete bed level crossings) can prevent the natural movement of bed material, causing:
  - the deposition of bed material upstream of the crossing, and
  - a deep scour hole downstream of the crossing.

Stepping stones

Risk of injury

Introduction

- Note: The author has no expert knowledge of the design of stepping stones.
- The use of stepping stones should always be a design decision that is treated with extreme caution for the following reasons:
  - the risk of slips and falls by pedestrians
  - the risk of serious injury, especially a head strike against a sharp edge of a stepping stone.

Vertical pipe sections

Stepping stones in clay-based creeks

- Stepping stones must sit firmly on the channel bed, and not shift or 'rock' under foot (please excuse the term).
- It can be very difficult to firmly anchor stepping stones into a clay bed.
- Vertically standing sections of pipe conduit appears to be a successful means of anchoring stepping stones in a deep clay soil.

Unknown

Stepping stones in sand-based creeks

- The author has very limited knowledge of the successful placement of stepping stones within a sand-based waterway.
- The stepping stones would be required to allow the natural migration of the sandy bed.
- Unfortunately, this natural migration of the sandy bed would likely cause the displacement of the stepping stones (refer to the discussion of 'Pool–riffle systems').

Stepping stones across a gravel bed

Stepping stones in gravel-based creeks

- The natural 'home' for stepping stones would be within gravel-based waterways.
- However, the stepping stones would again be required to allow the natural migration of the bed material.
- Unfortunately, this natural migration of the gravel bed would likely cause the displacement of the stepping stones.
- Fortunately, such mass movement of the gravel bed may only occur once every ten years (we hope!).

Stepping stones

Stepping stones (Qld)

Use as stepping stones

- When used to form stepping stones it is important to ensure:
  - the upper (tread) surface of each stepping stone is free draining in order to reduce potential algae growth
  - all stones are firmly anchored in order to provide a safe stepping platform.
- Constructing stepping stones is one way of disguising the existence of a more substantial underlying grade control structure.

Stepping stones (SA)

Stepping stones (Qld)

Stepping stones (SA)

Stepping stones (Qld)

Wetland stepping stones (ACT)

Wetland stepping stones (ACT)

Walking tracks

Unsealed walking track (Qld)

Introduction

- Note: The author does not hold an expert understanding of the design and maintenance of walking tracks.
- However, the author is aware that a key outcome of any civil design is long-term sustainability.
- This means that walking tracks should be able to provide a consistent level of service, over several decades, without requiring excessive ongoing maintenance.

Walking track with exposed tree roots

An unnatural feature

- In the author's opinion, unsealed walking tracks are as 'unnatural' in bushland as sealed walking tracks.
- Nature does not benefit from the existence of a dirt walking track.

Soil erosion on an unsealed access road

The problem of ongoing soil erosion

- Unlike in many other countries, the walking tracks found in Australia are relatively 'young' in geological terms.
- The problems that our unsealed tracks are likely to face over time include:
  - raindrop impact erosion released the cohesive clay particles
  - loss of clay particles causes sand and gravel particles to become mobile
  - stormwater runoff washes loose particles from the tracks.

Recessed log check dam (cross bank)

Managing track drainage

- The key to achieving long-term sustainable outcomes is to:
  - slowly add organic matter to the track soil
  - utilise recessed check dams (i.e. logs, stones, tree roots) to retain soil on the tracks
  - direct stormwater runoff off the track at regular intervals
  - utilise gravel to protect critical locations from raindrop impact.

Walking tracks – track steps

Timber steps (Qld)

Track steps

- The following images display examples of track steps that the author has observed.
- These examples neither represent 'good' or 'bad' examples, it just depends on the site conditions.
- Some images show stormwater being carried in a formal drain to the side of the steps (preferred option).
- Some examples show space for a bicycle to be pushed up or down the steps.

Timber steps (Tas)

Timber steps (Tas)

Timber steps (NSW)

Timber steps (NSW)

Stone steps (Qld)

Concrete stair (SA)

Walking tracks – drainage examples

Recessed log cross bank (Qld)

Track drainage

- The following images display examples of track drainage that the author has observed.
- These examples neither represent 'good' or 'bad' examples, it just depends on the site conditions.
- The images showing water movement (in blue) are provided only to assist readers in visualising the direction of water flow.
- In all cases the aim is to direct stormwater runoff off the track at regular intervals.

Recessed log cross bank (Qld)

Recessed log cross bank (Qld)

Recessed log cross bank (NSW)

Recessed log cross bank (NSW)

Earth cross bank (Tas)

Earth cross bank (Tas)

Walking tracks – drainage examples

Stone cross drain (Tas)

Stone cross drain (Tas)

Timber cross drain (Tas)

Timber cross drain (Tas)

Timber cross drain (Tas)

Timber cross drain (Tas)

Timber steps and drain (Tas)

Timber steps and drain (Tas)

Walking tracks – explaining the erosion process

Raindrop impact erosion

Raindrop impact erosion

- It does NOT matter how hard you compact a soil; the force that raindrops exert on the soil will be sufficient to explode fine clay particles out of the soil, and throw them about 500 mm into the air.
- The unsealed earth shoulder of rural roads is always heavily compacted when first installed, but over time, raindrop impact can turn these earth shoulders into a bed of washed gravel, which demonstrates the force of raindrops!

Jar settling test

The make-up of a well-mixed soil

- Soils can vary in their make-up from pure clay, to pure sand.
- A 'strong' soil is a soil that can be compacted to a condition that makes it both resistant to 'wear', and resistant to water infiltration.
- These soils typically contain around 25% clay, which acts as a binding element, along with some organic matter.
- If this clay is removed from the soil, the sandy particles can break free.

Eroded soil surface

The erosion process

- Raindrop impact causes the loss of clay particles.
- Loose sand particles begin to move with the stormwater runoff—often collecting with minor depressions.
- Gravel-sized particles typically remain on the soil surface, which eventually can make the walking track unstable under-foot due to the loose structure of the gravel surface.

Straw mulch placed on a walking track

The benefits of organic matter

- In engineering we take great efforts to minimise the organic content of structural soils (i.e. soils that are to be compacted for reasons of structural stability).
- **However**, if organic matter (or at least certain organic matter), is introduced to the surface of the soil after it has been placed and compacted, then this organic matter can reduce the effects of raindrop impact erosion.

Walking tracks – rehabilitation

Rill erosion on a walking track (NSW)

Rehabilitating eroded tracks

- Walking tracks can be subjected to:
  - raindrop impact erosion
  - stormwater runoff erosion resulting in rill erosion
  - traffic wear.

A closed track cover in mulch (Qld)

Cover with organic mulch

- Old tracks can be rehabilitated by covering the tracks with an organic mulch.
- Temporary drainage controls may be required to prevent the mulch from being washed of the track during storms.

A recently ripped walking track (Qld)

Ripping

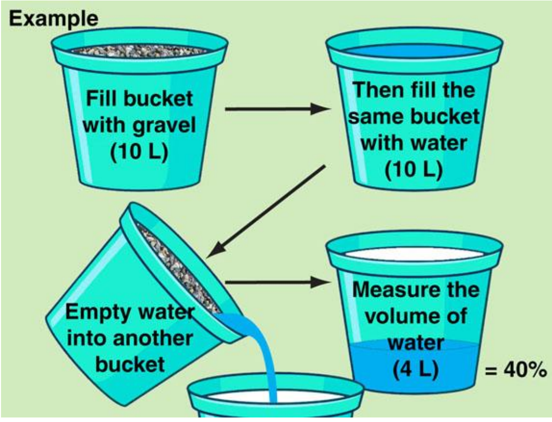
- Deeply rutted tracks should be ripped in order to avoid the need to import soil into the area.

A stabilised gravel-grass surface (NSW)

Gravel-grass (structural soils)

- Alternatively, deeply rutted tracks can be covered with clean aggregate to raise the track surface back up to natural land level.
- Ideally, this aggregate should be mixed with some local soil obtained from the track, or surrounding land, in order to produce an equivalent gravel-grass mixture.
- Native grasses can be used, if appropriate, otherwise, mix with a zero-seed mulch (i.e. straw, NOT hay).

Walking tracks – gravel-grass (structural soils)



Estimating the void spacing

Estimating the void spacing of gravel

- This type of structural soil is often referred to as: 'gravel-grass'; however, the type of rock used in this process is more commonly referred to as: 'aggregate'.
- 'Aggregate' is the term used rocks that have a near-uniform size.
- 'Gravel' is the term used for well-mixed rocks of various sizes.
- The void spacing of **aggregate** is normally around 40%, while the void spacing of **gravel** is likely to be less than 30%.

Initial placement of gravel and soil

Initial placement

- Prior to placement of the aggregate, determine the expected void spacing of the loose aggregate, if not already specified on the plans.
- Spread enough aggregate to completely cover the surface of the soil at the density or thickness specified in the approved plans.
- If the application density is not supplied, then apply at a thickness of at least 150 mm.

Grass seeded

Grass seeding

- Using a hand or machine broadcasting method, apply one-half the specified quantity of seed while moving back and forth across the area, making a uniform pattern.
- Then apply the second half in the same way, but moving at right angles to the first pass.
- Cover broadcast seed by raking or chain dragging; then firm the surface with a roller to provide good seed contact.

Fully established surface

Early phase of growth

- Watering the vegetation periodically is essential, especially in the first 7 days after establishment.
- Use low-pressure sprays because high-pressure jets can wash away the seed and mulch cover.
- If possible, fence off the area from pedestrian traffic while the grass establishes.

Caution use in bushland areas where the grasses are considered to be weeds!

13. Aquatic Habitats

Introduction

Introduction

- This chapter discusses the channel features that are most likely to influence (favourably or unfavourably) aquatic habitats and aquatic fauna.

Channel features

- Issues discussed in this chapter include:
  - Aquatic habitat
  - Aquatic fauna
  - Aquatic movement – barriers
  - Aquatic plants
  - Base flow (trickle flow)
  - Boulders
  - Channel banks
  - Channel bed
  - Cultural values
  - Culverts
  - Ephemeral creeks
  - Fish migration
  - Fish passage
  - Fishways
  - Floodplains
  - Flow conditions
  - Grade control structures
  - Invasive species
  - Lakes
  - Leaf litter
  - Pool-riffle systems
  - Pools (habitat ponds)
  - Recessed banks
  - Rock chutes, rock ramps and riffles
  - Rock
  - Sediment (unnatural inflow)
  - Sediment controls
  - Sediment flow – natural migration
  - Shading
  - Shelter
  - Sinuosity
  - Skylights (culverts)
  - Snags
  - Water quality
  - Weirs

Aquatic habitat

Aquatic habitat in a gravel-based stream

***Lomandra* planted along the water's edge**

Undercut creek bank (Qld)

Open void spacing between rocks (Qld)

Introduction

- The rehabilitation, restoration, or protection of aquatic habitats is different from the protection of aquatic fauna.
- The term 'habitat' refers to the environment in which the fauna lives, which includes those parts of the riparian zone used by aquatic life from time-to-time during flood events.
- Fish cannot be introduced to a waterway without Fisheries' permission; however, habitats can be rehabilitated with some degree of self-assessment.

Shading of the water's edge

- In the author's untrained opinion, one of the most important aquatic habitat features is the shading of the water's edge.
- The benefits gained from this feature include:
  - cooler water temperatures
  - protection from terrestrial predators
  - a potential source of food
  - reduced local flow velocity.

Undercutting of the creek bank

- What this photo (left) is displaying is a root system that is so massive that it is holding the upper bank in a firm condition, while being undermined by toe erosion.
- The upper bank is currently cantilevering over the lower bank, which has formed an 'undercut' (long dark cave), which can provide shelter and habitat values to aquatic life.
- However, this condition is not sustainable in the long-term.

Open void between submerged rocks

- The current eco-friendly recommendations for the placement of rocks on creek banks specifies that the voids between the rocks should be filled with soil and pocket planted.
- This outcome produces a fully vegetated rock-lined surface.
- However, if the rocks are located below the water level, then the recommendation is for the voids to remain open because they can provide good shelter and habitat value for aquatic life.

Aquatic habitat

Constructed pool (SA)

Permanent and semi-permanent pools

- Permanent pools provide an obvious habitat for a range of aquatic life.
- Desirable features include:
  - shading of the water's edge
  - open to the wind (to aid circulation)
  - maximum depth greater than 1 m
  - sufficient dry-weather flow.
- The long-term viability of pond can be threatened by sediment deposition and weed invasion.

Constructed riffle (Qld)

Riffles

- Riffles may not provide habitat value for fish, but there can be a greater diversity of aquatic life (invertebrates) within a riffle than within ponds.
- Desirable design features include:
  - variable rock sizes
  - random placement of rocks
  - no water individual step-fall that exceeds 100 mm.

Fallen tree (NT)

Logs, snags and boulders

- Logs, snags and boulders can provide good basking habitat for terrestrial fauna, while submerged logs and branches can provide habitat and shelter for aquatic life.
- Ideally, fallen trees should be retained within a waterway; however, there are competing issues in regards to the management of flood debris.
- Generally, flood and safety risks take priority, especially in urban areas.

Aquatic plants (SA)

Food supply

- Aquatic food supply is often closely linked with insect populations, aquatic plants, leaf fall from riparian vegetation, and the existence of snags.
- In urban areas, a large and unnatural supply of organic matter can enter our drainage system, which can alter the natural supply of food into urban creeks.
- Increasing the surface area of submerged objects such as rocks, plants and snags can also influence food supply.

Aquatic habitat – shelter from flood events

High-velocity flood flows (Qld)

Introduction

- Aquatic habitat features are not just required to support the health of aquatic fauna during normal dry weather flows, but also during flood events.
- Many aquatic fauna rely on areas of shelter to escape from high-velocity flood flows.
- Without such protection, fish could be swept well-downstream from their normal habitat during such flood events.

Large introduced boulder (NSW)

Boulders

- In general, the focus should be on the protection or restoration of natural habitats.
- Boulders can appear in all types of waterways (not just gravel-based waterways), and they can provide habitat, shelter, and fish passage values.

***Lomandra* and native grasses (NSW)**

Native grasses and sedges

- As much as people can love *Lomandra*, many experts have claimed that this plant is overused in creek restoration projects.
- There are numerous alternatives to the two dominant *Lomandra* species, which are best positioned in the lower bank to shade the water and provide the preferred boundary layer conditions.
- Yes, the root system is important, but it is the leaf structure of *Lomandra* that provides the real benefit to aquatic habitats.

Recessed creek bank (backwater zone)

Recessed banks

- A recessed bank is a location where the bank forms a 'cave' or side channel that acts like a 'backwater'.
- These areas can protect aquatic life from high-velocity flood flows, as well as shelter aquatic life from predators.
- Recessed banks can form naturally when a stream bank erodes, or a large riparian tree falls.
- A recessed bank can also be formed by a stormwater outlet structure.

Aquatic fauna

Platypus

Terminology often used in legislation

- Within fisheries legislation, the term 'fish' is said to include all aquatic species, including:
  - prawns, crayfish, rock lobsters, crabs and other crustaceans; and
  - scallops, oysters, pearl oysters and other molluscs; and
  - sponges, annelid worms and holothurians; and
  - trochus and green snails.

Turtle (Qld)

Aquatic fauna that may not be included in the definition of 'fish'

- Readers should refer to their local State or Territory legislation; however, the term 'fish' probably does **not** include:
  - crocodiles
  - aquatic fauna that is protected under other legislation
  - invasive or pest species.

Frog (NSW)

Habitat

- The term 'fish' usually means an animal (whether living or dead) of a species that throughout its life cycle usually lives:
  - in water (whether freshwater or saltwater); or
  - in or on foreshores; or
  - in or on land under water.

Snake (USA)

Temporary occupiers of aquatic habitats

- Some fauna will only spend part of their lifecycle within water.
- Some species breed in water, feed in water, hunt in water, cool themselves in water, or spend part of their lifecycle in water.

Aquatic fauna – Brisbane region

Crustaceans (Decapods): Australian Paratya, Indistinct Caridina, Commob Caridina, Riffle Shrimp, Common Australian River Prawn, Leichhardtian River Prawn, New Holland River Prawn, Swamp Yabby, Sand Yabby, Orange-fingered Yabby, Slender Yabby, Inland Yabby, Redclaw, Mount Glorious Spiny Crayfish, Lamington Spiny Crayfish, Powerful Spiny Crayfish.

Crustaceans (Crabs): River Swimming Crab.

Fishes: Queensland Lungfish, Southern Shortfin Eel, Lonhfin Eel, Oxeye Herring, Australian Smelt, Blue Catfish, Hyrtl's Catfish, Rendahl's Catfish, Freshwater Catfish, Snubnose Garfish, Marjorie's Hardyhead, Flyspecked Hardyhead, Crimsonspotted Rainbowfish, Ornate Rainbowfish, Pacific Blue Eye, Dusky Flathead, Bullrout, Agassiz's Glassfish, Estuary Glassfish, Mary River Cod, Golden Perch, Australian Bass, Barred Grunter, Silver Perch, Spangled Perch, Mouth Almighty, Black-naped Ponyfish, Common Silverbiddy, Yellowfin Bream, Diamonfish, Spotted Scat, Striped Scat, Sea Mullet, Pinkeye Mullet, Crimsontip Gudgeon, Striped Gudgeon, Empire Gudgeon, Firetail Gudgeon, Western Carp Gudgeon, Southern Purplespotted Gudgeon, Flathead Gudgeon, Dwarf Flathead Gudgeon, Smalleye Gudgeon, Crested Oystergoby, Blackspot Mangrove Goby, Bluespot Goby, Speckled Goby.

Frogs: Green Treefrog, Southern Orange-eyed Treefrog, Graceful Treefrog, Cascade Treefrog, Emerald-spotted Treefrog, Laughing Treefrog, Whistling Treefrog, Whirring Treefrog, Bleating Treefrog, Naked Treefrog, Eastern Sedgefrog, Cooloola Sedgefrog, Wallum Sedgefrog, Green-thighed Frog, Stony-creek Frog, Striped Rocketfrog, Broad-palmed Rocketfrog, Wallum Rocketfrog, Green-stripped Frog, Superb Collared-frog, Striped Marshfrog, Salmon-striped Frog, Spotted Marshfrog, Ornate Burrowing-frog, Scarlet-sided Pobblebonk, Tusked Frog, Great Barred-frog, Giant Barred-frog, Fleay's Barred-frog, Black-soled Frog, Copper-backed Broodfrog, Red-backed Broodfrog, Great Brown Broodfrog, Sandy Gungan, Eastern Gungan, Wrinkled Gungan, Beeping Froglet, Clicking Froglet, Wallum Froglet.

Freshwater turtles: Broad-shelled River Turtle, Eastern Long-necked Turtle, Snapping Turtle, Short-necked Turtle, Saw-shelled Turtle.

Sourced from the *Queensland Museum Wild Guide*, 2009, and presented only to demonstrate the potential diversity of aquatic life in waterways

Aquatic fauna – native fish (photos by Gunther Schmida)

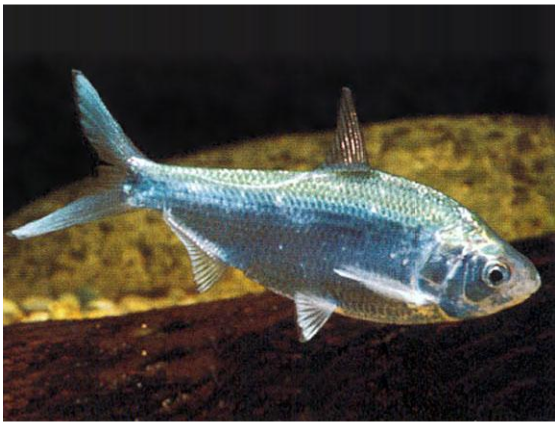
Delicate Blue-eye

Crimson-spotted Rainbowfish

Empire Gudgeon

Common Archerfish

Purple-spotted Gudgeon



Bony Bream

Black Catfish

Freshwater Lontom

Aquatic movement – <u>barriers</u> to fish passage

High flow velocities (Qld)

Introduction

- In life there is always an exception to every rule, and to every generalisation.
- To state that a particular flow condition is 'bad' for fish passage is just on of those generalisations that can so-often be wrong.
- **The truth is:** For every flow condition that one species finds difficult to negotiate, another species will experience no difficulties in negotiating.

High flow velocities (NSW)

Excessive flow velocities

- During flood events, flow velocities in many rivers often exceed 3 m/s.
- But that does <u>not</u> mean fish are not able to swim upstream during these periods of high flow velocity—close to the river banks fish will be swimming.
- However, most fish find it exhausting to move through high-velocity water, especially if the channel has a low surface roughness that does not develop a thick boundary layer.

Shallow water depth (SA)

Inadequate water depth

- Experts argue about the minimum flow depth that fish like, but it is hard to be exact.
- Obviously in riffles, fish can spend time in very shallow water, but only for short periods.
- Generally, a minimum depth of 300 mm is recommended.
- Also, the fin should not break the surface of the water, otherwise the fish will use increased energy due to higher drag.

Non-fish-friendly grade control structure

Rapid fall in water level

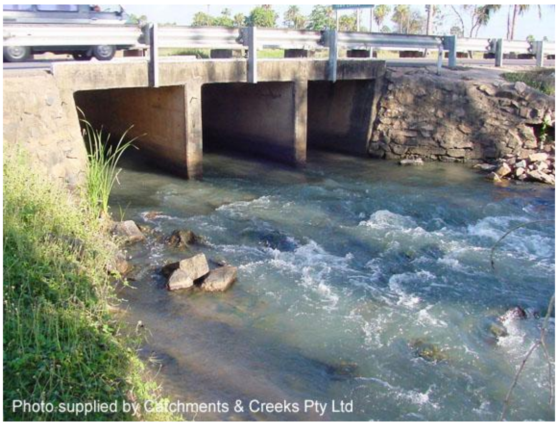
- Rapids consist of a cascading waterfalls, but fish can generally find a pathway where the maximum fall in the water at any location does not exceed 100 mm.
- In a natural riffle, the position of the rocks may change from time to time, but the random position of the rocks means that a 'good' pathway is usually available.
- However, at weirs, the fall can exceed 100 mm, and the flow condition can be uniform across the full width of the structure.

Aquatic movement – barriers to fish passage at <u>culverts</u>

Excessive flow velocities (Qld)

Excessive flow velocities

- At culverts, the same problems exist as previously mentioned for open channels:
  - high flow velocities
  - shallow water
  - outlet waterfalls.
- However, what can make things worse at culverts is the uniform nature of the flow.
- In smooth-wall culverts there is minimal boundary layer development.



Shallow water depth (Qld)

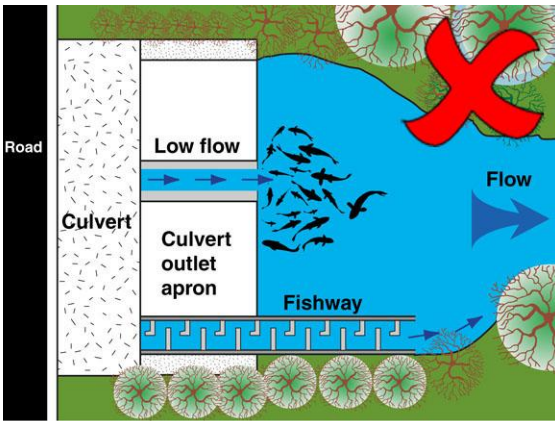
Inadequate low-flow water depth

- If the culvert was originally designed to have a floor level equal to the current bed level of the channel, then conditions can initially be 'bearable' for fish.
- However, the bed of streams can rise and fall over time, while the culvert floor stays fixed.
- As the downstream channel falls, the flow depth in the culvert can become shallower over time.

Turbulent flow conditions (Qld)

Excessive inlet and outlet water turbulence

- There are two types of turbulence—'irregular turbulence', and 'large-scale eddies'.
- Fish can find irregular turbulence exhausting, while large-scale eddies can hide the true direction of the flow.
- Turbulence most commonly occurs at the outlet of culverts, but it can also occur a the culvert inlet (as shown in this image).



Inappropriate fishway location

Non-attracting flows

- Fish need to find the entrance to a culvert fishway by following the stream flow.
- During periods of low flow, the fishway should either be the primary carrier of the base flow, or suitably integrated into the low-flow system such that fish will be attracted to the fishway.
- Fish should <u>not</u> be able to swim past the entrance of the fishway as they swim towards the culvert.

Aquatic movement – barriers to fish passage at culverts

Debris blockage of culvert entrance

Waterway blockage by trapped debris

- Flood debris can block the entrance to a waterway culvert to a degree that prevents fish passage.

A long, smooth-wall culvert

Excessive culvert length

- If a culvert cell (barrel) has uniform flow conditions, then in general, the flow velocity should be less than 0.3 m/s and the culvert length less than 10 metres.
- However, we can avoid these design restrictions by making the culvert fish friendly, by providing:
  - favourable boundary layer conditions
  - resting zones
  - a recessed culvert floor.

Very dark culvert

Inadequate natural light

- In general, fish are most likely to migrate during daylight hours.
- If the culvert is too dark, then it is believed that this condition can stop the migration of <u>some</u> species.
- Further research is required on this topic.

Outlet waterfall

Existence of a low-flow hydraulic step

- If the culvert floor is elevated above the downstream creek bed, then during periods of low flow, a waterfall can occur at the outlet, which is not a favourable flow condition for some fish species.

Aquatic plants

Aquatic plants (Qld)

Introduction

- Aquatic plants can be a major source of aquatic food both in the plant material and through substances that grow on the submerged surface area of the plant.
- These plants are usually beneficial when located around the edges of pools.

Aquatic plants (NSW)

Plant leafs

- The leaf of the plant can provide a source of food.
- It is also the leaf of many plants that helps to generate boundary layers within the flow, thus aiding fish passage.

Aquatic plants (SA)

Plant roots

- The plant's roots anchor the plant to the soil.
- However, not all aquatic plants have a root system that anchors the plant—floating plants are very effective in the removal of nutrients from the water column.

Aquatic plants (Qld)

The plant structure

- Alga can attach itself to the wetted surface of the plant, which increases the potential food source.
- It is noted that the same alga can attach to rocks and other wetted surfaces.

Base flow (trickle flow)

Trickle flows in a pool–riffle system (Qld)

Introduction

- Base flow is often referred to as the 'low flow' or 'trickle flow' condition.
- The provision of high quality base flows is probably one of the most important factors in the establishment of a healthy aquatic ecosystem.
- As a general rule; the lower the flow rate, the greater the need for high-quality water.

Trickle flow in a gravel-based stream (Qld)

Creeks that have turbit flood flows, but clear base flows.

- Many creek systems contain turbid water during storm and flood events.
- However, most natural creeks will return to a clear-water condition during extended periods of dry weather—this is because the inflows into the creeks during these periods are usually filtered spring flows.
- But not all creeks experience clear-water trickle flows—creeks in dispersive soil regions can be permanently turbid.

Trickle flows passing down a riffle (Qld)

The effects of urbanisation

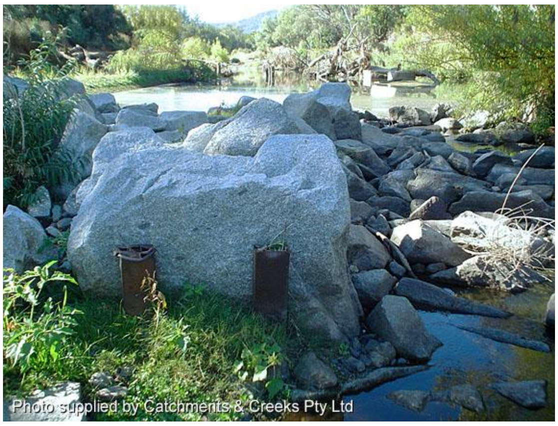
- It has often been reported that urbanisation decreases base flows due to the increased impervious surface area.
- This increase in impervious surface area is thought to cause a reduction in rainwater infiltration.
- However, garden and lawn watering in urban areas can result in an increase in the base flow, especially during periods of drought when stream flows would normally have ceased.

Swampy Plains River, NSW

River systems

- The base flow in a river can be near constant, or more commonly, vary in-line with the seasons.
- Snow melts can supply much of the base flow within several of our river systems.

Boulders



Placed habitat bounder (NSW)

Introduction

- Boulders placed on the bed of the watercourse can increase habitat diversity, while boulders recessed into the low-flow channel, or the pools, can increase the total submerged surface area of all matter at a given location.
- Increasing the submerged surface area can increase the available food supply for aquatic life.
- Boulders can also help to increase dissolved oxygen levels in the water.

Random boulder (natural)

Distribution

- The recommended placement density of isolated boulders is 1 per 30 m^2, or 2 per 70 m^2.
- Alternative, triangular clusters of 3–5 boulders should be placed at least 1/3 the channel width apart.
- **Warning:** Boulders can deflect high-velocity flows onto a bank causing erosion.

Natural gravel bed (Qld)

The stability of boulders

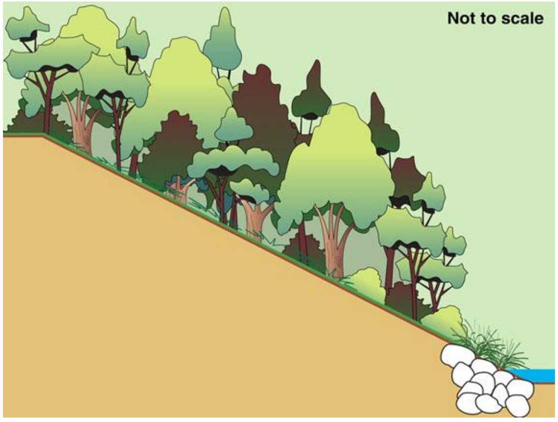
- The stability of a boulder <u>cannot</u> be determined by using a standard rock sizing formula such as (d_{50} = 40V5) because such design formulas are only suitable for rock that is placed flush with the channel surface.
- A boulder is subjected to much higher hydraulic forces because the majority of the boulder protrudes into the flow.
- Boulders are typically 0.6 to 1.5 metres in diameter.

Rock weir (SA)

Mimic the natural size and distribution of boulders in similar streams

- Where possible, inspect the watercourse for evidence of existing boulders that have remained undisturbed within the channel for some time.
- The size of these boulders will provide a good indication of the rock size needed to withstand flood flows in the rehabilitated channel.

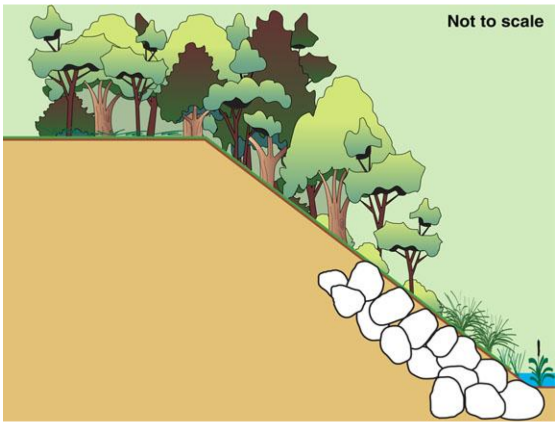
Channel banks



Fully vegetated creek bank

Vegetated banks

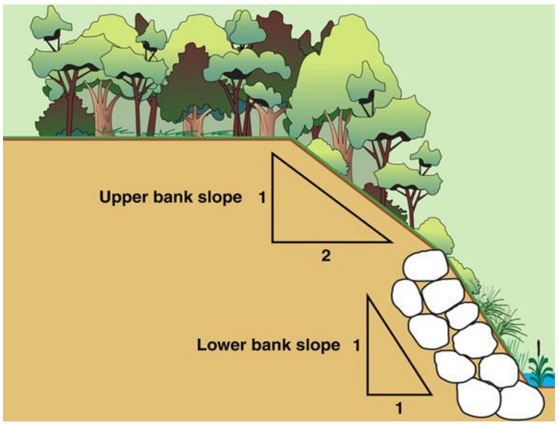
- Recommended <u>maximum</u> gradients:
  - 1-in-2 (V:H) on the outside of channel bends; however, such slopes can be difficult for workers to vegetate, especially on bank higher than 3 metres
  - 1-in-3 on the inside of channel bends.
- If safety issues are expected due to the height or steepness of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



Dumped rock

Rock stabilisation

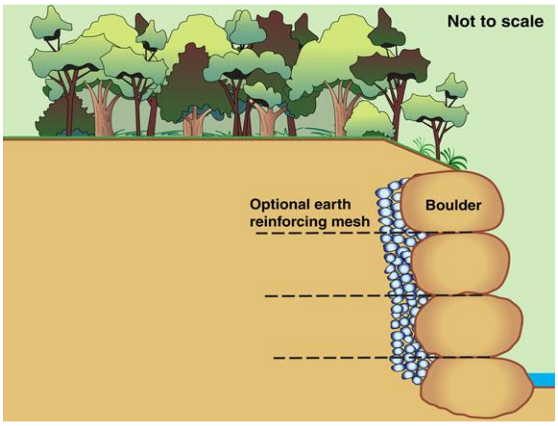
- Recommended <u>maximum</u> gradients:
  - 1-in-0.5 for stacked boulders
  - 1-in-1 for vegetated, individually placed rock; however, such slopes can be difficult, if not unsafe, for workers to plant
  - 1-in-2 for dumped rock on the outside of channel bends
  - 1-in-3 for dumped rock on the inside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



Placed rock on outside of a channel bend

Placed rock

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



Stacked rock retaining wall

Stacked rock

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

Channel bed

Clay-based channel bed (Qld)

Introduction

- The bed conditions in a watercourse basically depend on: the composition of the bed substrate, the size of the catchment, and the existence or non-existence of bed vegetation.
- Ultimately it is the type of rock found in the upper catchment (the mountains) that usually governs the type of bed substrate.
- Clay-based channel bed are generally stable relative to alluvial streams.

Sand-based channel bed (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 flood events.
- Bed vegetation (if any) typically consists of quick-response, short-lived, non-woody species.

Gravel-based channel bed (Qld)

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 major 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.

Pool–riffle system (Qld)

Pool–riffle systems

- Pool–riffle systems are generally found only in gravel-based waterways, but a type of pool–riffle systems can also occur in sand and clay-based waterways.
- In sand and clay-based waterways, the ‘riffle’ component is often represented by exposed bedrock, or bridging tree roots on a narrow creek.

Ephemeral creeks

Ephemeral sandy creek (Qld)

Introduction

- Ephemeral creeks are waterway that are frequently dry.
- They generally experience flows for short periods following storm events.
- Pool and riffle systems can still exist in these systems, but the pools are often dry.
- However, some deep pools may retain water all year round.

Ephemeral clay creek with pool (Qld)

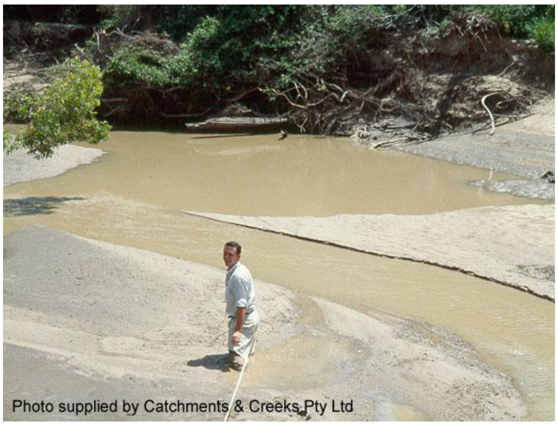
Fish habitat waterways

- Permanent pools are important fish habitats.
- In urban areas, some creeks (that would normally be ephemeral) may experience long periods of low flow caused by the unnatural inflows generated by lawn and garden watering.
- This water can help to maintain water quality within permanent pools.

Ephemeral clay creek (NSW)

Non-fish habitat waterways

- Before designing or modifying an ephemeral watercourse, visit, investigate, and study, existing ephemeral systems in the local area.
- In particular, take note of the channel features and the dimensions of any pools.
- The fact that the waterway is 'dry' does not mean that the waterway is not recognised by the State as a fish habitat (always seek local expert advice).



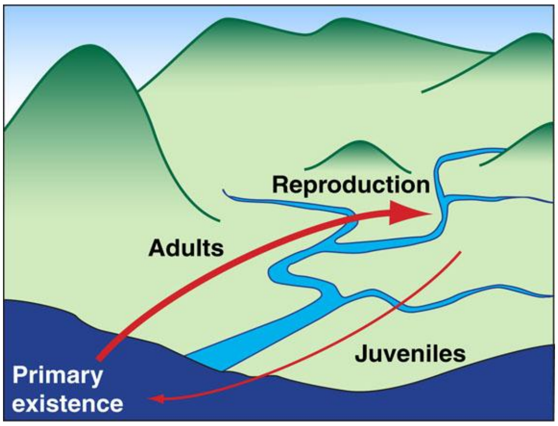
An unstable sandy bed (Qld)

Unstable post flood bed conditions

- Sand-based ephemeral creek beds can be very stable, and trafficable during extended periods of dry weather.
- **However**, a deep sandy bed can become unstable, and sometimes act a bit like 'quicksand' (liquefaction) in the days or weeks after a flood event.

Photo (left): A council officer suddenly sunk to his knees while walking over a previously firm sand bar, in a sand-based creek, in the days following a flood event.

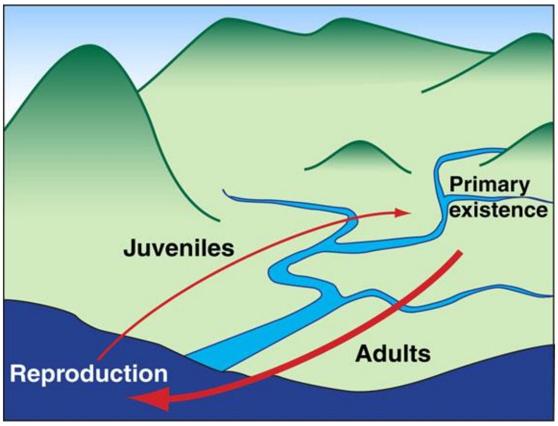
Fish migration



Anadromous fish movement

Introduction

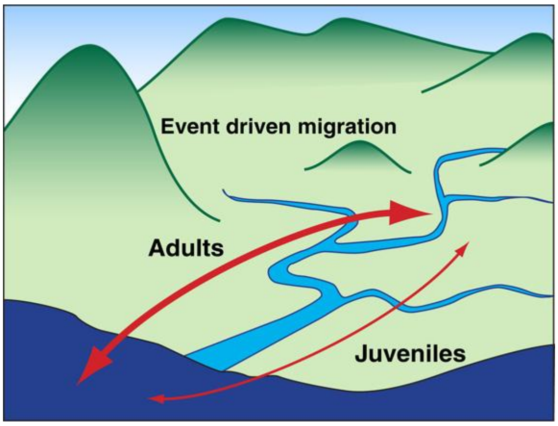
- The term 'fish migration' refers to a specific form of fish passage where the directional movement of fishes, either upstream or downstream, is in response to a lifecycle need, including, but not limited to, reproduction.
- The term 'anadromous' refers to the migration of fish that spend much of their life in a marine environment and which migrate to freshwater as adults to reproduce.



Catadromous fish movement

Catadromous

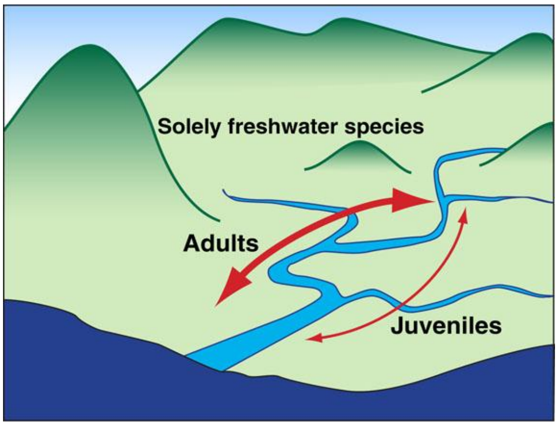
- The term 'catadromous' refers to the migration of fish that spend most of their life cycle in freshwater and which migrate to the marine environment to reproduce.
- The opposite is **anadromous**.



Diadromous fish movement

Diadromous

- The term 'diadromous' refers to the migration of fish that regularly migrate between fresh and salt water during a definite period of their life cycle.
- This includes **anadromous** and **catadromous** species.



Potamodromous fish movement

Potamodromous

- The term 'potamodromous' refers to the migration of fish that make migrations wholly within freshwater.

Fish passage

Fish in a storm drain (Qld)

Fish passage (SA)

Fish trapped at a fish barrier (Qld)

Estuary fish (NSW)

Introduction

- Fish passage along our waterways is critical to the survival of native fish.
- All freshwater fish and some saltwater species, regardless of their size, move within waterways at different times to access food and shelter, to avoid predators, and reproduce.
- Of the 83 species of freshwater fish in south-eastern Australia, approximately half migrate at least once as part of their life cycle.

Types of fish movement

Examples of the various types and reasons for fish movement include:

- Local movement to access food, avoid predators, and shelter from high temperatures.
- Daily movement to access habitat, food and shelter, and avoid predators.
- Seasonal movement as part of their breeding cycle.
- Upstream movement to access new habitats, or in response to their displacement during flood events.
- Downstream movement after spawning to avoid predators.
- Some fish spend much of their life in a marine environment, but then migrate to freshwater as adults to reproduce.
- Some fish spend most of their life cycle in freshwater, then migrate to the marine environment to reproduce.
- Some fish migrate between waters during a specific period of their life cycle.
- Some fish migrate solely within freshwater environments.

A natural response to flood flows

- Flood events can trigger the upstream migration for some fish.
- For many other species there is a general need for the fish to progressively move upstream during periods of low-flow in order to counter the effects of flood events, which can carry these fish well-downstream during flood events.
- This means that barriers to fish passage can be a problem even for species that don't need to migrate as part of their life cycle.

Fish passage – the swimming ability of fish

Pygmy perch (NSW Fisheries)

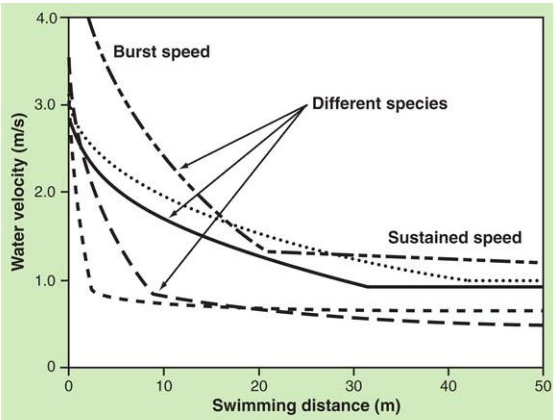
Size and species

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

Large fish in shallow water (SA)

Swimming ability in shallow water

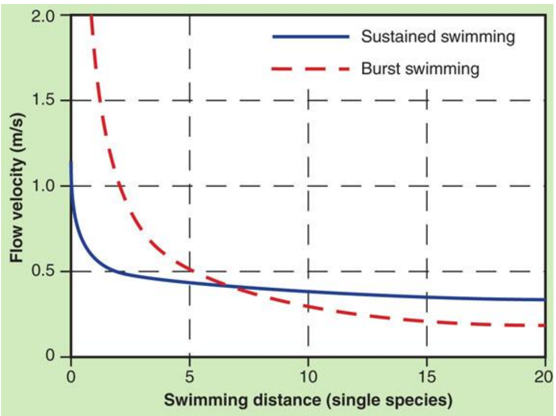
- The swimming ability of fish can also be affected by the depth of the water.
- If the body of the fish is partially exposed, then their swimming speed and endurance are reduced.
- Some engineering structures, such as flat-bed box culverts, can create shallow water conditions that are difficult for fish to negotiate.



Examples of fish swimming ability

Approximate swimming speeds

- Fish use a combination of burst speed and sustained speed to negotiate waterway obstacles.
- In general terms, their swimming speed varies with the size of the fish, with:
  - burst speed being approximately 6 to 10 body lengths per second (BLPS)
  - sustained speed being approximately 3BLPS.



Example of speed over distance

Swimming ability over long distances

- Fish use different muscle groups during different types of swimming.
- During burst swimming the initial speed can be high, but energy levels are quickly exhausted and eventually the swimming speed will fall below that which would have been achieved during sustained swimming.
- This means the effective 'length' of a waterway obstacle is critical in determining if the obstacle becomes recognised as a barrier to fish passage.

Fishways

Fish ladder (vertical jump)

Introduction

- A 'fishway' is a structure designed to enable fish to move past a physical barrier (e.g. dam or weir) in a waterway.
- A 'fish ladder' is a constructed fishway that requires fish to 'jump' from pool to pool, or cell to cell, in order to climb the structure.

Block-ramp fishway (Walaman)

Block-ramp fishways

- The Walaman system uses pre-cast concrete blocks to form a fishway.
- This system can carry fish up a small weir or through a culvert.

Baffled fishway (NSW)

Baffled fishways

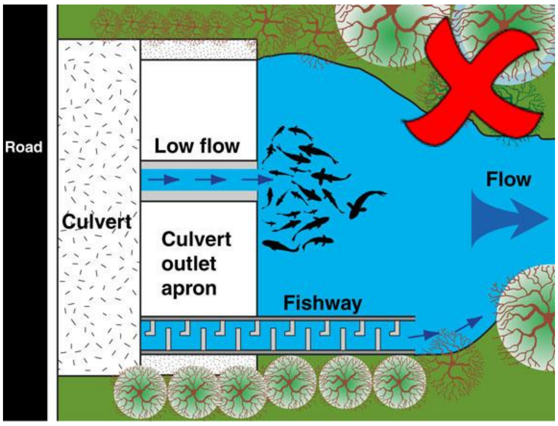
- Baffled fishways provide resting ponds (on the side) and fish passage for both adult and juvenile fish.

Vertical slot fishway

Vertical slot fishway

- Always seek local expert advice when designing any fishway.

Fishways – design issues



Poor fishway design

Floodwater overtop a road culvert

Mary River Cod (Qld)

Sediment deposition within a fishway

Non-attracting flows

- Fish need to find the entrance to a culvert fishway by following the stream flow.
- During periods of low flow, the fishway should either be the primary carrier of the base flow, or suitably integrated into the low-flow system such that fish will be attracted to the fishway.
- Fish should not be able to swim past the entrance of the fishway as they swim towards the culvert.

During a full range of expected flows

- Before specifying that a fishway must be useable for 'a full range of expected flow', think about what this actually means.
- **Remember:** During a 1-in-100 year event, the stream flows will likely operate below the 1-in-10 year (or event 2 year) flow rate for possibly 80% of the flood event.
- Designing for large flood events will likely only be required for critical habitats, and when fish migrate in response to flood events, and even then, it is likely that a bridge will be required instead of a culvert.

Understand the needs of the fish

- Much of engineering design is based on understanding the needs of the client, and/or the target audience.
- The audience, or customers, may include:
  - road users
  - affected property owners, and
  - local fauna (aquatic and terrestrial).
- Designers need to know if fish passage is required during low flows and/or flood flows, and if fish passage is required along the sidewalls and/or along the bed.

Understand the characteristics of the waterway

- Different types of waterways have different characteristics, which can interact differently to the fish passage components of the waterway.
- Of critical concern is the expected movement of bed material.
- Baffles located on the floor of a waterway structure must be compatible with the expected movement of bed material along the waterway.

Floodplains (fish passage)

Fish trapped in a drying floodplain pond

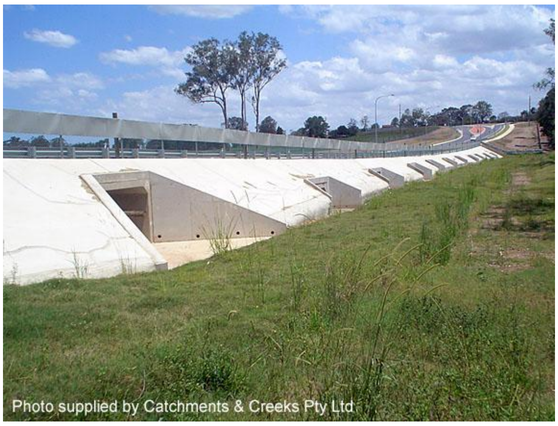
Introduction

- Some species will enter the floodplain during a flood event in order to:
  - escape the high flow velocity of the main channel
  - migrate upstream.

Floodplain culvert (Qld)

Floodplain culverts

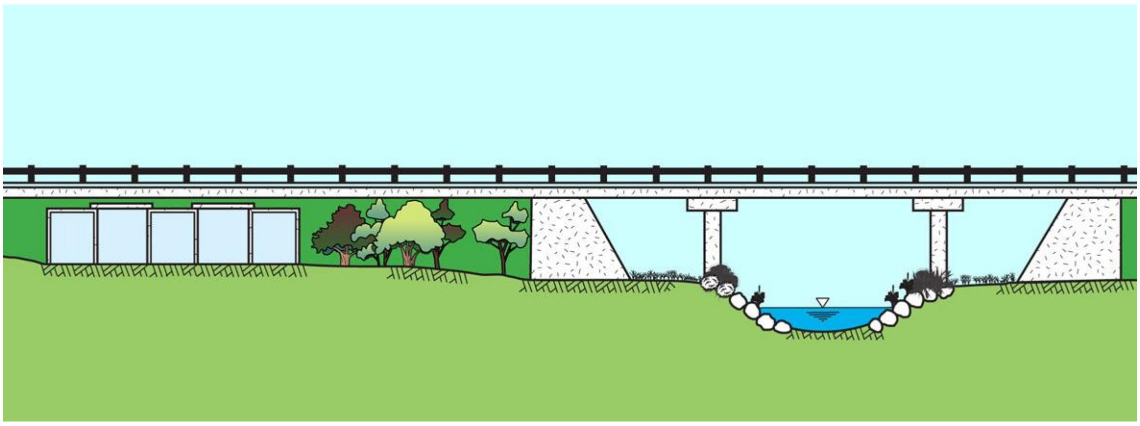
- Unfortunately there appears to be a common belief that culverts located within floodplains do not need to be fish friendly.
- Such a belief is of course untrue.
- However, fish passage through floodplain culverts will likely need to cater for only adult fish—which does not necessarily mean that the fish will be large (always check with a local expert).



Floodplain culvert (Qld)

Terrestrial passage

- Floodplain culverts usually need to cater for both fish passage and terrestrial passage.



Floodplain culvert adjacent to a bridge crossing of the waterway

Flow conditions

Dry weather trickle flow (Qld)

Base flow (dry weather trickle flow)

- The base flow is the persistent dry weather flow rate, which is typically the minimum flow rate of a waterway.
- In rural areas, this base flow can originate from groundwater, springs, or snow melt.
- In urban areas, garden watering can make a significant contribution to the dry weather flow rate.
- Fish passage may not be possible at all locations along the channel during these periods of low flow.

Bankfull flow (Qld)

Bankfull flow

- Bankfull flow is defined by the water surface reaching the elevation of the lowest bank.
- Bankfull flow typically represents the worst possible fish passage conditions with regard to flow velocity.

Minor overbank flood event (Qld)

Minor flood

- Minor floods allow fish passage to occur within overbank areas, extending into the floodplain.

Brisbane River flood of 2011

Major flood

- Major floods can place significant water depth over the floodplains, which can make fish passage slightly more difficult, but in general, fish passage should be possible along the full length of the waterway.

Grade control structures (open channel drop structures)

Weir (Qld)

Introduction

- Grade control structures are used to control the extent of bed erosion, and sometimes to help maintain a minimum water level in an upstream pond.
- Grade control structures include:
  - open channel drop structures
  - rock chutes and rock ramps
  - weirs and causeways.
- In many constructed channel, these structures becomes a necessary evil.

Stepped rock-mattress drop structure (Qld)

Non-fish-friendly structures

- Traditional vertical and near-vertical drop structures and weirs can cause serious impediments to fish passage.
- Some drop structures can even cause breaks to terrestrial movement corridors.
- Many structures are even dangerous to humans.
- To avoid disruptions to aquatic and terrestrial corridors, several small drop structures should be built rather than one large structure.

Whitewater rafting in Denver (USA)

Whitewater rafting structures

- Grade control structures can be designed for use by whitewater rafting adventures.
- Typically, a dedicated fishway is built around these structures using a bypass channel.

Rock chute (rock ramp) drop structure

Rock ramps (rock chutes)

- In areas where fish migration is required, the maximum fall height for any riffle, or rock ramp, should be 500 mm.

Grade control structures – fish-friendly structures

Gravel-based creek (Qld)

Desirable creek bed features

- Within fish habitats, bed stabilisation measures should generally aim to provide the following features:
  - bed roughness that simulates the natural bed roughness
  - a diversity of surface conditions that produce a diversity of flow conditions
  - random objects that can provide fish with protection from high-velocity flows
  - a suitable source of food.

Constructed rock ramp/chute (NSW)

Fish-friendly rock ramps

- Rock ramps (rock chutes) are often used to stabilise bed scour problems.
- In order to be fish friendly, these structures need to comply with certain physical and hydraulic requirements:
  - a maximum gradient of around 1-in-20 to 1-in-30
  - a maximum fall of around 500 mm
  - stable outer flanks that provide suitable fish passage conditions during elevated flows (i.e. minor floods).

Constructed rock riffle (Qld)

Fish-friendly hydraulic steps

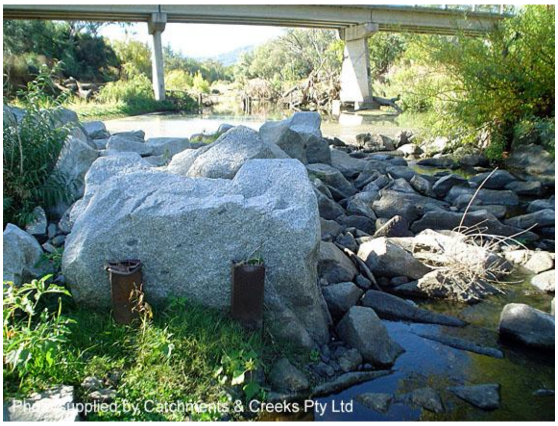
- Ideally, the 'spill height' between two adjoining rocks, or any other part of a fishway, should not exceed 100 mm.
- Ideally, no hydraulic structure should be 'uniform' in its flow conditions across the width of the channel.
- Minor variations in the positioning of rocks means fish can search for their preferred pathway during different flow conditions.
- Such diverse hydraulic conditions are commonly found in natural riffles.

Bed level falling downstream of culvert

Allowance for future changes in bed levels

- In waterways, nothing stays the same for long periods, banks move left and right, creek beds move up and down.
- In order to be fish friendly, all waterway structures must be able to accommodate expected changes in bed level.
- This means:
  - extra rock may need to be placed below the current bed level, and/or
  - recessed rock check dams may need to be installed within some waterways.

Grade control structures – fish-friendly structures



Habitats formed by placement of boulders

Random placement of boulders

- Rock riffles do not 'naturally' occur in all waterways.
- Similarly, rock boulders do not exist in all waterways.
- However, with the guidance of waterway and fisheries experts, the random placement of boulders can:
  - provide resting areas for fish
  - provide roosting areas for aquatic and terrestrial fauna.

Constructed pool-riffle system (Qld)

Use of pool-riffle systems

- The construction of a series of pools and riffles is one option for the rehabilitation of head-cut erosion within a waterway.
- However, a pool-riffle system is not a natural feature in all types of waterways.
- To be fish friendly:
  - the rocks must be stable during the expected flow range (unlike natural riffles which allow the rocks to move)
  - the total fall of the riffle should not exceed approximately 500 mm.

Constructed fishway (Qld)

Use of fishways

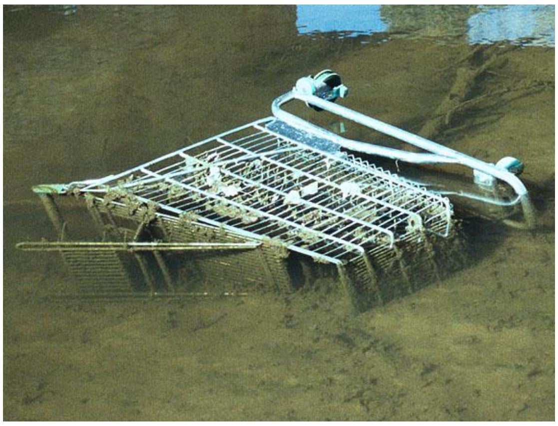
- Constructed fishways are often used as a component of the rehabilitation of existing non-fish-friendly waterway structures, such as culverts and weirs.
- To be fish friendly:
  - the spill height across any ridge should not exceed 100 mm
  - the design of the fishway must accommodate the natural movement of bed material (i.e. sediment and gravels) during flood events.

Fish ladder on a river weir (USA)

Use of fish ladders

- A 'fish ladder' is a type of fishway that normally requires fish to 'jump' from pool to pool in order to ascend the fishway.
- In Australia, it is generally preferable for fishways to utilise the 'burst speed' of the fish in order to ascend the fishway, instead of the fish's jumping skills.
- Obtaining advice from fisheries experts is essential prior to the placement of any fishway within Australian waters.

Invasive species (observations of the author)



Saebda minor **(Rustic side-winder)**

Trollos australis **(Three-wheel rattler)**

Botm dwellan **(Easter bottom dweller)**

Crike trollos **(Common creek trolley)**

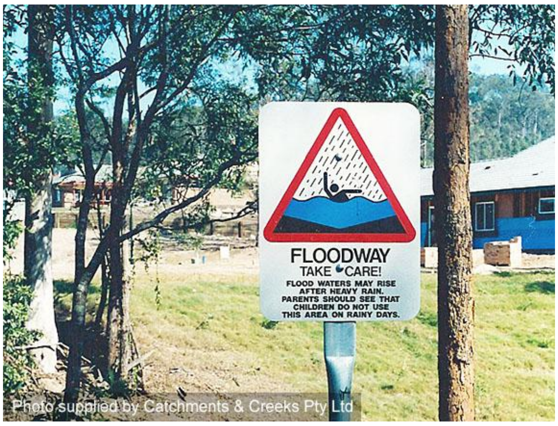
Shopper-trollos **(Reedy bed trolley)**

Trollos regia **(Royal silver cage)**

Trollos-trollos **(Eastern red tip trolley)**

Quattuor-wile caveal **(Four-wheel roller)**

Lakes



Safety sign (Qld)

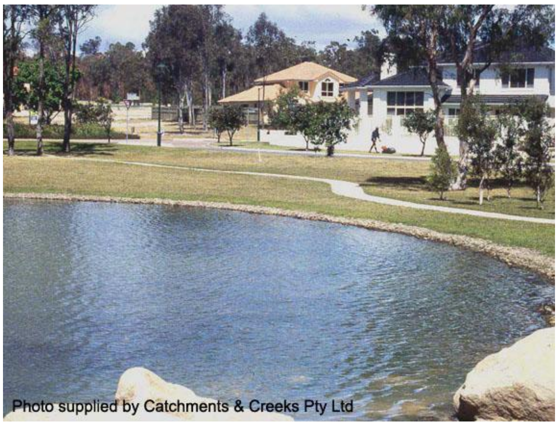
Introduction

- Constructed urban lakes can be used by land developers to:
  - increase the overall appeal of an estate
  - increase the value of the properties surrounding the lake
  - act as part of the estate's stormwater treatment system
  - act as part of the estate's stormwater detention/retention requirements.

Downstream control weir (Qld)

Barrier to fish passage

- Urban lakes can either be located off-stream (which is rare), or instream (sometimes termed 'on-stream').
- Instream lakes have the advantage of a near constant through-flow, but the disadvantage of accepting the pollutant inputs of this through-flow.
- Instream lakes typically require an upstream grade control structure, and/or a downstream weir in order to maintain the water storage.



On-stream urban lake (Qld)

Barrier to terrestrial passage

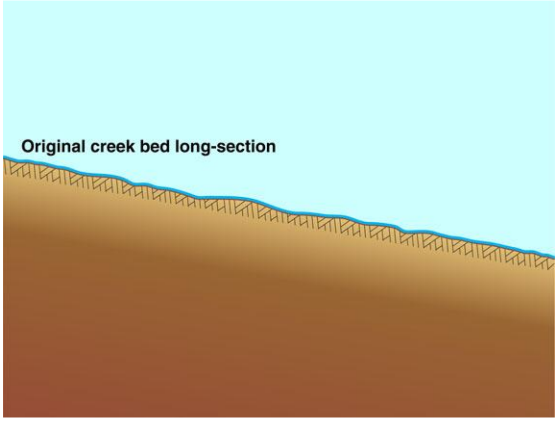
- Both the upstream grade control structure, and the downstream weir, can act as barriers to fish passage.
- If the lake is not surrounded by a riparian zone, then the lake can also become a barrier to terrestrial movement.

Fish kill from low dissolved oxygen

Barrier to natural sediment flow

- Urban lakes can becomes 'sinks' for sediments and nutrients.
- Fish kills are common in many urban lakes due to high nutrient inflows, and poor oxygen levels.

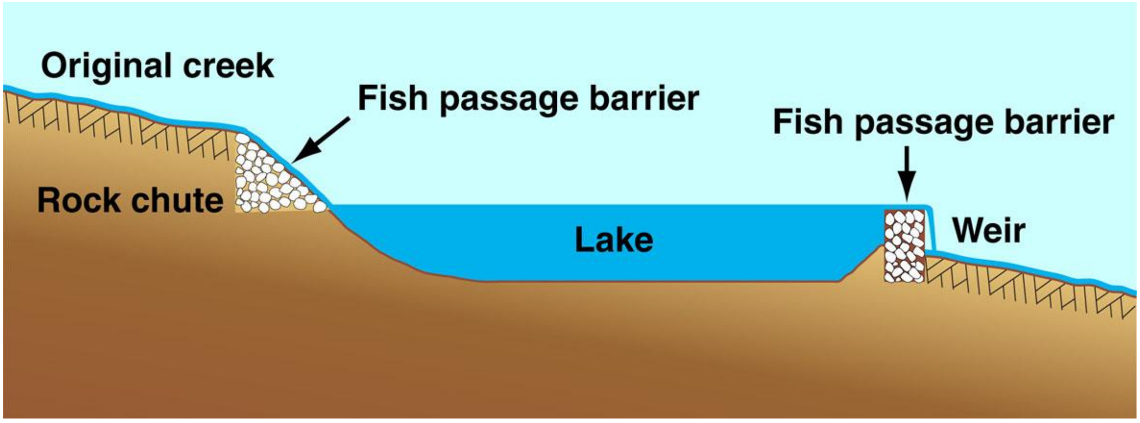
Lakes – the potential problem of incorporating a lake into a waterway



Pre-lake stream gradient

The problem

- Prior to construction of an instream lake, the original waterway would have had a regular channel fall, with the possibly of a few pools and riffles (shown left).
- The construction of an urban lake usually requires the installation of a grade control structure at the upstream end of the lake in order to prevent the formation of erosion within the upstream channel, and a downstream weir (shown below).



Post-lake stream gradient with a drop-inlet and drop-outlet

Rock chute inlet upstream of a lake

Upstream grade control structure

- If the original waterway was a recognised fish habitat, and approval has been given for the construction of the lake, then this grade control structure should be designed as a fish-friendly structure.
- Such a design requirement would exist even if the downstream weir acts as a barrier to fish passage.

Rock weir downstream of a lake

Downstream weir

- If the original waterway was a recognised fish habitat, and approval has been given for the construction of the lake, then a bypass fishway must be installed around the downstream weir.
- Stocking a lake with aquatic life can help to control mosquitos, BUT such an action:
  - requires Fisheries approval
  - requires the advice of an aquatic biologist.

Leaf litter (a source of food)

Introduction

- In a natural system, much of the stormwater runoff that enters a stream, would enter in the form of sheet flow passing through the riparian zone.
- The riparian vegetation would filter significant amounts of organic matter from the stormwater, along with many other pollutants.
- As a result, much of the organic matter that enters a natural waterway comes not from stormwater runoff, but directly from overhanging vegetation (leaf fall).

Leaf litter (SA)

Urban catchments

- However, in urban areas stormwater runoff is usually concentrated into some type of drainage system, which discharges directly into waterways.
- Consequently, most of the organic matter that falls onto roads will enter a waterway unfiltered by the riparian zone.
- This very high, unnatural supply of organic matter can alter the food balance resulting in the production of >eutrophic= (over-fed) conditions within the waterway.

Eutrophic water conditions

Deciduous trees

- The rate of decay of the leaf matter can be an important factor.
- Many native leaves (e.g. gum leaves) decay slower than the non-native leaves that fall from the deciduous trees that are often used to decorate our street landscapes.

Eutrophic water conditions

Green water

- Water that has a 'green' colour is usually water that has an excess inflow of nutrients.
- For most inland waterways, the best form of treatment is to focus on reducing the inflow of phosphates, which can be achieved by filtering stormwater through an earth filter, such as:
  - filtration systems
  - infiltration systems
  - bio-filtration systems.

Pollution

Turbid stormwater runoff

Waterway pollution

Wetland (Qld)

Stormwater filtration system (Qld)

Introduction

- The pollutants that are likely to adversely affect the health of aquatic life include:
  - excess nutrients (especially nitrogen and phosphates)
  - turbidity (suspended clay particles)
  - metals (which are most likely attached to clay particles—p.s. there is no such thing as a 'heavy metal')
  - elevated water temperature.

Removal of pollutants

- The 'Clean-up Australia' campaign, which is fully supported by the author, typically involves the physical removal of 'visual' pollutants from our waterways, which are not the pollutants that are likely to adversely affect aquatic life in our waterways.
- Aquatic life in our waterways are more likely to be affected by pollutants that are not visible to the human eye.
- Turbid inflows are one pollutant that is visible, but also difficult to remove.

Protecting coastal waterways

- In order to best protect most coastal waterways, the pollutant that is targeted by modern stormwater treatment systems is: 'nitrogen'.
- The treatment systems that remove nitrogen typically incorporate wetlands or bio-retention basins, which encourage 'wetting' and 'drying', and areas of shallow surface waters.
- 'Filtering' systems are also used to remove clays and their attached metals.

Protecting inland (rural) waterways

- In order to best protect most inland waterways (such as our large river systems), the key pollutant is the phosphates.
- The removal of phosphates requires the water to be filtered through soil, which means focusing on stormwater filtration and infiltration.
- For this reason, inland sewage treatment plants focus on phosphate removal, and low-P washing products are used the community.

Pool–riffle systems

Constructed pool–riffle (Qld)

Introduction

- A series of pools and riffles is one of the best ways of increasing the gradient of a constructed waterway, while maintaining fish passage along the channel.
- A single riffle, followed by an energy dissipation pool, with a downstream recessed rock check dam, can work together as a single 'grade control structure'.
- A 'recessed rock check dam' acts like a 'riffle' when exposed by bed erosion.

Constructed pool–riffle (Qld)

The use of pool–riffle systems

- In an ideal world, a pool–riffle system would only exist in waterways that naturally contain pool–riffle systems, typically gravel-based waterways.
- A pool–riffle system is a fish-friendly structure that can be used to:
  - stabilise a channel bed
  - replace a non-fish-friendly weir or drop structure
  - act as a fish-friendly inlet and/or outlet of a waterway culvert.

Constructed riffle (NSW)

Rock ramps (rock chutes)

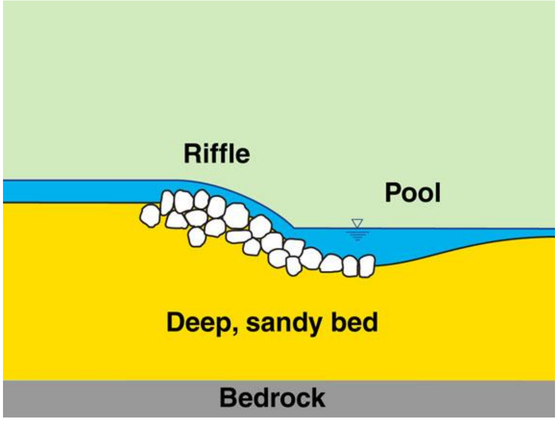
- A rock ramp, which is a fish-friendly grade control structure, is just another form of a rock riffle, and generally follows the same design requirements.

Constructed pool–riffle sequence (Qld)

Rehabilitation of modified waterways

- When old urban waterways and drainage channels are rehabilitated, it is often essential to incorporate several pools and riffles (rock ramps) into the channel because of the often 'unnatural' steep gradient of the channel.
- Even though such a bed structure is not natural to the waterway, it sometimes becomes a necessary evil in order to return aquatic values to the waterway.

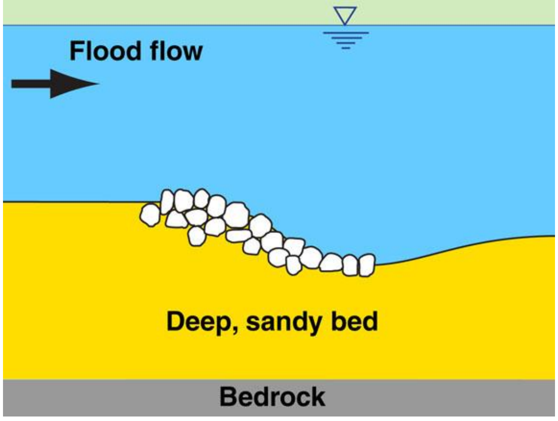
Pool–riffle systems – Caution the placement of rocks on a sandy bed



Recessed check dam in a sandy bed

Introduction

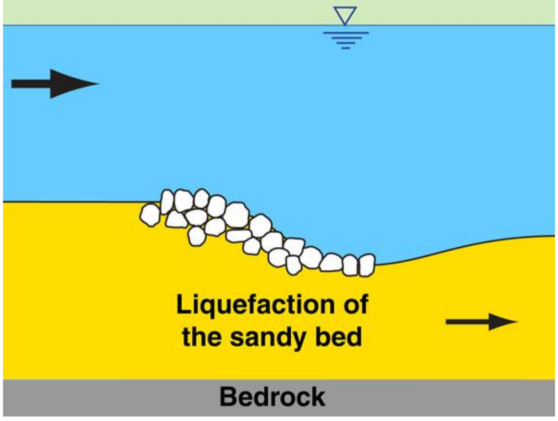
- These four diagrams illustrate the potential problem that can result when a rock riffle is formed on the surface of a deep, sandy creek bed.



Flood event

Major flood event

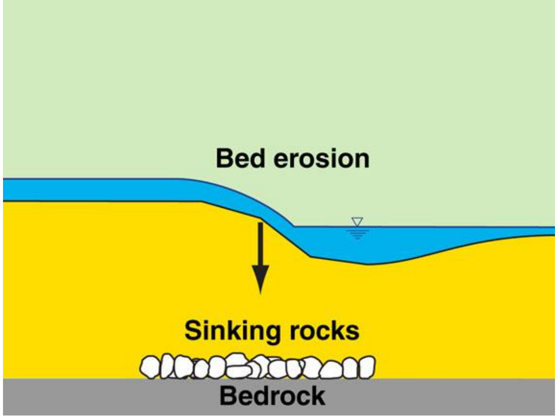
- During most floods, the sandy bed will migrate slowly down the channel, which can cause disturbance to the rocks.



Liquefaction of the sandy bed

Liquefaction of the sandy bed

- During a major flood, the sandy bed can liquefy, which can turn the sandy bed into a form of 'quicksand'.



Rock sink into the sandy bed

Sinking rocks!

- When the sand is in this form, the riffle rocks can simply sink into the sand, which will leave the sandy bed unprotected, subjected to bed scour.

Pools (habitat ponds)

Pool–riffle system (Qld)

Introduction

- In most creek systems, pools provide essential habitat for aquatic life, especially during dry weather, and periods of drought.
- Pools are also located:
  - immediately downstream of riffles, waterfalls, chutes, and drop structures to assist in energy dissipation, and
  - at channel bends.

Habitat pond (SA)

Habitat ponds

- Ponds provide habitat diversity, but they should not be placed in a constructed waterway channel if their existence creates a barrier to fish passage.
- In sandy streams, pools are often found adjacent to structures such as bridges and culverts.
- These pools tend to fill with sediment during periods of low flow, and scour during periods of high flow, such as bankfull flow.

Habitat pond (Qld)

Maintaining water quality

- Ideally, pools should always contain moving water to prevent mosquito breeding, and to maintain healthy water quality within the pool.
- The edge of pools should be shaded by overhanging vegetation

Farm dam (Qld)

Farm dams

- A farm dam is typically just a large pond.
- Farm dams can either be located on an overland flow path, where there is only running water during rainfall, or on a permanent stream, which may have a near-constant inflow of water.
- It is the author's experience that farm dams are most commonly located on drainage lines that would <u>not</u> normally be classified as fish habitats (I could be wrong).

Recessed banks

Habitat pond recessed into creek bank

Recessed stormwater outlet (Qld)

Reed bed at a stormwater outlet (Qld)

Recessed stormwater treatment channel

Introduction

- A recessed creek bank is a channel feature that can be used for a variety of purposes, including:
  - forming a small instream pond, which does not experience the normal through-flow of water, but instead the channel flow passes along the side of the pond causing water 'circulation'
  - forming a mini wetland
  - forming a side-channel that connects to a recessed stormwater outlet.

Recessed stormwater outlets

- It is preferable for stormwater outlets to be recessed into creek banks so that ongoing bank erosion and channel migration do not expose the outlet to damage.
- Recessing the outlet can allow for the energy dissipation of outflows, as well as allow stormwater treatment to occur, such as a mini wetland.
- The creek shown here (left) has yet to have the riparian zone fully restored.

Mini wetlands

- If a mini wetland is formed within a recessed channel, then the invert of the stormwater pipe should be at least 200 to 300 mm above the normal wetland water level.

Side channels

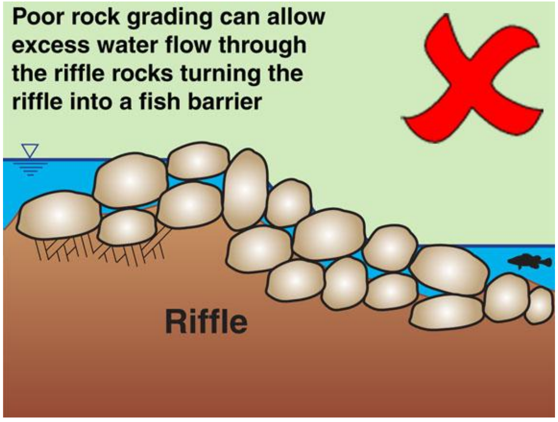
- If space allows, then instead of forming a short recessed channel that is transverse to the main channel, a side-channel can be formed that is parallel to the main channel.
- These side-channels can provide:
  - stormwater treatment
  - shelter for aquatic life from flood flows
  - additional habitat and protection for aquatic life
  - increased length of the water's edge.

Rock chutes, rock ramps and riffles

Constructed riffle (Qld)

The above riffle during a storm (Qld)

Constructed riffle (Qld)



Consequence of poor rock grading

Introduction

- A rock ramp is a grade control structure or fishway that conveys water at a gradient steeper than the average gradient of the watercourse.
- In most circumstances the term 'ramp' can be interchanged with the term 'chute'.
- The term 'rock ramp' is more commonly used by fisheries biologists, while the term 'rock chute' is more commonly used by hydraulic engineers.
- A 'riffle' is just a natural rock ramp.

Fish-friendly rock ramps

- To allow fish migration, rock ramps should have a maximum grade of 1-in-20 and a maximum fall of 500 mm and length of around 10 metres between pool resting areas.
- Ideally the grade should be 1-in-30 or flatter; however, this can result in a very long chute.
- Because fish can swim at a burst speed for only short distances, the greater the flow velocity, the shorter must be the distance between resting pools.

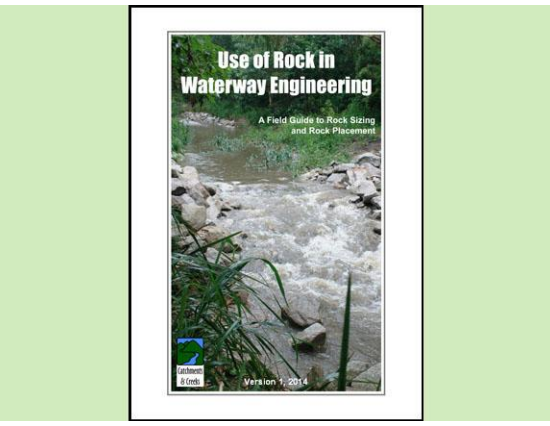
Sizing the rock

- In a gravel-based waterway, riffles should be formed from the natural bed gravels; however, this does mean that the riffle will be disturbed during flood events.
- In a clay-based waterway, the rock size can be determined using the information presented in Section 10.1 of Part 2.
- In a sand-based waterway, the rock size can be based on Section 10.1, BUT designers should expect the rocks to sink into the sand during flood events.

The need for some smaller rocks

- In a traditional, non-fish-friendly rock chute, the rock size is near-uniform, with minimal smaller rocks incorporated into the mix.
- However, for a fish-friendly rock ramp, there should be sufficient small rocks and fines to restrict the flow of water passing through the voids between the rocks.
- **The water should pass over the rocks, not through them.**

Rock



Use of Rock in Waterway Engineering

Introduction

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

Bankfull flow conditions (Qld)

Factors affecting rock size

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

Vegetated rock protection (Qld)

Long-term stability of rock-lined banks

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

Waterway maintenance (Qld)

Waterway maintenance

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

Rock – Design issues

Partial vegetated bank stabilisation (NSW)

Single layer of rock over filter cloth (black)

Rock placement over filter cloth (Qld)

Vegetated, rock-stabilised bank (Qld)

Rock type and grading

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

Thickness of rock protection

- The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size (refer to Part 2 of this four-part document).
- The thickness of rock protection must also be sufficient to accommodate the largest rock.
- **It is noted that increasing the thickness of the rock placement will not compensate for the use of undersized rock.**

Backing material or filter layer

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

Manning's roughness of vegetated rock

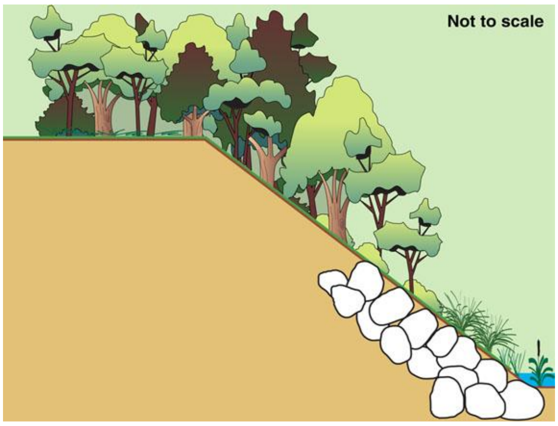
- Once the rock stabilisation is vegetated, the Manning's roughness of the surface becomes dominated by the hydraulic roughness of the vegetation.
- If highly flexible plants are used (e.g. grasses), then the surface can become relatively smooth during high-velocity flows.
- If woody plants are used, then the vegetation roughness can push flows away from the creek bank.

Rock – Gradient of rock stabilised banks

Example of 'placed rock' (Qld)

Introduction

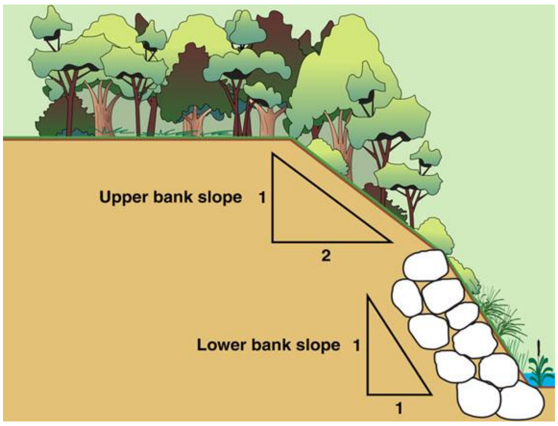
- The maximum gradient of rock-lined surfaces depends on:
  - how the rocks are placed (dumped from the back of a truck, individually placed by a rock grab, or stacked so as to minimise any individual movement)
  - the existing bank slopes upstream and downstream of the proposed rock work (so that the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



Dumped rock

Dumped rock

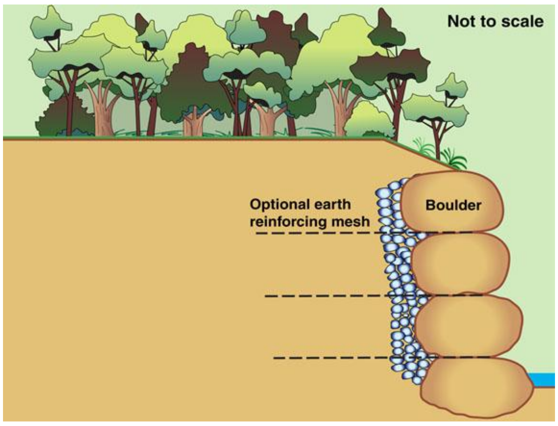
- Typical bank gradients for dumped rock are:
  - 1-in-2 on the outside of channel bends
  - 1-in-3 on the inside of channel bends.
- Wherever practical, bank gradients should blend well with the existing upstream and downstream banks, i.e:
  - avoid sudden changes in bank slope
  - make sure your bank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



Placed rock on outside of a channel bend

Placed rock

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

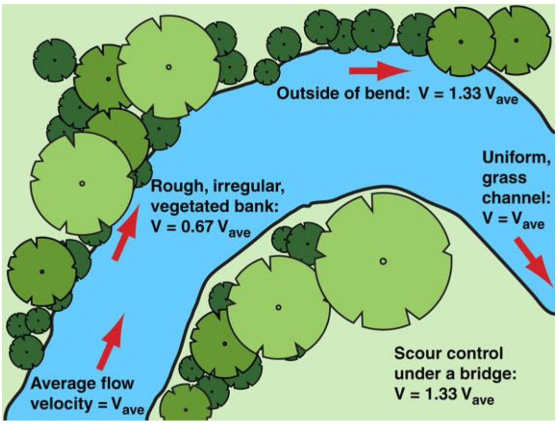


Stacked rock retaining wall

Stacked rock

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

Rock – Hydraulic conditions at channel bends



Velocity multipliers at channel bends

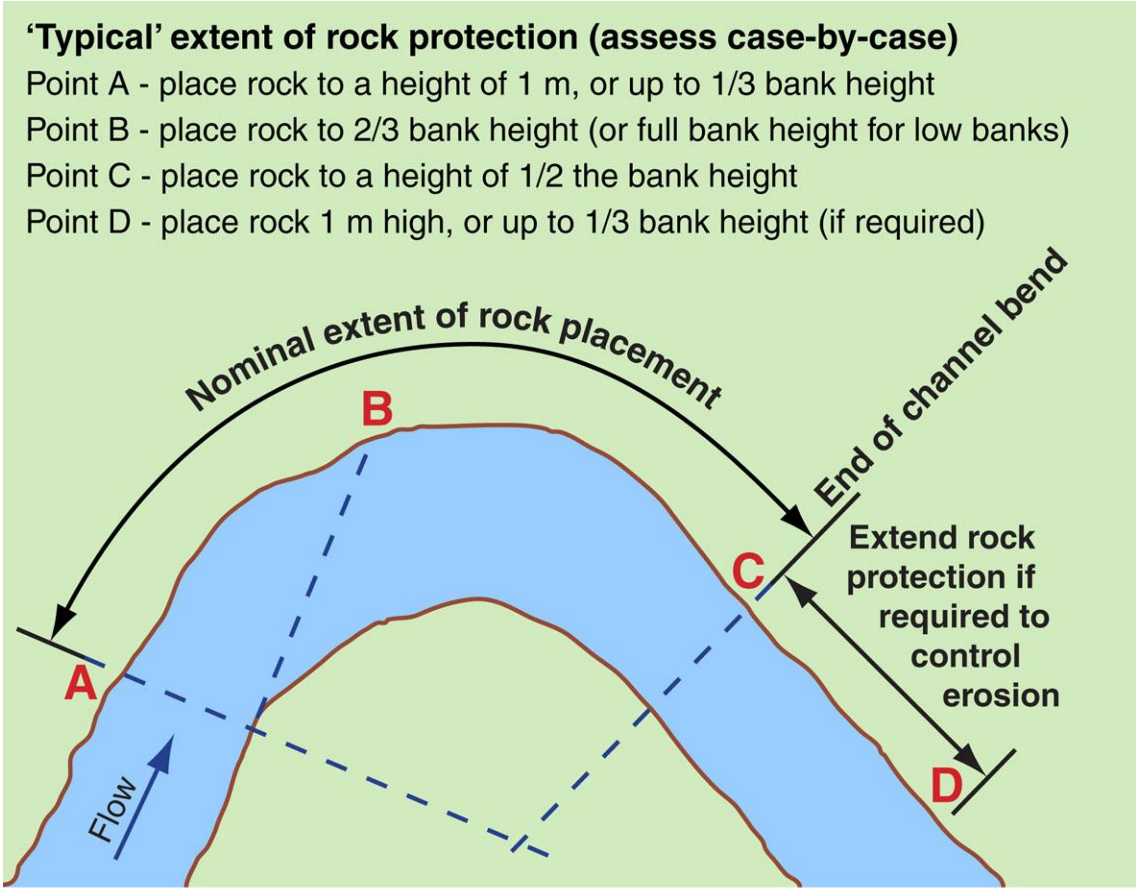
Rock placement on a channel bend (Qld)

The flow velocity using in 'designs'

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

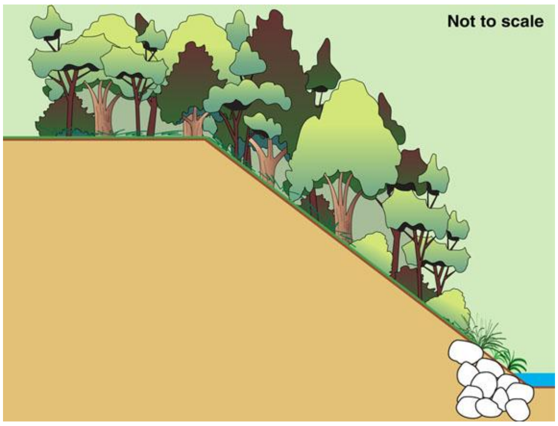
Height of rock placement on banks

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



Height of rock placement around the bend of a major waterway

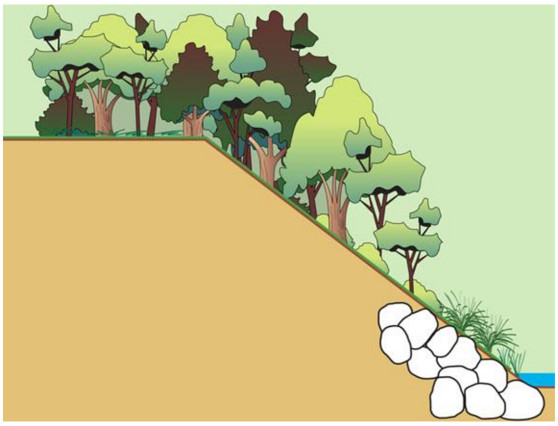
Rock – Height of rock placement



Toe protection

Toe protection

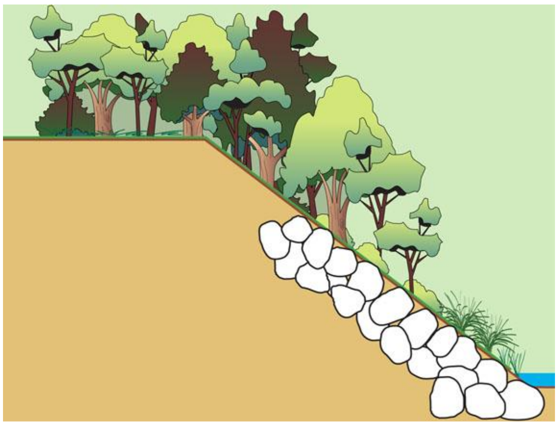
- If flow velocities are low enough to allow a fully vegetated bank, then there may still be the need for additional stabilisation of the toe of the bank in order to protect the bank during plant establishment.
- The height of the toe protection is usually 0.5 to 1.0 m above the bed.
- The rock should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



One-third bank height placement

One-third bank protection

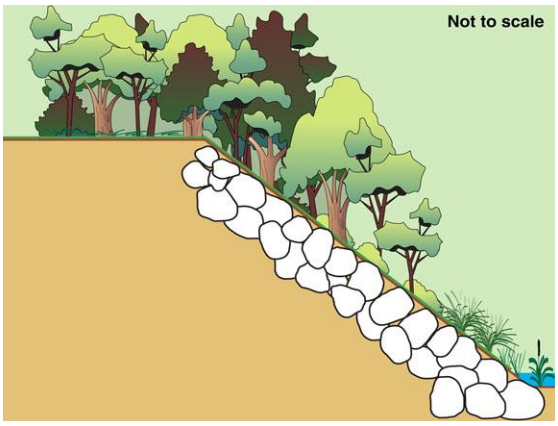
- On the inside of channel bends, the required height of the rock protection is likely to be in the range of 1 m high to one-third of the bank height (depending on the flow velocity).
- If the average channel velocity is less than 2 m/s, then minimal rock protection is likely to be required (unless that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



Two-third bank height placement

Two-thirds bank protection

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



Full bank height placement

Full-height rock placement

- Full bank height protection is likely to be required if:
  - the channel velocity exceeds 4 m/s
  - the bank is on the outside of a tight channel bend
  - the planned revegetation consists only of non-woody species (e.g. grasses) that are likely to encourage high velocities to exist close to the bank.

Sediment (unnatural inflows into waterways)

Deposited sediment (USA)

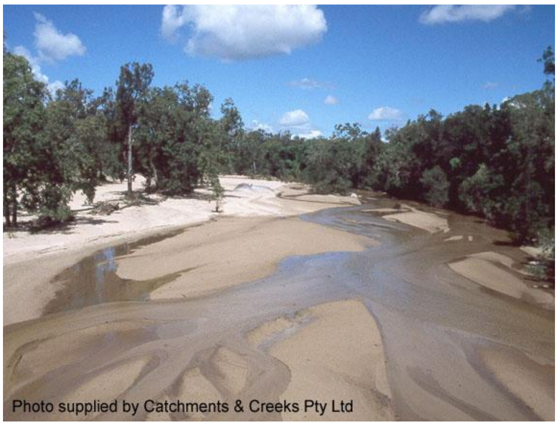
Introduction

- The term 'sediment' is most often used to describe the unnatural material that is incorporated into the stream bed.
- The term 'substrate' is most commonly used to describe the natural sediment and gravels that make-up the bed material.
- Sediment can be introduced to a water via:
  - farming and construction activities
  - unnatural channel or gully erosion.

Sediment in a clay-based waterway

Clay-based waterways

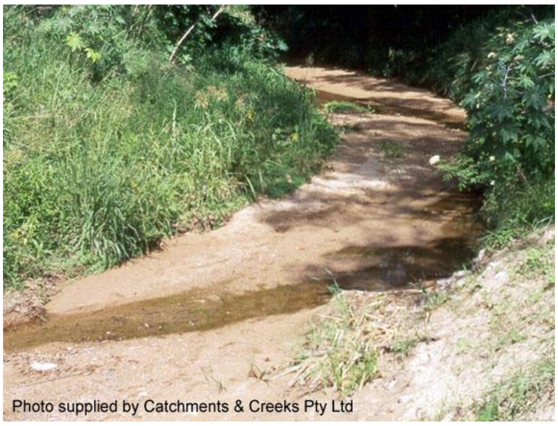
- The release of coarse sediment can:
  - infill permanent pools
  - smother bed vegetation
  - promote weed growth
  - increase maintenance costs.
- The release of turbid water can:
  - adversely affect the health and bio-diversity of aquatic life
  - increase the concentration of nutrients and metals within water bodies
  - reduce light penetration into pools.



Sand-based waterway

Sand-based waterways

- Sand-based waterways have a naturally high concentration of coarse sediment (sand) within the bed substrate.
- In general, sand-based creeks are not significantly impacted upon by the inflow of coarse sediment because the bed is formed from such material.
- However, these creeks often have clear base flows that can be severely impacted upon by the release of turbid runoff (fine sediments) from construction activities.

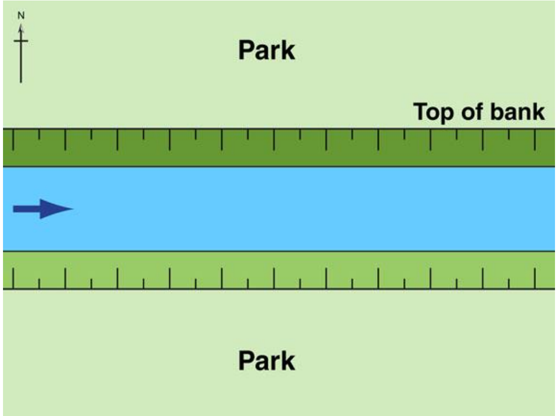


Sediment smothers a gravel-based creek

Gravel-based waterways

- Gravel-based waterways can experience the most severe impacts as a result of sediment inflows.
- In some high-energy streams these sediments can be quickly mobilised.
- The release of sediments can:
  - infill permanent pools
  - smother the natural gravel bed
  - promote weed growth
  - adversely affect the health and bio-diversity of aquatic life.

Sediment – the channel meander problem

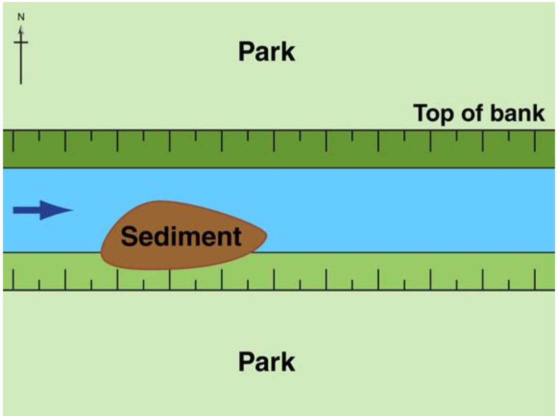


Straight waterway channel

Introduction

- In order to understand the potential impacts of sediment slugs on waterway behaviour, please consider the following scenario.
- Imagine a relatively straight channel, possibly a creek passing through a heavily-modified urban park.

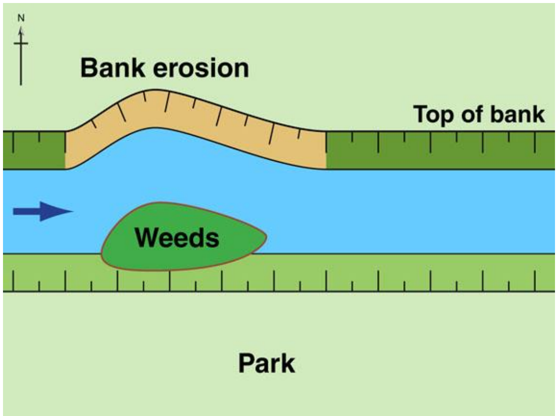
This scenario could well have been an event observed by the author in a city park, in a State north of NSW—but who knows!



Deposition of a sediment slug

Creation of a sediment slug

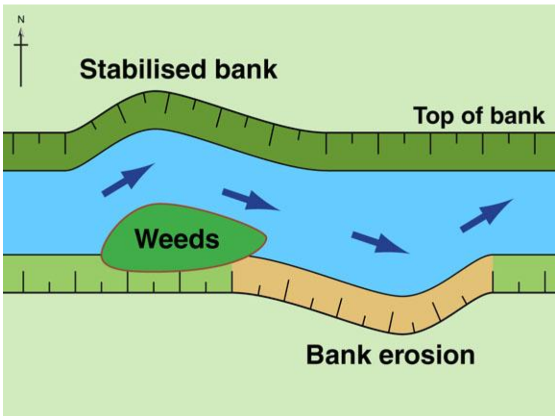
- Now consider the situation where sediment has began to collect on the bed of the creek just downstream of say, a footbridge (i.e. where stream flows expand and slow after passing under the footbridge).
- Add to this situation an extended drought during which time the only in-channel vegetation to remain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



Initial bank erosion

Resulting bank erosion

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



Formation of a channel meander

Channel meander

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

Sediment flow – natural migration of bed substrate

Natural sediment flow post flood (Qld)

Introduction

- It is important for waterway professionals to be able to recognise the difference between 'natural bed migration', and 'unnatural sediment inflows'.
- The visual difference between these two events is difficult to describe.
- During major floods, say > 1-in-50 years, the amount of sediment flow can be overwhelming.

Clay-based waterway (Qld)

Clay-based waterways

- In most cases, a clay-based creek (not a river) will have minimal natural sediment flow, so almost everything you can see is likely to be unnatural.
- However, this only applies to small waterways, such as creeks and streams, in larger clay-based waterways, such as rivers, there can be a significant amount of natural sediment flow that will look identical to the unnatural sediment flow.

Sand-based waterway (NSW)

Sand-based waterways

- In a sand-based waterway, no matter its size, there will always be difficulties in visually spotting the difference between natural and unnatural sediment flows.
- Of course, expensive atomic testing can used to determine the likely source of the sediment.
- However, the presents of 'mud' (clay) is a likely indicator of unnatural sediment.

Gravel-based waterway (Qld)

Gravel-based waterways

- Gravel-based waterways are the sleeping giants of the river world.
- For flood after flood the waterway may display only minor gravel movement; however, there will be that major flood when all hell breaks loose, and the river moves more gravel that the construction industry would use in a year.
- The flood damage can be viewed as being extraordinary, but if fact it can be a totally natural process, which may have occurred many times before.

Shading

Typical shading of a minor waterway

Introduction

- Shading is essential for the control of many weeds and water temperature, particularly for habitat pools.
- The physical covering of parts of the water surface is essential for the protection of both aquatic and terrestrial fauna from external predators.

Shading of the northern bank (Qld)

Shading

- Shading can be provided by riparian vegetation, both canopy cover trees and overhanging understorey vegetation.
- Shading by riparian vegetation reduces the quantity of light and heat reaching the low-flow channel.
- It can also help in the control of weeds and unwanted aquatic vegetation.

Shading of water's edge (Qld)

The effects of the creek's alignment

- Shading is most efficiently produced by canopy trees located along the northern bank of east-west aligned watercourses (in the southern hemisphere).
- On north-south aligned watercourses it is important to have canopy trees on both sides of the channel.

Shading of a storm drain (Qld)

Shading of stormwater drains

- The introduction of canopy cover over constructed storm drains can have both positive and negative outcomes.
- On the positive; a canopy cover can improve the overall aesthetics of the drain, and can even hide storm-mobilised litter.
- On the negative; if the drain requires maintenance, then such works can require the removal of established vegetation, which increases the cost of the maintenance work.

Shading – 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 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)

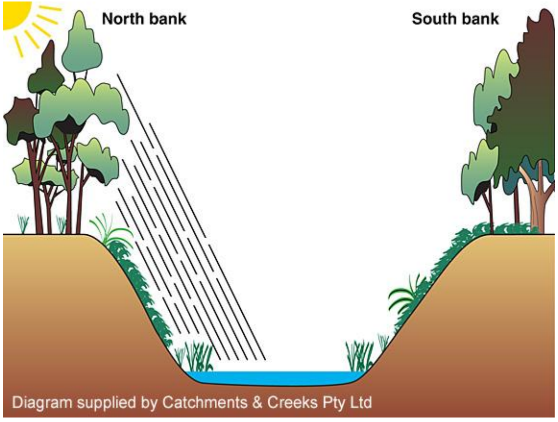
Bank slumping along the north bank (Qld)

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 may be the southern (sun-exposed) bank that has the least vegetation cover, and consequently experiences the more severe bank erosion, but not always!

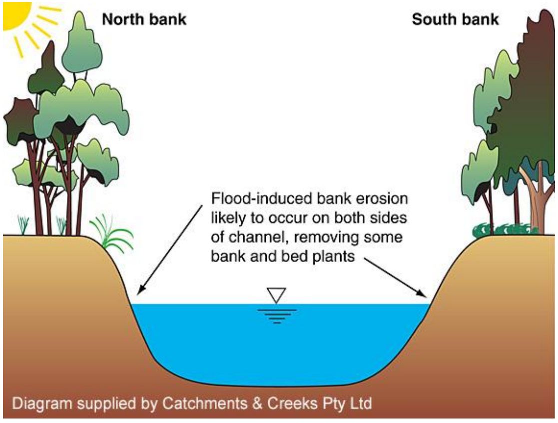
Shading – the north bank problem (southern hemisphere)



Partially shaded northern bank

Stage 1

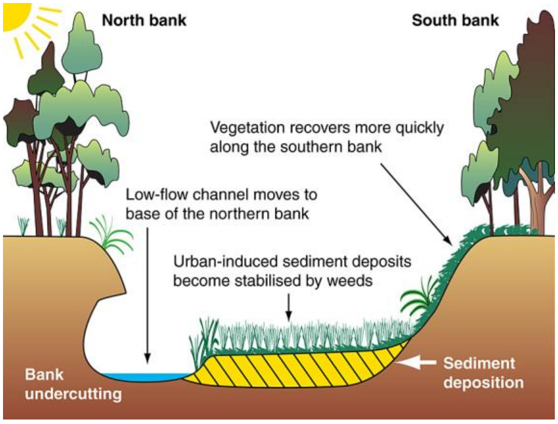
- South of the Tropic of Capricorn, the sun will always appear in the northern part of the sky, shading the northern bank (i.e. the bank that faces south).
- This means that the vegetation that establishes along the northern bank can be different from that observed along the southern bank.
- Channel 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

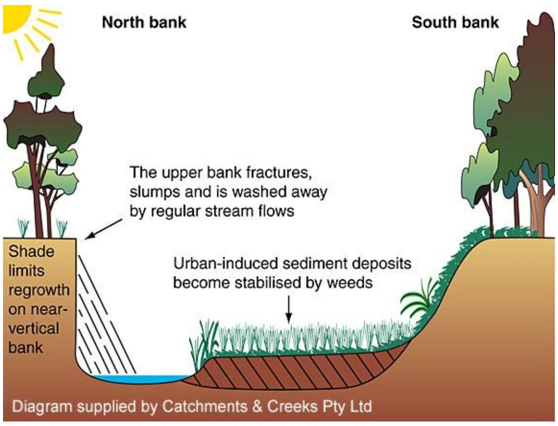
- If the waterway experiences a significant flood, or a series of high-velocity flows, then the resulting channel erosion can cause a temporary enlarging of the channel, and a loss of bank vegetation.
- Erosion could occur along both banks, but the northern bank is likely to experience more intense erosion 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 undermining of this bank.



Bank erodes to a near-vertical face

Stage 4 (may not occur on each site)

- Earth slumped from the northern 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 inside of a channel bend, then the erosion associated with a channel bend will usually dominate over this north-bank problem.

Shelter – aquatic habitats

Shading of water's edge (NSW)

Introduction

- Shelter is different from 'cover' because cover only hides wildlife from predators, while shelter can protect wildlife from terrestrial predators and as well as high-velocity flows.
- In fast flowing waterways, the diversity and density of fauna can be limited by the amount of available shelter.
- A rough, irregular bed can provide many cavities that can act as shelter for aquatic life during times of flood.

Large rocks on the channel bed (Qld)

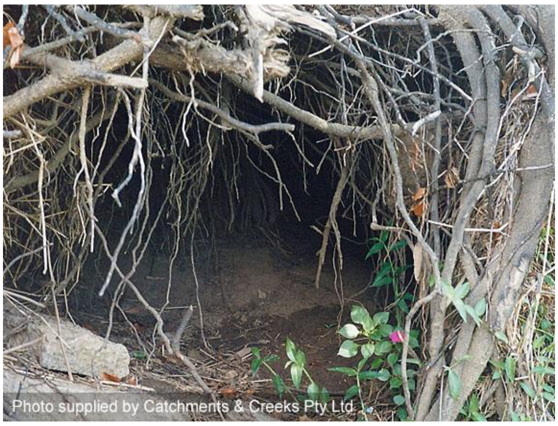
Shelter between rocks

- Shelter may consist of cavities between rocks, areas of quiet water behind and under weed beds, rocks or snags, and backwater areas.
- Where possible, introduced rock should be uniformly graded (i.e. of similar size) to avoid smaller rocks infilling the voids between the larger armour rock (but this is not the case for riffle rock—refer to the discussion on 'riffles').

Large rocks on the submerged bank (Qld)

Open void between submerged rocks

- The current eco-friendly recommendations for the placement of rocks on creek banks specifies that the voids between the rocks should be filled with soil and pocket planted.
- This outcome produces a fully vegetated rock-lined surface.
- **However**, if the rock are located below normal water level, then the voids should remain open because they can provide good shelter and habitat value.



Undercut creek bank (Qld)

Undercut banks and exposed tree roots

- Cover can also be provided by overhanging (undercut) banks and exposed tree roots.

Shelter – types of waterway predators

Kookaburra (Qld)

Potential predators

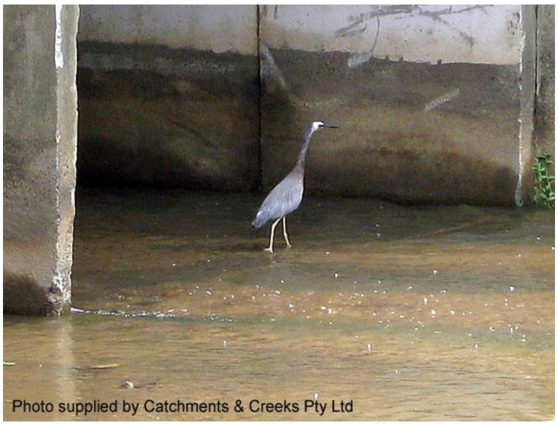
Question: How do you spot a fish barrier?

Answer: Look for a bird that is looking down into the water.

Azure Kingfisher (NSW)

Azure Kingfisher (NSW)

White-faced heron (Qld)

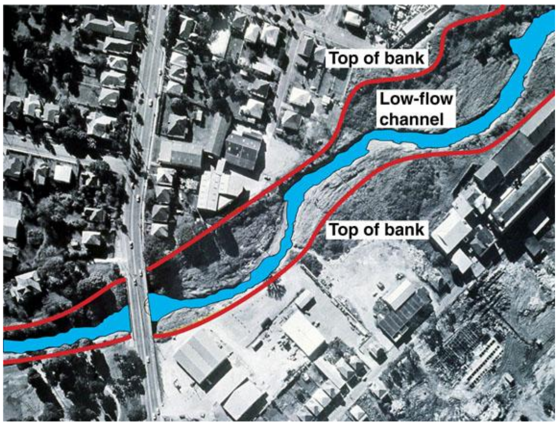


White-faced heron (Qld)

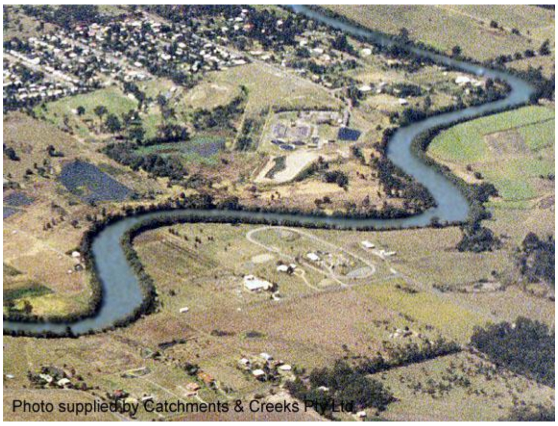
White-faced heron (Qld)

Domestic cat (Qld)

Sinuosity



Meandering low-flow channel (Qld)



Meandering river channel

Meandering low-flow channel

Active channel meander (Qld)

Introduction

- Ideally, the waterway channel should follow the natural drainage path of the valley.
- Any meander pattern should mimic the natural meander of the valley floor.
- However, meander conditions can apply to both the main channel and the low-flow channel, which can meander across the bed of the main channel.
- Meanders are typically not utilised within drainage channels.

Typical geometry of meander patterns

- Meander length is typically 10 to 14 times the width (W) of the meandering channel.
- Maximum bend radius is typically 3W.
- If measured to the outside channel bank, then the maximum radius is likely to be 3.5W.
- Tighter channel bends usually require significant rock stabilisation.

Benefits of a channel meander

- Meandering the channel can improve its aesthetics, increase habitat and channel diversity (through large-scale hydraulic turbulence) and can increase the effective channel length.
- Increasing the channel length is one of the most effective ways of reducing the bankfull flow velocity.
- However, in the author's opinion, the meandering shown in this example (left) is not sustainable (i.e. it will be altered by the flows over time).

Benefits of channel meanders to aquatic habitat

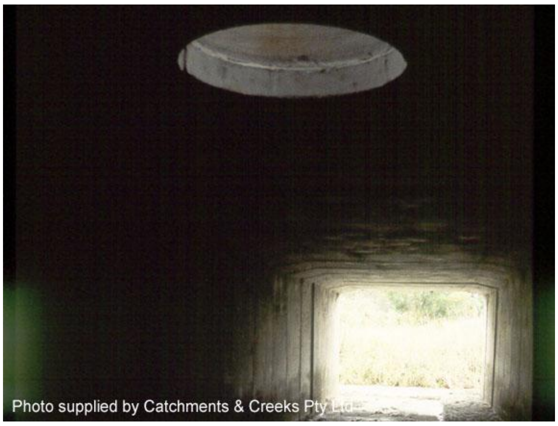
- Active channel erosion and meandering can be destructive to the channel banks and riparian vegetation.
- However, these actions can provide valuable aquatic habitat, shelter and bank roughness (i.e. bank erosion is not always considered to be a problem—each example must be judged on a case-by-case basis).

Skylights (culverts)

The big question: Is it needed?

Skylight installed into the grass verge

Skylights installed in a raised median (Qld)



Light projected from the <u>above</u> skylight

Introduction

Again I need to remind readers that I am a retired civil engineer who specialised in fluid mechanics. I am <u>not</u> a fisheries biologist.

- My knowledge of the 'lighting' requirements of fishways is very limited.
- That said, since I first got involved in fish passage issues some twenty years ago, I have come across very little hard information on 'lighting' issues—just a range of different people's opinions.
- Further research is required.

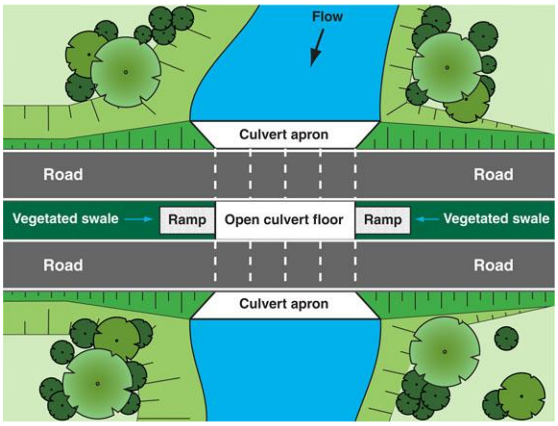
My recommendations

- Given the above, my advice is:
  - if the road has more than two lanes, then consideration should be given to the inclusion of a skylight into at least on of the wet cells
  - if the road has a painted median, then consideration should be given to the possible inclusion of a stormwater inlet within the painted median (noting the importance of a high-grip surface for the inlet screen, i.e. for bike safety)
  - if the roadway includes a raised median, then a skylight should be installed into the median above one or more of the wet cells
  - for divided roads, refer to the discussion and examples presented over the page.

Wet cells

- Skylights are typically only placed in the nominated 'wet' cells; however, given that a multi-cell culvert may have several wet cells, it is the author's recommendation that skylights should appear in the most fish-friendly cell only.
- Fish that seek a brighter pathway can seek out this one brighter cell.

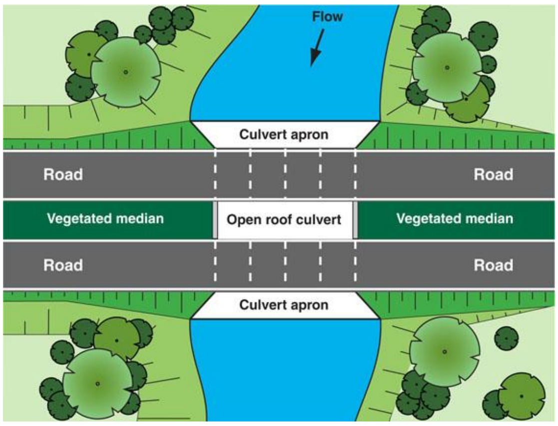
Skylights – dual carriageway roads



Trapezoidal channel formed in median

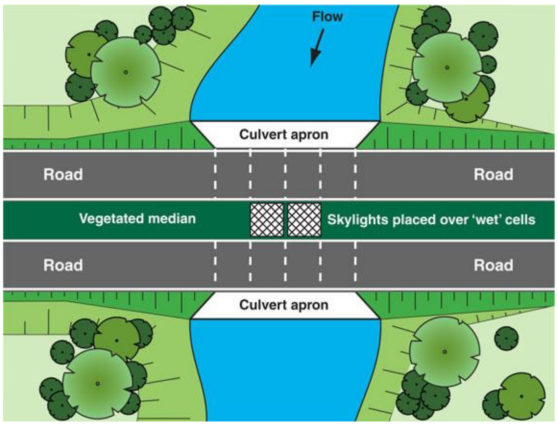
Dual carriageway roads

- In general, the wider the road, the longer the culvert; however, dual carriageways provide us with the opportunity to introduce 'resting' areas for fish.
- These resting areas can also help to improve lighting conditions within the culvert.
- The difficulty for designers is to achieve these outcomes without introducing excessive energy loss within the culvert, which would reduce the culverts flow capacity.



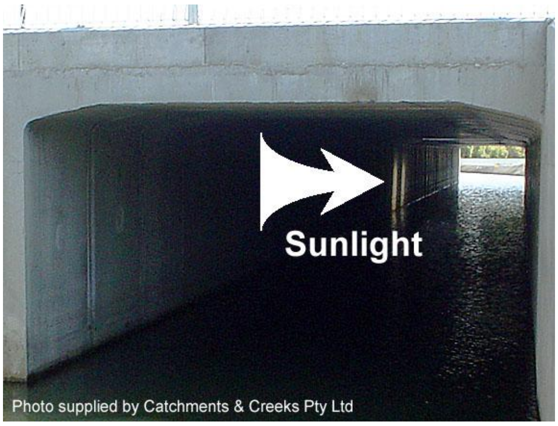
Open roof section within a long culvert

Open roof section within a long culvert



Skylights placed within the median

Skylights placed within the median (Qld)



Light entering the culvert (Qld)

Skylights placed within the median (Qld)

Snags (aquatic and terrestrial fauna issue)

Eastern Water Dragon basking on a log

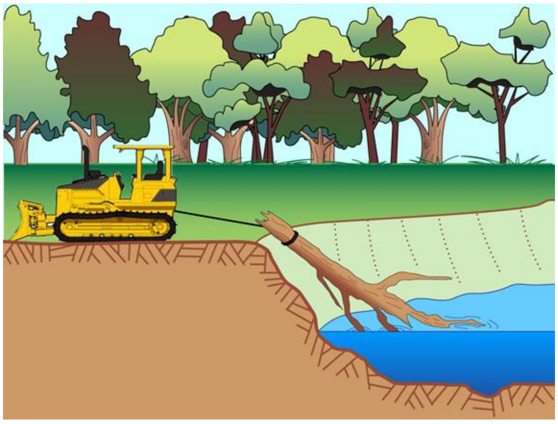
Introduction

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

Severe snag blockage (Qld)

Potential problems resulting from snags and fallen trees

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



Snag removal

Snag management

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

Log jam (Qld)

Increasing instream timber content

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

Water quality

Clear water base flow (Qld)

Introduction

- Some waterways in their natural condition (such as rainforest streams), can experience clear water conditions during a wide range of flows.
- However, the majority of Australian waterways, in their natural state, experience turbid flow conditions during flood events.

Turbid storm runoff (Qld)

Storm conditions

- In their natural state, most waterways would be clear during trickle flows (except inland rivers), and also clear during most storms, but not during flood events.
- However, urbanised waterways are often clear during trickle flow, but they turn turbid (brown) during storm events.
- These short-term turbid flow conditions are bad for aquatic life, but not necessarily fatal (always check with local expert advice).

Stormwater treatment wetland (Qld)

Post storm conditions

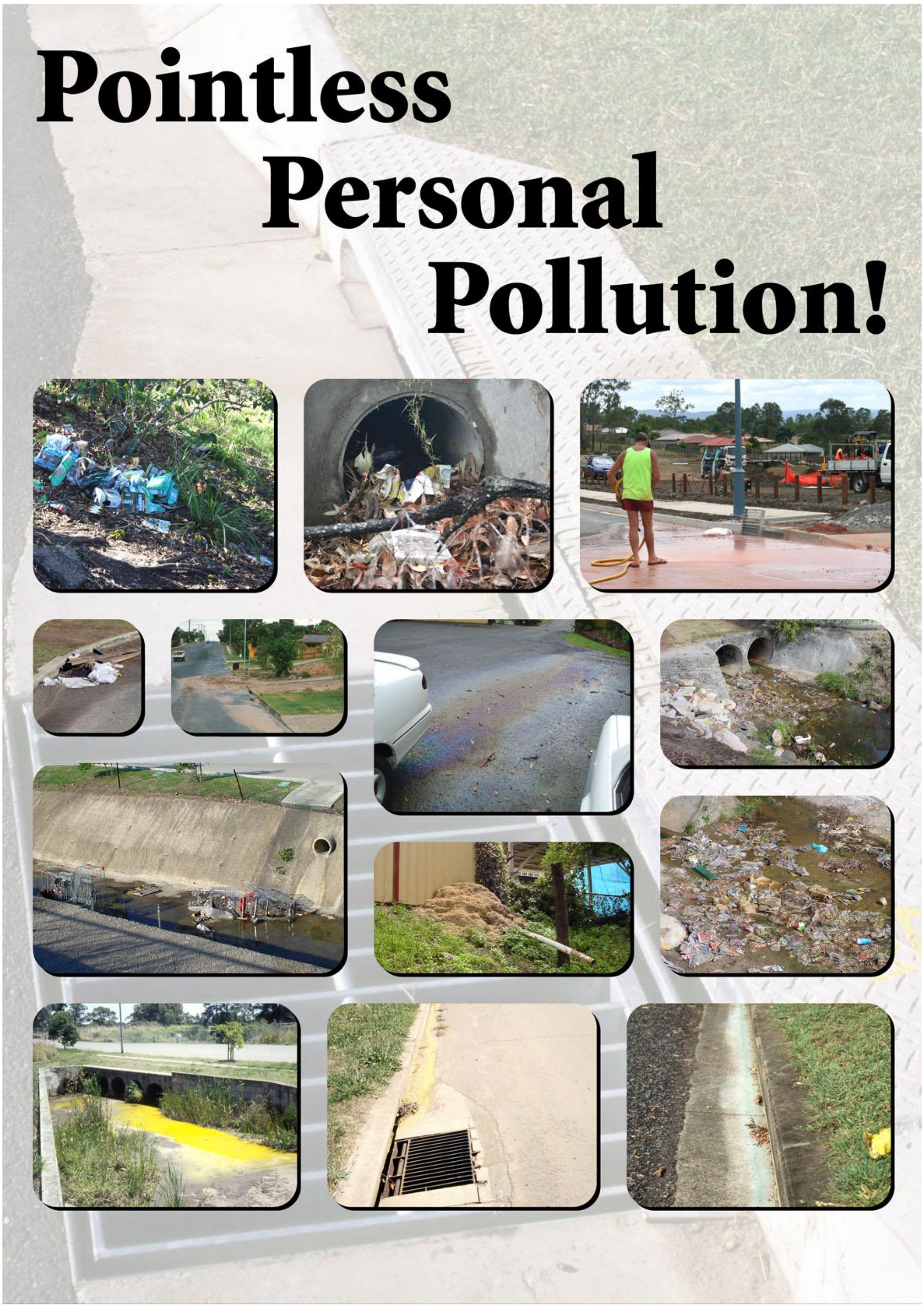
- In their natural state, most waterways would return to a clear water condition shortly after the flood event had ended.
- However, urban waterways can experience turbid flow conditions for weeks after each flood event.
- What modern stormwater treatment systems are designed to achieve is a more rapid return to clear-water conditions following storm and flood events—thus the focus is on the water quality released after a storm, not during a storm.

Shaded waterway (Qld)

Water temperature

- Water temperature can be a critical component in maintaining good aquatic health.
- Shading should be provided, especially along the water's edge, and around habitat pools.
- In the southern hemisphere, trees planted on the northern bank can provide the best shade.

One of the free-download posters from the *Catchments and Creeks* website (available in various sizes)



Weirs

Small town water supply weir (Qld)

Introduction

- Weirs are a form of grade control structure; however, unlike most grade control structures, a weir has a crest that is elevated above the channel bed, which results in the retention of water upstream of the weir.
- Weirs can be used as a source of drinking water for small communities.

Fish collecting downstream of a weir

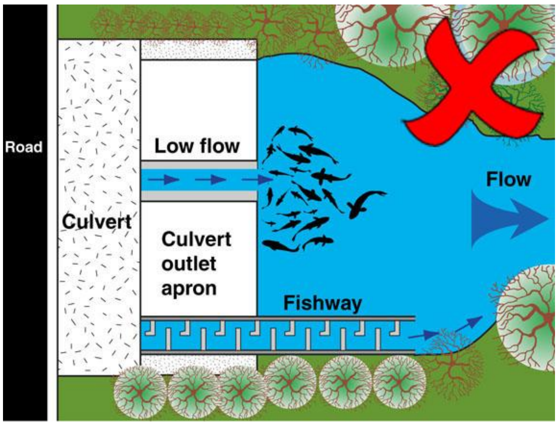
Impact on fish passage

- An energy dissipation basin (plunge pool) is normally created downstream of a weir, and this pool can provide significant aquatic habitat.
- However, the weir often represents a major barrier to fish passage, unless supported by a bypass fishway.
- A lot of technical advancements have been made on the design of these fishways over the past few decades.

Whitewater canoeing (UK)

Use of weirs for whitewater activities

- There is a growing demand for weirs to be modified so as to introduce whitewater sporting and recreational activities to the local area.
- Consequently, modern weirs often need to accommodate a wide range of functions.



Poor fishway design (culvert example)

Attracting flows

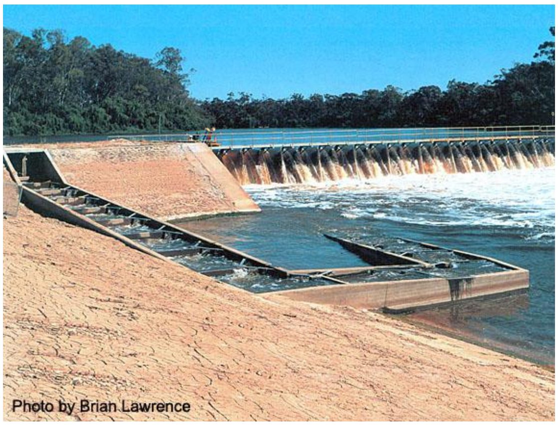
- Just like in the design of a culvert fishway, the entrance to a weir fishway must be close to the low-flow spill point of the weir.
- During periods of low flow, the fishway should either be the primary carrier of the base flow, or suitably integrated into the low-flow system such that fish will be attracted to the fishway.
- Fish should not be encouraged to swim past the entrance of the fishway as they swim towards the weir.

Weirs – example fishway designs

1. Penrith weir fishway (NSW)

Fishways

- This page contains several examples of fishways installed at weirs.
- These examples do not necessarily represent current best practice.



2. Fishway bypass fishway (SA)

3. Torrens River (SA)

4. Rock ramp located within a rock weir (Tamworth, NSW)

5. Torrens River outlet weir fishway (SA)

Weirs – case study

Reverse image of the Penrith weir fishway

Introduction

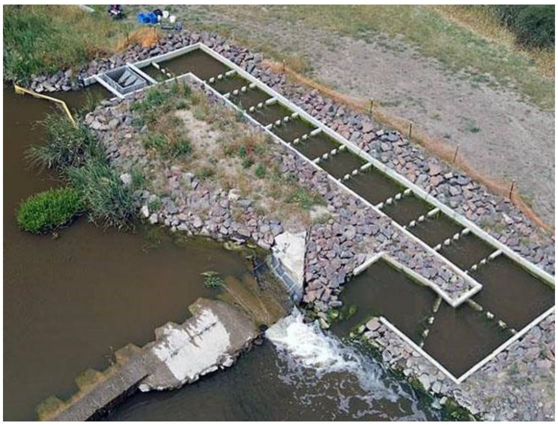
- In this example (which is totally fictitious and has nothing to do with a weir in the western suburbs of Sydney), the inlet of the fishway is correctly located adjacent to the low-flow spill point of the weir.
- This fishway design would be considered very effective if the sole aim was to aid fish passage during normal dry weather flows.

Current weir in flood

Use as a grade control structure

- **However**, a potential problem with this fishway design is its performance during higher weir flows.
- As the weir flow increases, the highly turbulent flow conditions at the base of the weir will make it impossible for fish to reach the inlet of the fishway.

Note: The 'inlet' of the fishway is defined as the location where fish enter the fishway, not where flows enter the fishway.



Alternative fishway design

Potential impact of fish passage

- One solution to this problem is to design the fishway so that the initial reach is in a downstream direction, as shown here (left) and in the South Australian example on the previous page (Image 2).
- An alternative solution is to have two inlets, with the second inlet located downstream of the energy dissipation zone.

Alternative fishway in flood

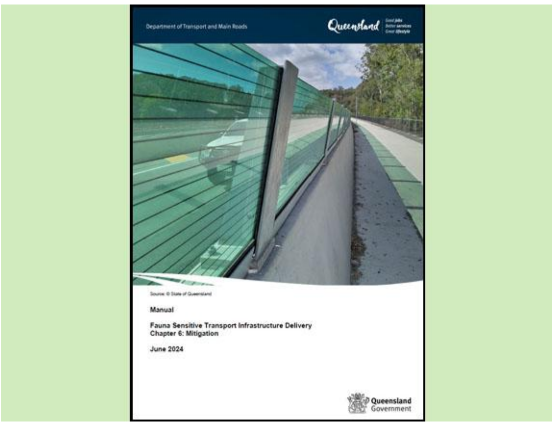
Impact of natural sediment migration

- It will be necessary for the rising tailwater to begin to flood the inlet section of the fishway to allow fish to enter the fishway at various locations.
- It is assumed that the river bank in this location is heavily armoured in order to prevent bank erosion.

Note: None of this would be a problem if during high flows, fish passage was able to occur within the adjacent floodplain, and not in the fishway (which is the likely case!).

14. Terrestrial Habitats

Introduction



Queensland Transport, 2024

Reference document:

'Fauna Sensitive Transport Infrastructure Delivery – Chapter 6: Mitigation', The State of Queensland (Department of Transport and Main Roads) 2024.

This DoT reference document, and the rest of the documents in this series, contain a LOT MORE information than the summary information provided in this chapter.

Skink

Waterway features

The issues discussed in this chapter include:

- Corridor connectivity and continuity
- Culverts
  - integration of aquatic and terrestrial passage features
  - lizard runs
  - fauna exclusion fencing
  - fauna passage furniture
- Fauna crossings
- Fauna monitoring
- Shelter from predators
- Snag management
- Waterway crossings – traffic calming systems

Dragon

Monitor

Snake

Terrestrial fauna (Brisbane region)

Damselflies: Aurora Bluetail, Common Bluetail, Redtail, Red and Blue Damsel, Orange Threadtail, Wandering Ringtail, Common Flatwing, Sapphire Rockmaster.

Dragonflies: Australian Duskhawker, Blue-spotted Hawker, Australian Emperor, Twin-spot Hunter, Stout Vicetail, Australian Tiger, Coastal Petaltail, Australian Emerald, Yellow-tipped Tigertail, Wandering Percher, Scarlet Percher, Blue Skimmer, Slender Skimmer, Fiery Skimmer, Graphic Flutterer, Common Glider.

Praying Mantids: Stick Mantid, Purple-winged Mantid, Garden Mantid, Burying Mantid.

Earwigs: Colossus Earwig, Elaunon Bipartitus.

Phasmids (Stick Insects): Spiny Leaf Insect, Titan Stick Insect, Goliath Stick Insect.

Grasshoppers: Hedge Grasshopper, Longheaded Grasshopper, Dead Leaf Grasshopper, Vegetable Grasshopper.

Katydids: Spotted Katydid, Mountain Katydid.

Crickets: Giant King Cricket, Common Mole Cricket, Field Cricket.

Lacewings: Green Lacewings, Mantid Lacewing, Nymphes Myrmelonides, Antlion Lacewing, Glenoleon Pulchellus.

Frogs: Green Treefrog, Southern Orange-eyed Treefrog, Graceful Treefrog, Cascade Treefrog, Emerald-spotted Treefrog, Laughing Treefrog, Whistling Treefrog, Whirring Treefrog, Bleating Treefrog, Naked Treefrog, Eastern Sedgefrog, Cooloola Sedgefrog, Wallum Sedgefrog, Green-thighed Frog, Stony-creek Frog, Striped Rocketfrog, Broad-palmed Rocketfrog, Wallum Rocketfrog, Green-stripped Frog, Superb Collared-frog, Striped Marshfrog, Salmon-striped Frog, Spotted Marshfrog, Ornate Burrowing-frog, Scarlet-sided Pobblebonk, Tusked Frog, Great Barred-frog, Giant Barred-frog, Fleay's Barred-frog, Black-soled Frog, Copper-backed Broodfrog, Red-backed Broodfrog, Great Brown Broodfrog, Sandy Gungan, Eastern Gungan, Wrinkled Gungan, Beeping Froglet, Clicking Froglet, Wallum Froglet.

Freshwater turtles: Broad-shelled River Turtle, Eastern Long-necked Turtle, Snapping Turtle, Short-necked Turtle, Saw-shelled Turtle.

Lizards: Stone Gecko, Dtella, Zigzag Velvet Gecko, Robust Velvet Gecko, Spotted Velvet Gecko, Thick-tailed Gecko, Common Delma, Excitable Delma, Collared Delma, Burton's Snake Lizard, Common Scaly-foot, Nobbi Dragon, Frillneck Lizard, Tommy Round-head, Southern Angle-headed Dragon, Eastern Water Dragon, Common Bearded Dragon, Gould's Goanna, Yellow-spotted Monitor, Lace Monitor, Verreaux's Skink, Calyptotis Scutirostrum, Carlia Foliorum, Carlia Munda, Carlia Pectoralis, Carlia Schmeltzii, Lively Skink, Coeranoscincus Reticulatus, Wall Skink, Ctenotus Arcanus, Ctenotus Eurydice, Eastern Striped Skink, Copper-tailed Skink, Pink-tongued Skink, Major Skink, Land Mullet, Egernia Modesta, Tree Skink, Narrow-banded Sand-swimmer, Elf Skink, Martin's Skink, Murray's Skink, Eastern Water Skink, Bar-sided Skink, Secretive Skink, Couper's Skink, Garden Skink, Grass Skink, Boulenger's Skink, Fire-tailed Skink, Ophioscincus Ophioscincus, Ophioscincus Truncatus, Three-toed Skink, Saproscincus Challengeri, Saproscincus Oriarus, Saproscincus Rosei, Gully Skink, Blue-tongued Skink.

Land Snakes: Death Adder, Small-eyed Snake, Tiger Snake, Coastal Taipan, Spotted Black Snake, Red-bellied Black Snake, Eastern Brown Snake, Rough-scaled Snake, Golden-crowned Snake, Yellow-faced Whip Snake, Black Whip Snake, Marsh Snake, Pale-headed Snake, Stephen's Banded Snake, Bandy Bandy, Australian Coral Snake, White Crowned Snake, Dwarf Crowned Snake, Carpentaria Snake, Red-naped Snake, Grey Snake, Dwyer's Snake, Brown Tree Snake, Common Tree Snake, Keelback, Spotted Python, Carpet Python.

Mammals: Platypus, Echidna, Spotted-tailed Quoll, Brush-tailed Phascogale, Yellow-footed Antechinus, Subtropical Antechinus, Common Dunnart, Common Planigale, Northern Brown Bandicoot, Long-nosed Bandicoot, Koala, Feathertail Glider, Yellow-bellied Glider, Sugar Glider, Squirrel Glider, Greater Glider, Common Ringtail Possum, Short-eared Brushtail Possum, Common Brushtail Possum, Rufous Bettong, Long-nosed Potoroo, Agile Wallaby, Black-stripped Wallaby, Red-necked Wallaby, Whiptail Wallaby, Grey Kangaroo, Brush-tailed Rock-wallaby, Swamp Wallaby, Red-legged Pademelon, Red-necked Pademelon.

Sourced from the *Queensland Museum Wild Guide*, 2009, and presented only to demonstrate the potential diversity of terrestrial fauna within riparian zones.

Corridor connectivity and continuity (terrestrial movement corridors)

Dragon

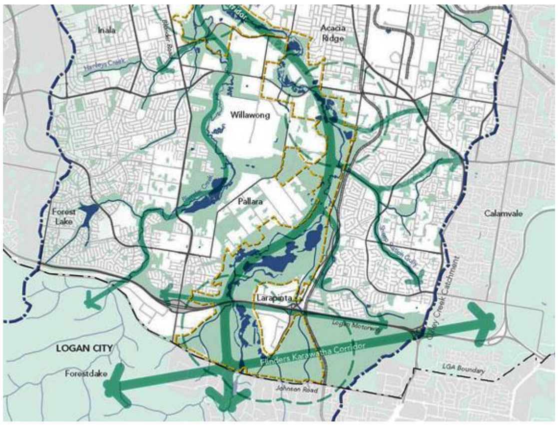
Introduction

- Unlike some birds and some fish, the terrestrial fauna that is most commonly associated with waterways do not migrate as part of their lifecycle.
- Consequently, terrestrial fauna can spend the majority of their life living within their chosen territory, only venturing beyond these areas to find a mate.
- If bushland and riparian areas remain isolated for extended periods of time, then inter-breading of reptiles can lead to a decline in biodiversity.

Isolated bushland

Isolated bushland

- Areas of isolated bushland can experience a long-term decline in wildlife biodiversity.
- Ideally, at least one of the overland flow paths that exits from bushland should be retained in a vegetated (bushland) condition in order to link the bushland to an adjacent waterway.
- If roadways act as the primary overland flow paths leaving bushland, then residential backyards can become the only terrestrial corridor links to the bushland (thus a town planning issue).



Wildlife corridor map

Connecting bushland to waterways

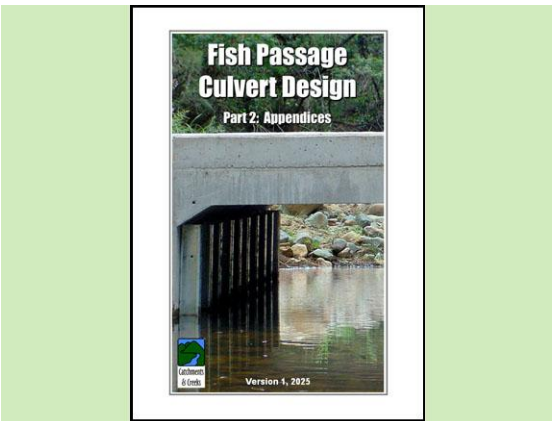
- Poor open space planning can result in the formation of isolated areas of parkland and bushland that are evenly spread across the suburbs.
- Some planners favour the idea of retaining hilltops as bushland reserves because it can give the city a 'green' appearance when viewed from a distance.
- It is VERY important that these bushland reserves are connected to the bushland corridors associated with waterways.

Mountains to Mangroves initiative

'Mountains to Mangroves'

- Campaigns, such as Mountains to Mangroves, can help to:
  - spread public awareness about the need to connect bushland
  - maintain our current biodiversity
  - return wildlife to areas of bushland devastated by fire
  - retain future pedestrian pathways and bikeways.
- The author fully endorses these *Mountains to Mangroves* campaigns.

Culverts



Fish Passage Culvert Design – Part 2

Reference document:

'Fish Passage Culvert Design – Part 2'

Catchments & Creeks, Version 2, 2026, Bargara Queensland.

A three-part PDF document:

- Part 1: Design Steps
- Part 2: Appendices A to F
- Part 3: Appendices G to M

Elevated (dry) terrestrial pathway (Qld)

Consideration of terrestrial passage

- The policies and focus of a Fisheries office, or any fish passage guideline, cannot be limited to just the consideration of aquatic life.
- All agencies, and all designers, have a duty of care to consider the wider impact of their policies and designs on the greater environment, which includes terrestrial wildlife, including terrestrial passage.
- Potential conflicts must be addressed, if not fully prevented.

Lizard run and 'dry' terrestrial pathway

'Wet' and 'dry' movement paths

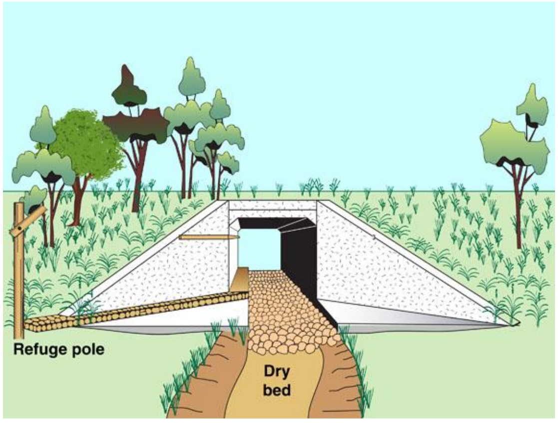
- Fish passage, at least in Australia, typically requires a water depth that exceeds the body-depth of the fish.
- However, the movement of most native terrestrial species requires a 'dry' pathway (of course, exceptions do exist).
- Unfortunately, both fish passage and terrestrial passage can be required within the culvert cells that are located adjacent to the waterway banks—meaning that both a wet and dry path must be provided.

Alternative lizard run (NSW)

Fauna tunnels

- Fauna passage culverts are often located away from waterways in order to provide dry terrestrial passage (fauna tunnels) under major roadways, especially where road-kills are be a major concern.
- However, it should be noted that if these fauna tunnels are located within the floodplain of a waterway, then fish may also need to pass through these tunnels during flood events, especially if the fish movement is associated with migration.

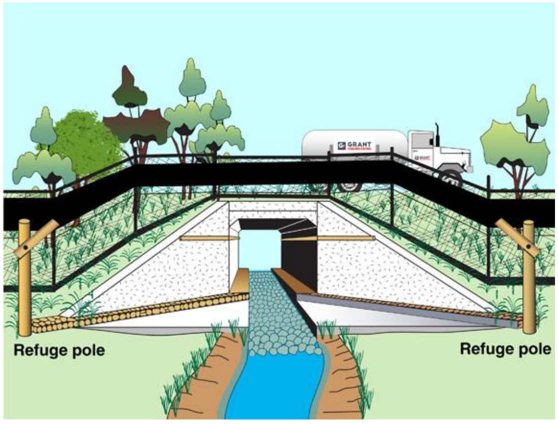
Culverts



Single cell culvert on an ephemeral creek

One side of the waterway channel

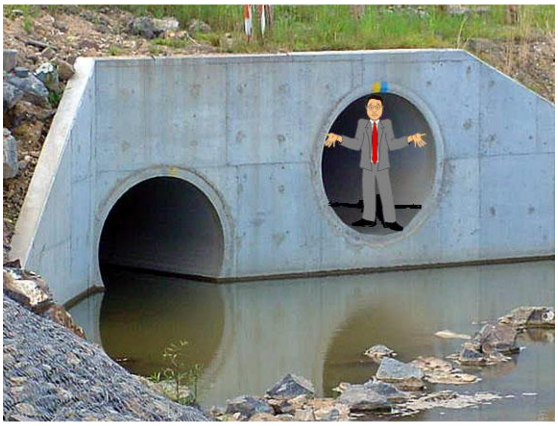
- Terrestrial pathways are generally only required on one side of a culvert if the culvert spans across:
  - an ephemeral waterway (i.e. a channel that is usually dry, in parts, during normal dry weather), or
  - a permanent waterway that has sufficient 'land bridges' (i.e. fallen trees) that allow reptiles to cross from bank to bank).



Single cell culvert on a wet creek

Both sides of the waterway channel

- Terrestrial pathways are typically required along both sides of a culvert if the culvert spans across:
  - a permanent waterway (i.e. a waterway that is usually flowing during normal dry weather conditions), and
  - the waterway does not have sufficient 'land bridges' (i.e. fallen trees) to allow reptiles to cross from bank to bank).



A 'dry' cell not connected to dry land

Continuity of the 'dry' paths

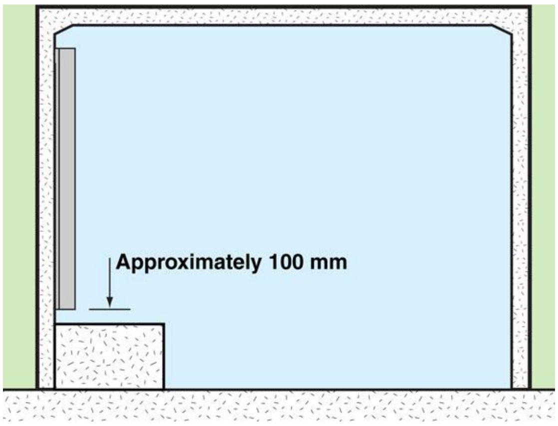
- It is essential for terrestrial pathways to have a continuous 'dry' pathway from bank to bank (through the culvert).
- This means that the dry pathway must extend from dry land to dry land.

Street light with shield (Qld)

Reducing artificial light at night

- Nearby street lighting should have shields attached to minimise light spilling into sensitive areas.
- If necessary, the culvert's headwalls and wingwalls can be painted (typically a dark green) to reduce the impact of reflected light.

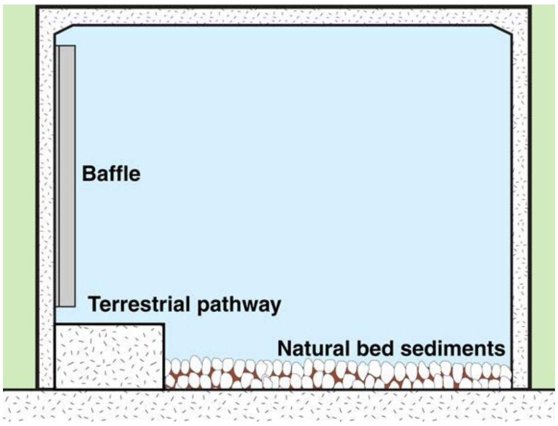
Culverts – integration of aquatic and terrestrial passage features



Single sidewall baffle

Basic design

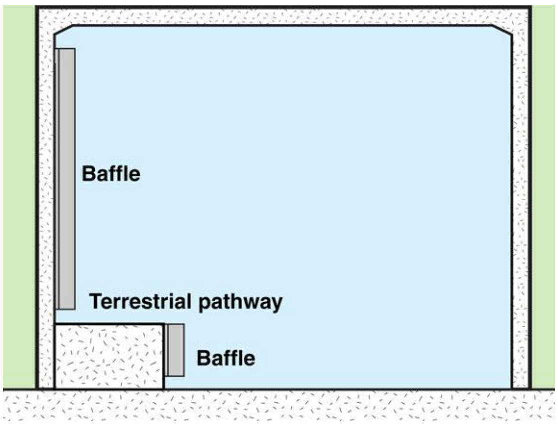
- Terrestrial pathways can be integrated into fish-friendly culverts.
- A dry terrestrial pathway set above the dry weather flow.
- Minimum clear path width of 300 mm.
- Desirable clear path width of 500 mm in culvert cells at least 1800 mm wide.



Natural bed sediment

Inclusion of natural or introduced bed roughness

- The elevation of the dry pathway must take into account the hydraulic effects of added bed roughness, including expected sedimentation.



Baffles attached to the terrestrial pathway

Baffles placed on the side of the dry pathway

- If fish passage is expected during periods of zero or low flow, and bed roughness is not included, then consideration should be given to the placement of baffles on the side of the dry fauna pathway.

Baffles attached to the terrestrial pathway

Example

- This images shows an example (good or bad?) of baffles attached to the side of the dry fauna pathway.

Culverts – lizard runs

Access ramps (Qld)

Introduction

- Lizard runs and elevated pathways aim to provide a dry passageway for the smaller terrestrial fauna that would normally be preyed upon by larger animals.
- The use of flat planks is generally preferred to that of round poles.
- Access ramps to logs should be no steeper than 1-in-5.

Central elevated pathway (Qld)

Central pathways

- If the target species is koalas, then spacing from the floor, roof and sidewalls becomes important.
- Potential effects of debris blockage must be considered.
- Desirable:
  - minimum 3 m x 3 m cell dimensions
  - 1.5 m above the floor
  - 0.75 m clearance from the ceiling (1 m recommended by VicRoads, 2012)
  - position along centre of the cell.

Evidence of human activity in the culvert

Human use of terrestrial pathways

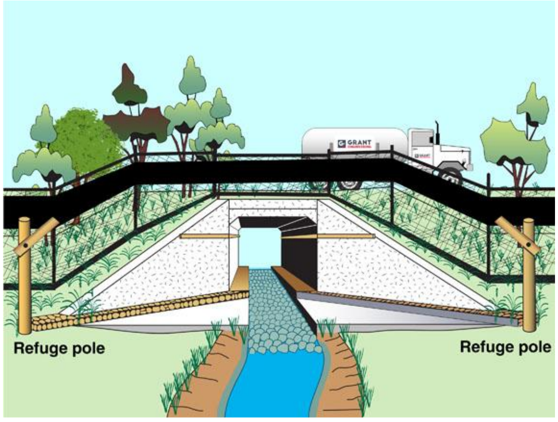
- Children should be discouraged (somehow) from using terrestrial pathways to cross under roads, or as 'hideaways'.

Lack of connectivity

Connection to the creek bank

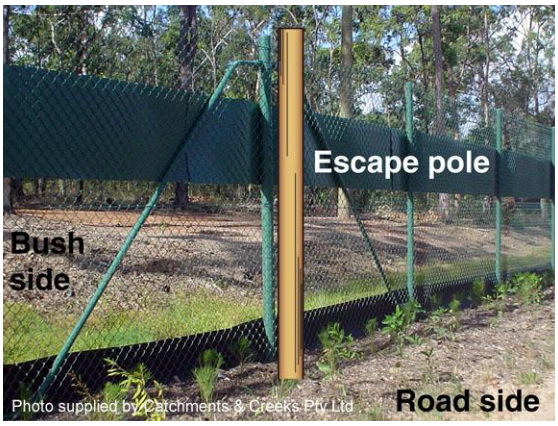
- It is essential for terrestrial pathways to have a continuous dry pathway from bank to bank (through the culvert).
- Lizard runs must extend along the wingwalls to the creek bank.

Culverts – fauna exclusion fencing



Fauna culvert with exclusion fencing

Exclusion fencing (Qld)



Exclusion fence with escape pole (Qld)

Qld. Dept. of Transport and Main Roads

Introduction

- Queensland Department of Transport and Main Roads reports that studies have shown that roadside fencing can reduce rates of mortality on roads by an average of approximately 50%, and up to almost 100% in some cases.
- However, fauna exclusion fencing without appropriate crossing structures should only be considered under specific circumstances (refer to your local authority).

Design features of exclusion fencing

- Designed to prevent fauna from accessing the road, as well as funnelling fauna to the culvert.
- Always consider the potential impact of overtopping flows and flood levels.
- Dark coloured mesh is less visually obtrusive than galvanised mesh.
- Barbed-wire should never be used near fauna crossing structures.
- The base of fencing should be buried to prevent fauna digging underneath.
- Fauna fencing should typically include a ‘return’ – an angled section of fence (the last 10 to 20 m of fencing) to encourage fauna to turn back towards their habitat, rather than move around the fence and onto the transport corridor.
- For preliminary planning purposes, assume 500 m of fencing at each crossing structure and continuous fencing where it passes through large areas of habitat.
- Vegetation must be managed to prevent fauna from climbing over the fence.
- Ensure appropriate escape mechanisms.

Integration of fauna exclusion features into noise control fencing

- New fence designs are being developed that integrate fauna exclusion features into traditional noise control fencing.
- The aim of this fencing is to prevent arboreal mammals, including koalas, from entering the road reserve, while also providing noise control benefits.

Culverts – fauna passage furniture

Elevated pathway (Qld)

Introduction

- Fauna furniture can include constructed shelters and the rehabilitation of natural waterway features.
- This furniture can be installed on the culvert floor, its sidewalls, or built into the low-flow channel.
- Most of these features will be placed within the nominated dry cells, but of course, single cell culverts are required to cater for both wet and dry features.

Non-use of flowering plants

Landscaping within the road reserve

- Plants in and around a road culvert can create habitat for native fauna, assist fauna movement, and reduce soil erosion.
- Plants placed outside the road reserve can consist of those that attract native fauna, for shelter or feeding.
- However, plants placed inside the road reserve should not attract fauna (native or non-native).
- Placing flowering plants in a road reserve will increase the risk of road kills.

Roosting (NT)

Artificial shelters and roosts

- Waterway culverts are often used by lizards as habitat—the concrete headwall and wingwalls can act as roosting areas to gather the morning sun.
- Non-biodegradable shelters, including sections of pipe, can be used to mimic a log pile, with numerous options for small fauna to enter and exit.
- Where appropriate, the low-flow channel should include randomly placed boulders, some partially submerged, to act as roosting areas.

Elevated logs (lizard runs, Qld)

Elevated logs

- Elevated horizontal logs or log rails should be approximately 300 mm in diameter (width), set 1.5 m above the ground, and with a minimum 500 mm clearance from the ceiling.
- Access ramps should be no steeper than 1-in-5.
- Flat planks are preferred to round logs.

Fauna crossings

A treacherous road crossing (Qld)

Introduction

- A common feature of many native fauna is their desire to avoid 'wet' crossings.
- Fauna may need assistance crossings:
  - creeks
  - open-grass floodways
  - roadways.

Lizard on a log bridge (Qld)

Fallen log crossings of waterways

- Terrestrial fauna can use logs to bask in the sun, and to cross streams.

Lizard on a culvert wingwall (Qld)

Use of footbridge and culvert crossings

- In order to improve the benefits to terrestrial fauna, road culverts can incorporate a slightly recessed headwall, or 'lizard run', that would allow reptiles to pass along the headwall with minimal exposure to pedestrians and predators.
- Ultimately these features become apart of the culvert 'furniture', which should be specified before the culvert progresses to the detailed design phase.

Rope bridge (Qld)

Rope bridge aerial crossings

- Rope bridges can be used by fauna to pass over roads as well as over streams (i.e. riparian zone to riparian zone).
- A rope crossing of a stream becomes important when the stream has a permanent, or near-permanent flow.

Fauna monitoring

Observation of actual fauna (NSW)

Introduction

- After spending significant amounts of money accommodation the fauna requirement of a waterway corridor, or a waterway crossing, some government agencies choose to investigate the actual usage of these channel features to confirm that:
  - their designs are working appropriately
  - their designs are being used by the intended species
  - consideration of future design improvements.

Footprints in a culvert (SA)

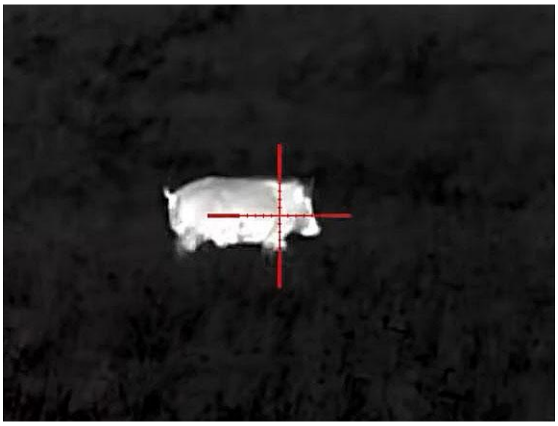
Sand trays and double-sided tape

- Sand trays can be placed at key locations to record footprints.
- Double-sided tape can be used to collect strands of fur.

Footprint adjacent to a culvert (SA)

Monitoring fauna movement prior to conducting major channel works

- If the proposed channel works are expected to have an impact on fauna movement, then if possible, a fauna survey should be conducted prior to the work activities.



Wild pig (Vic)

Photography

- Motion-sensitive photography can be used to identify both native and non-native fauna.

Shelter from predators

Domestic animals

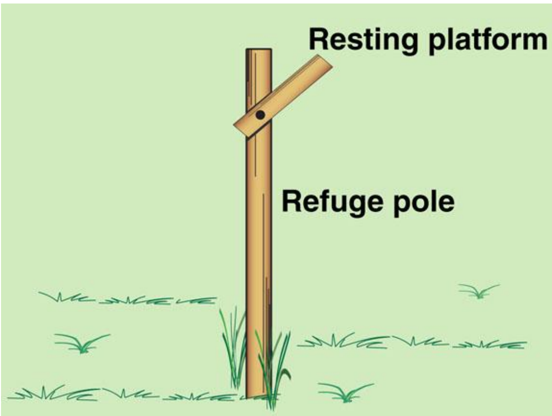
Introduction

- Predators can arrive on both two and four feet.

White-faced heron waiting for dinner

My observations

- Over the past 25 years the author has travelled the country and stopped to photograph many fauna corridors.
- As a result of these travels the author has observed and photographed:
  - examples of kingfisher birds sitting in trees adjacent to fish barriers
  - fish-hunting birds standing next to fishways
  - many animal carcasses at the entry/exit of culverts.



Refuge pole with resting platform

Refuge poles

- Refuge poles should have resting platforms to provide koalas refuge from predators.
- Refuge poles should be approximately 4 m tall and include a V-shaped resting platform at least 2.5 m from the ground.
- The author does not support the placement of refuge poles inside waterway culverts due to the high risk of trapping large woody debris, which ultimately may lead to the full blockage of the cell.

Two-legged predators collecting at the culvert exit waiting to trap and tag fauna (Qld)

Snag management

Eastern Water Dragon basking on a log

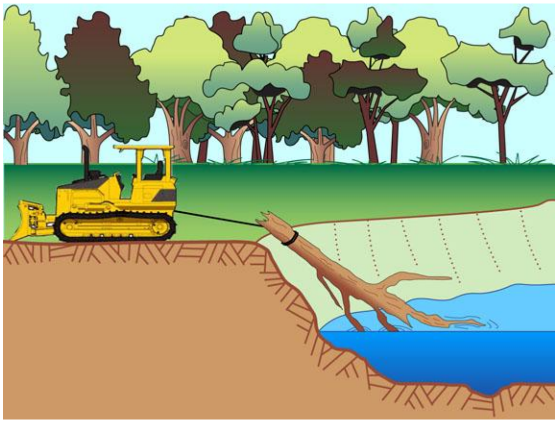
Introduction

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

Severe snag blockage (Qld)

Potential problems resulting from snags and fallen trees

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



Snag removal

Snag management

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

Log jam (Qld)

Increasing instream timber content

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

Waterway crossings – traffic calming systems for fauna safety

Traffic calming on a rural road (Qld)

Introduction

- The risks to wildlife crossing roadways are influenced by a number of factors, including:
  - the traffic volume
  - the number of trafficable lanes
  - the speed of the vehicles
  - the distance of drivers' clear vision.
- Traffic calming is the process of managing the speed of traffic on a road to reduce these risks.

Traffic calming on a back road (Qld)

Traffic calming

- Unfortunately it is not practical to reduce vehicle speeds, or 'thin' the traffic on high-speed arterial roads due to the resulting safety risks to the road users.
- On low speed back roads and urban roads, traffic calming can be used to slow vehicles as they approach a culvert crossing.

Readers should refer to DoT or Main Roads guidelines in each State and Territory, or to the AustRoads publications.

Traffic calming speed bump (Qld)

Warning sign (Qld)

Signage

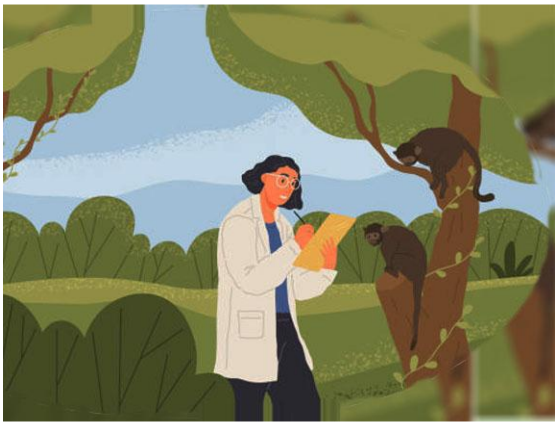
- Roadside warning signs are intended to modify driver behaviour by warning them of an increased risk of confronting wildlife on a section of roadway.
- Enhanced signs may be larger than standard signs and include flashing lights.

15. Riparian Zones

Introduction


Drainage engineer


Fisheries biologist


Wildlife officer


Bushcare officer

Introduction

- We could tell a drainage engineer that a creek is more than just a drainage corridor.
- We could tell a biologist that a creek is more than just an aquatic habitat.
- We could tell a wildlife officer that a creek is more than just a fauna habitat.
- But we don't need to tell a bushcare officer that a creek is anything less than a complex environment with multiple habitat issues—they already know.

Riparian features

Issues discussed in this chapter include:

- Introduction – the benefits provided by riparian vegetation
- Access through riparian zones
- Adjacent land use
- Berms (benching)
- Channel meanders
- Fire trails
- Flood control
- Floodways
- Mangroves
- Native grasses
- Recessed channel banks
- Stormwater outlets
- Width of riparian zones

Riparian zone

- The riparian zone can be defined as that part of the landscape adjacent to a watercourse that influences, and is influenced by, processes occurring within the watercourse.
- These zones usually include the instream habitats, beds, banks, and floodplains of watercourses.

Introduction – the benefits provided by riparian vegetation

Riparian vegetation (SA)

Riparian vegetation (SA)

Riparian zone adjacent a park (Qld)

Creek in an arid environment (NSW)

The benefits that riparian zones provide to waterways

- Supply of aquatic and terrestrial food, shelter and habitat requirements, including the supply of logs and essential leaf litter.
- Aesthetic and recreational benefits.
- Shade of the channel to control water temperature.
- Shading of the riparian zones to control weed infestation.
- Reduction in channel velocities during overbank flood flows, especially in channels that meander across the valley.
- Provision of a visual buffer between well-maintained grassed parklands, and the low-maintenance watercourse channel.
- Provision of terrestrial movement corridors.
- Providing a filter for sediments and nutrients contained within sheet flow as it enters the watercourse—however, in urban areas most stormwater enters waterways in the form of concentrated flow, and thus remains unfiltered by the riparian zone.

Design issues

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

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

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

Access through riparian zones

Walking track – a break in riparian cover

Introduction

- Ideally, the riparian zone should consist of a continuous band of native vegetation; however, there can be physical gaps between some plants.
- These physical gaps can represent a partial barrier to the movement for some terrestrial wildlife along the waterway corridor.
- Crossing such 'gaps' can cause wildlife to be vulnerable to predators.

Maintenance access ramp (Qld)

The potential cause of 'breaks' in the riparian corridor

- Breaks and visual gaps in the riparian corridor can result from:
  - formation of a walkway through the riparian zone, especially if formed in a straight line
  - installation of a piped stormwater drain
  - formation of an open drainage channel through the riparian zone
  - formation of a maintenance access track and/or ramp.

***Lomandra* access trail (Qld)**

Use of non-woody vegetation

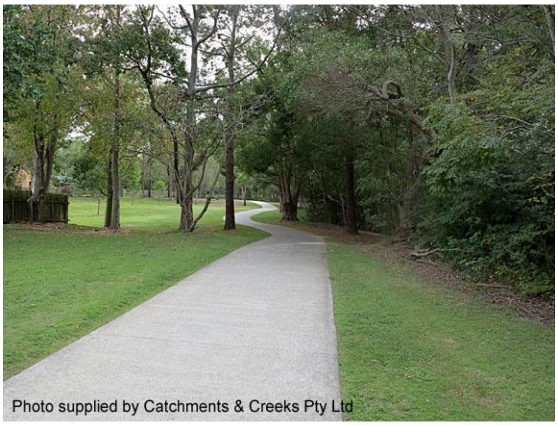
- Walking tracks, maintenance access tracks, and access ramps, can be vegetated using a variety of structural soils (gravel-grass, or block-grass).
- Maintenance access tracks can also be planted with non-woody species that can be driven-over and partly damaged during periods of maintenance.
- However, fire trails should NOT be grassed (always seek expert advice).

Recessed stormwater outlet (NSW)

Recessed banks

- Modern stormwater design practice stipulates that piped stormwater outlets should be recessed (set-back) into the waterway bank so that the outlet structure is not damaged, or exposed, if the creek bank migrates or erodes.
- This design practice can result in a major break in the riparian zone.
- The adverse effects of such works can usually be mitigated through intelligent landscaping.

Adjacent land use



Floodway adjacent to riparian zone

Paved path adjacent the riparian zone

Parkland meets bushland

Disposal of domestic garden waste

Introduction

- The land adjacent to riparian vegetation can have an adverse effect on the riparian zone in the following ways:
  - weed infestation
  - unwanted intrusion by mowing services
  - the side-intrusion of sunlight into the riparian zone, which increases the risk of weed invasion (see 'Edge effects')
  - noise pollution (terrestrial fauna)
  - entry of domestic pets
  - unwanted public access.

Weed invasion

- The choice of plant species placed within the land adjacent to a waterway can have a significant influence on the retention of native plants within the riparian zone.
- If the adjacent land consists of a grassed surface, then a border of *Lomandra* (mat rush) with its dense fibrous root system, can reduce the lateral invasion of many grasses.
- A sealed footpath (shown, left) can also reduce the risk of weed invasion.

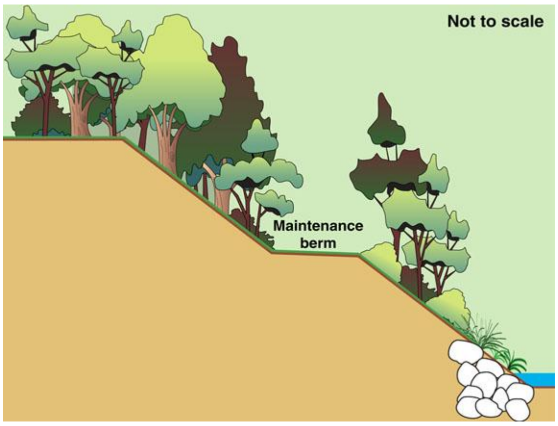
Damage by mowing activities

- Mowing activities can sometimes intrude too far into the designated riparian zone, often cutting down newly planted seedlings.
- Once again, a border of *Lomandra* can provide an obvious mowing edge.

Illegal dumping

- Ideally, the edge of the riparian zone should adjoin:
  - bushland
  - public open space.
- It is highly undesirable for the rear boundary of residential properties to abut riparian zones because of:
  - vermin control
  - fire control
  - risk of garden waste dumping.

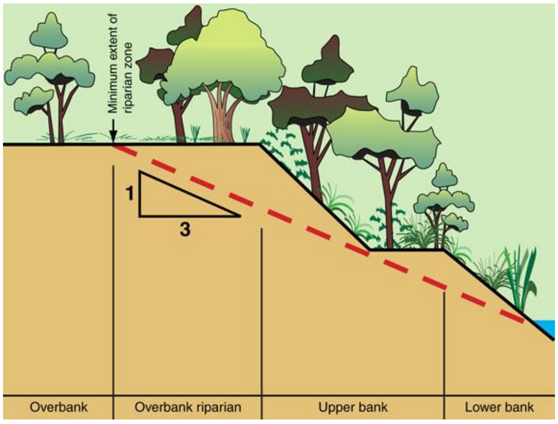
Berms (benching)



Permanent maintenance berm

Introduction

- Berms may need to be introduced to steep banks that are higher than three metres, or where erosion is expected along the toe of the bank.



Minimum riparian width for bank stability

The use of berms to aid full-bank revegetation

- A mid-bank berm can be used to delay the progression of toe erosion up the bank.
- Delaying the progression of bank erosion can allow time for deep-rooted vegetation to reach maturity.
- This approach is unlikely to be of benefit on the outside of channel bends where the toe erosion is likely to continue, which means hard-engineering toe protection, such as rock, may be required.

Planting on a tall, steep bank (Qld)

Berms can improve safety for revegetation teams

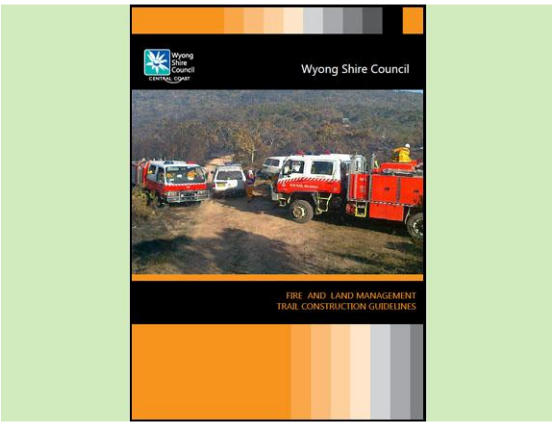
- In major projects, the formation of an earth berm can be used to provide necessary machinery access for bank construction.
- These berms can be grassed to provide ongoing maintenance access, or fully vegetated to provide continuity across the riparian zone.
- Berms or benching can provide added safety for bushcare teams revegetating tall steep banks.

Narrow berm on a revegetation project

Berms can provide safe access for weed control teams

- If weed control teams or community groups are expected to visit a site on a regular basis, then mid-bank berms, even if just 1.5 m wide, can provide safe access for these workers.
- These berms can be stabilised with native grasses and other groundcovers.

Fire trails



Wyong Fire Trail guidelines, 2012

Reference document:

'Fire and Land Management Trail Construction Guidelines'

Wyong Shire Council, Wyong, NSW, 2012.

Also refer to various NSW Rural Fire Service (RFS) publications.

Infall trail drainage

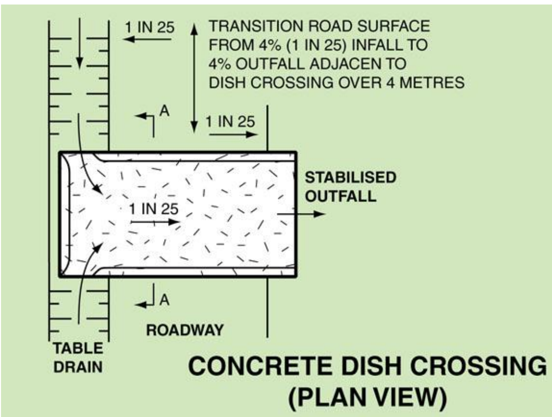
Fire trails

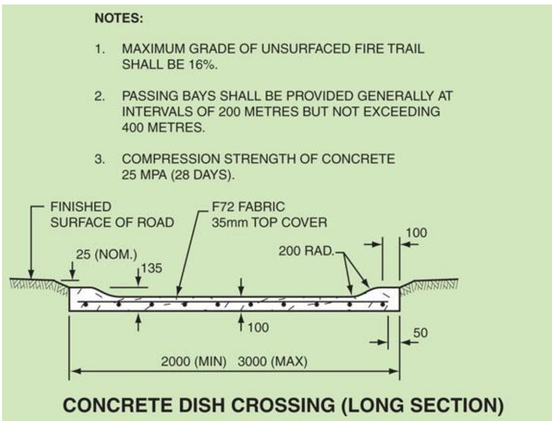
- Fire trails should not be grassed.
- Where possible, the trails should be graded with infall drainage that directs stormwater runoff inwards, towards the hill slope.
- If the trail is graded with outfall drainage, then the earth windrows, which can form with time along the edge of the trail, will interfere with the free flow of stormwater runoff (i.e. problems will occur).

Crossing of a drainage swale (NT)

Trafficable cross drainage

- Trafficable drainage swales need to be provided at locations where the fire trail crosses a drainage line, such as:
  - overland flow path
  - cross drain
  - spoon drain, etc.
- The road surface needs to be stabilised, otherwise, deep rutting can occur, which can undermine the fire trail.





Concrete dish crossing (NSW Rural Fire Service design details)

Flood control

Floodway adjacent to riparian zone

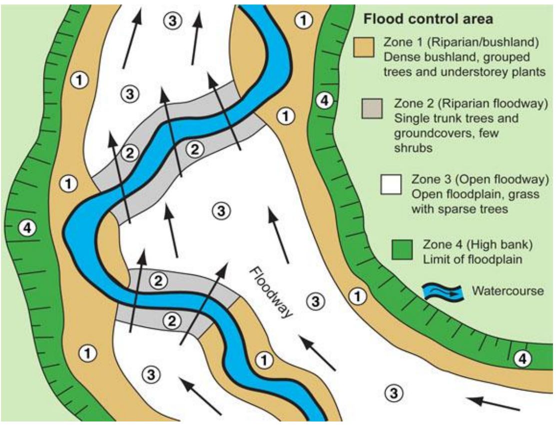
Introduction

- In the author's opinion, flood control is better achieved by establishing grassed floodways, rather than:
  - trying to reduce the density of riparian vegetation, or
  - widening the channel.
- If space is limited, then benching one of the banks is a better option to widening the channel bed (both options require a rebuilding of the riparian zone).

Open grassed floodway/sports oval

Floodways

- Open grassed floodways can incorporate:
  - pathways
  - bikeways
  - sporting and exercise facilities.
- If possible, an effective canopy connection should be achieved between the riparian zone and any bushland located on the outside edge of the floodway—think about the 'connection' from the point of view of a migrating glider possum.



Floodway passing over a channel

Floodways crossing a meandering channel

- If the main channel meanders across the valley floor, then floodwater will be required to pass through the riparian vegetation (Zone 2 in the diagram).
- In these regions of the riparian zone, the selection of plant species becomes very important—plants should consist of very flexible species, with trees, stiff grasses and groundcovers, put **very few** shrubs (refer to 'Discussion' in Step 4, in Part 2).

Floodway trees without an understorey

Trees without an understorey

- Some low-velocity floodways are covered with a stand of trees, without an understorey.
- These trees can provide shade, and specific habitat values.
- Obviously mowing operations can becomes more difficult.
- If flow velocities during flood events are high, then soil scour can occur around the base of the trees.

Floodways – tree planting within regions of high flow velocity

Flood-induced soil scour

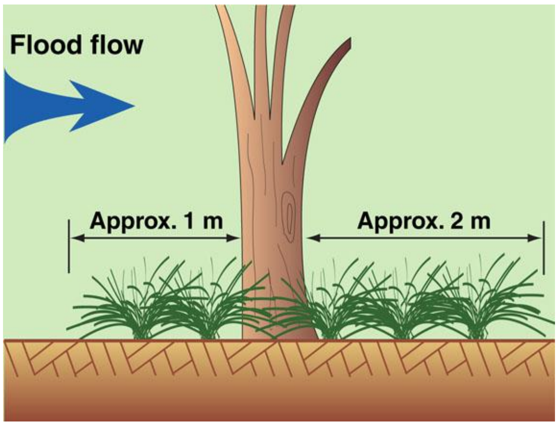
Introduction

- This is an example of the soil scour that can occur on the downstream side of isolated trees.

Erosion downstream of a floodplain tree

Erosion potential

- Isolated trees do not survive well when they are located within areas of high flow velocity (say greater than 1.5 m/s).
- As floodwater passes around the tree trunk it can generate an eddy, which can drill a scour holes immediately downstream of the tree.
- This action is one of the ways that flood events can remove trees that are growing in the 'wrong place'.



Companion planting around a tree

The protection of trees located with floodways

- The erosion problem described above, which can damage isolated trees that are located in regions of high flow velocity, such as a floodway, can be managed by companion planting:
  - planting native stiff grasses around the base of the tree, such as *Lomandra*
  - planting understorey plants around the base of the tree.

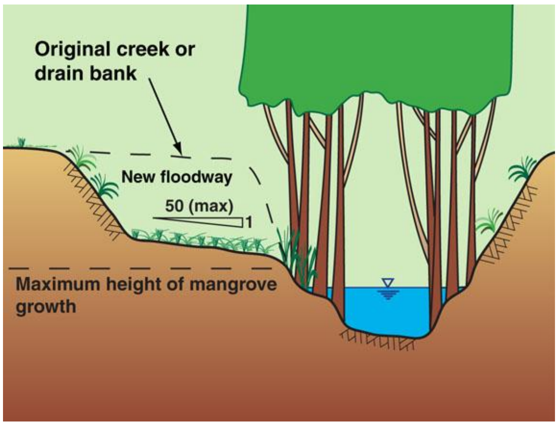
Companion planting

Companion planting

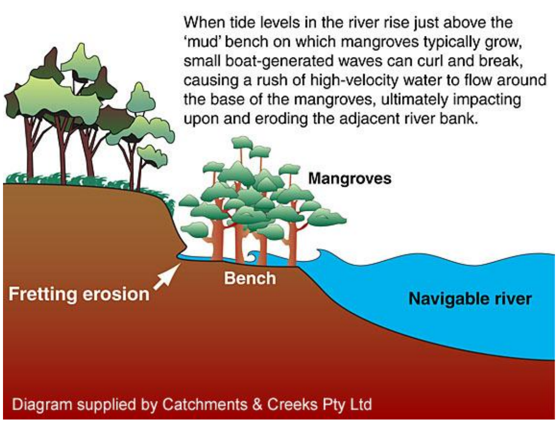
Mangroves

Mangrove root system (Qld)

Tidal drainage channel (Qld)



Salt-grass bypass floodway



Waves pass through mangroves

Introduction

- Mangroves exist within tidal waters, but primarily in tidal waters that are not subjected to wave action.
- Mangrove forests can have a very high Manning's roughness, meaning that they are not suitable for use in floodways.
- Mangroves are a protected species, and cannot be trimmed, or thinned, without State Government approval (not even the removal of dead material—check local advice).

Blockage of drainage channels

- Mangroves can readily 'block' a narrow drainage channel.

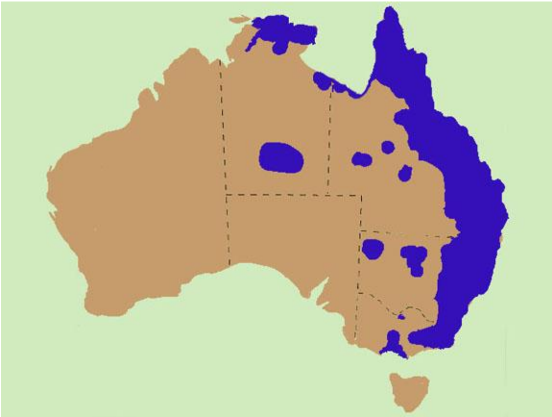
Bypass floodway (benching)

- Flood control is best achieved by obtaining a licence to form a salt grass floodway at the side of the mangroves, rather than:
  - attempting to widen the drainage channel, or
  - trying to maintain the drain free of mangroves.
- The elevation of the floodway must be above the normal elevation of the mangroves, which usually varies along tidal rivers.

Potential damage caused by bow waves

- If boat traffic is introduced to a tidal river (e.g. a boat ramp, or ferry system), then the bow waves generated by this boat traffic can slowly erode the mudflats that support mangroves, which can:
  - cause the unlawful loss of mangroves
  - allow bank erosion to occur on the landward side of the mangroves (such erosion has been observed by the author along the Brisbane River).

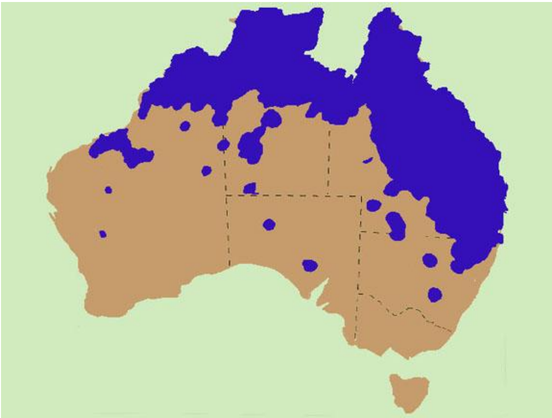
Native grasses



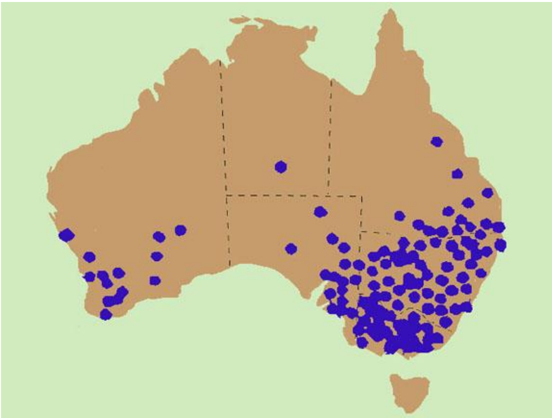
Barbed Wire grass (Lemon-scented grass)

Location maps for native grasses

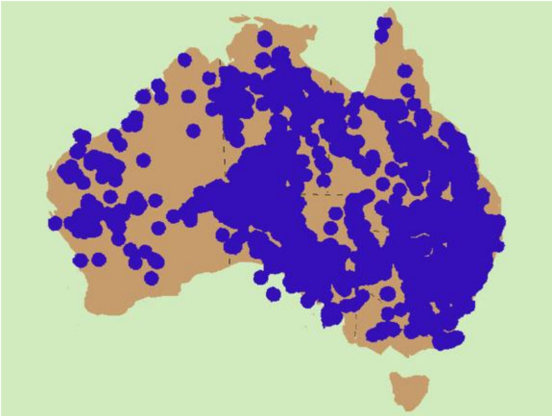
- The following maps show the approximate location of recorded sightings of native grasses.
- The maps are not accurate, and were developed from a variety of sources.
- Designers should always seek local advice and locally-prepared location maps.



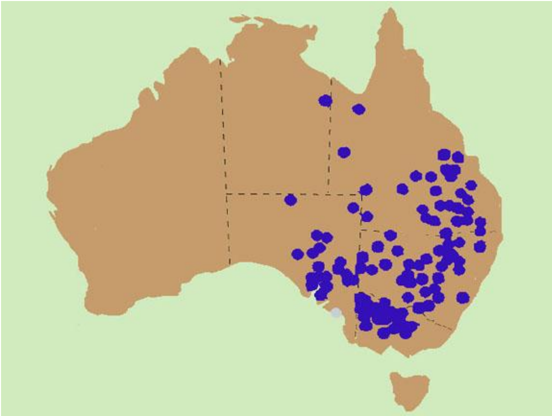
Black Spear (*Heteropogon contortus*)



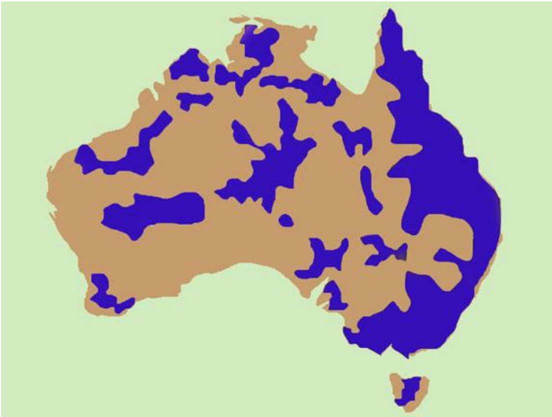
Chloris grass



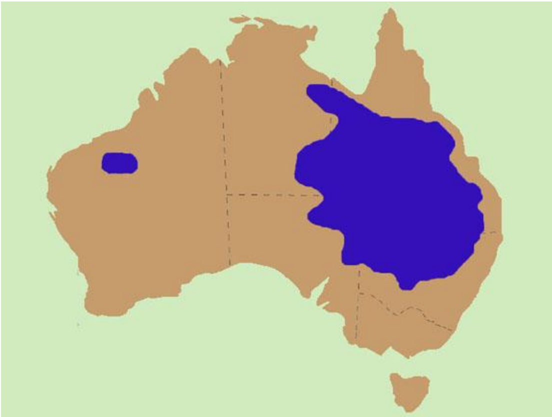
Cotton Panic grass (*Digitaria brownii*)



Curly Windmill grass

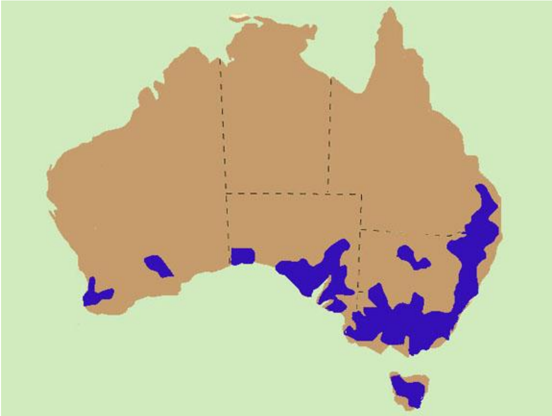


Kangaroo grass (*Themeda australis*)

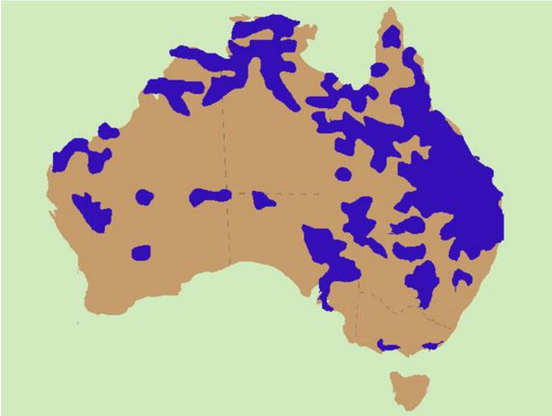


Mitchell grass (*Astrebla spp.*)

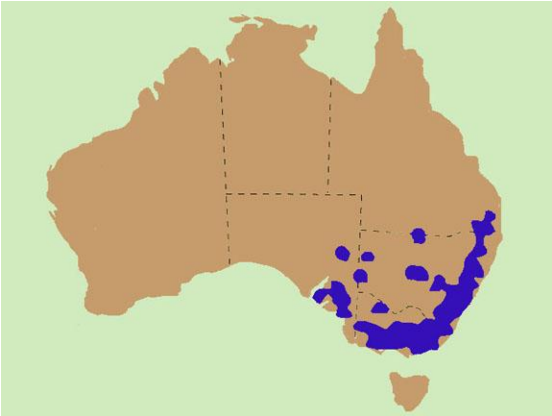
Native grasses



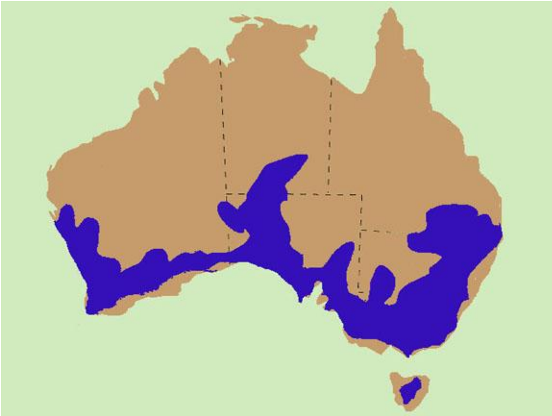
Native Wheat grass (*Elymus scaber*)



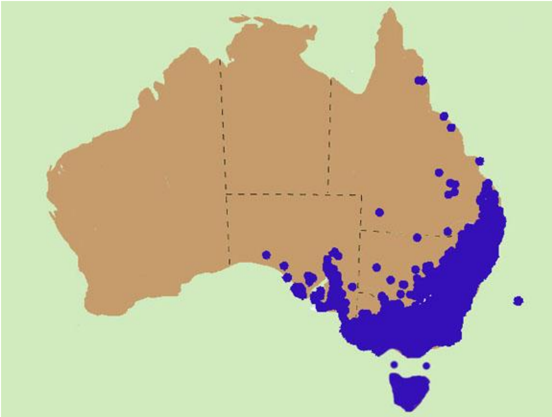
Queensland Blue grass



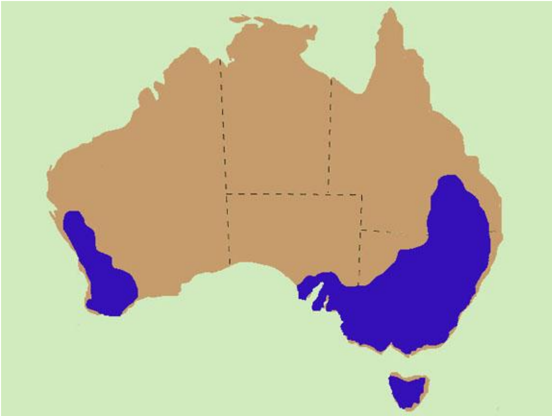
Redgrass (*Bothriochloa macra*)



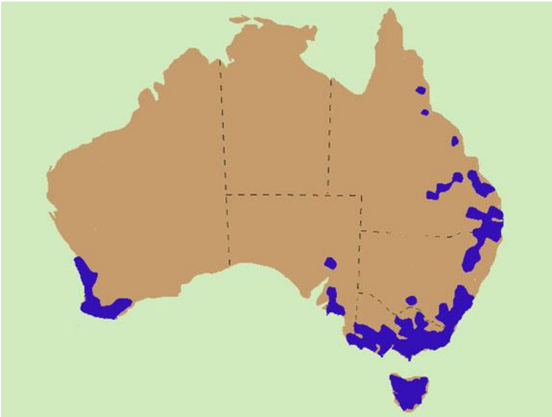
Spear grass (*Austrostipa species*)



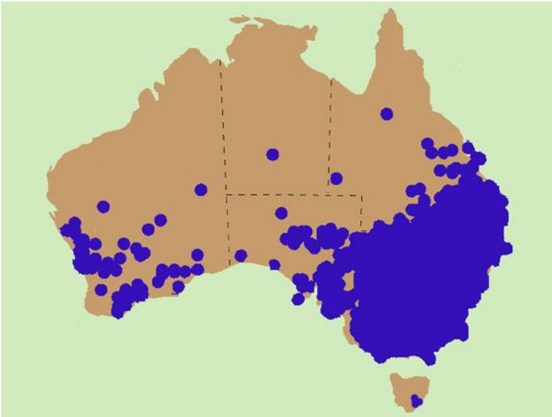
Tussock grass (*Poa labillardieri*)



Wallaby grass (*Austrodanthonia spp.*)



Weeping grass (Meadow rice grass)



Windmill grass (caution use of this map)

Recessed channel banks

Recessed stormwater outlet (Qld)

Introduction

- A recessed creek bank is an occasional channel feature that can be used for a variety of purposes, including:
  - forming a small instream pond, which does not have the usual through-flow of the channel flow, but instead the channel flow is along the side of the pond
  - forming a mini wetland
  - forming a side channel that connects to a recessed stormwater outlet.

Restoration of riparian values (Qld)

Treatment of the riparian zone

- In the above example, there currently is no effective riparian zone, which is unfortunately common in some of the older suburbs of Brisbane.
- Over time, each of these waterway will undergo a Habitat Brisbane creek rehabilitation program.
- Ideally, the restored riparian zone will fully enclose the recessed stormwater outlet, and the outlet will not represent a 'break' in the continuity of the riparian corridor.

Maintenance access to the waterway

Maintenance access ramps

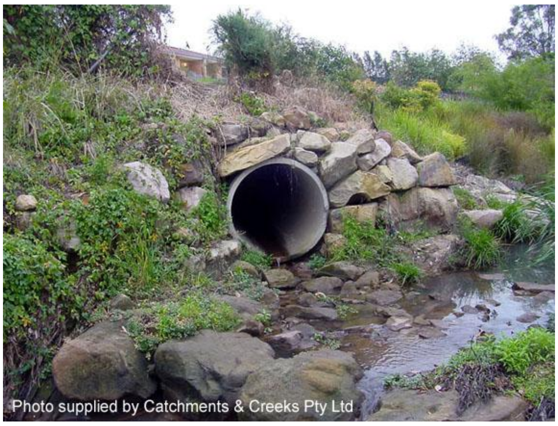
- In some locations, maintenance equipment may need to enter the waterway at regular intervals in order to conduct maintenance work, such as de-silting.
- In such cases, permanent access ramps should be formed into the channel banks.
- These recessed ramps can be vegetated with non-woody species, or plants that can withstand occasional branch damage.

Permanent road access (NSW)

Permanent waterway crossings

- Some waterway crossings require the footpath or roadway to descend the channel bank, which will form a permanent recess into the bank.
- These recessed ramps can provide useful shelter for aquatic life during flood events, protecting them from being washed downstream.
- The ramps should ideally be aligned perpendicular to the channel so that approaching vehicles have clear vision of the waterway and crossing conditions.

Stormwater outlets



No headwall (NSW)

Example stormwater outlets

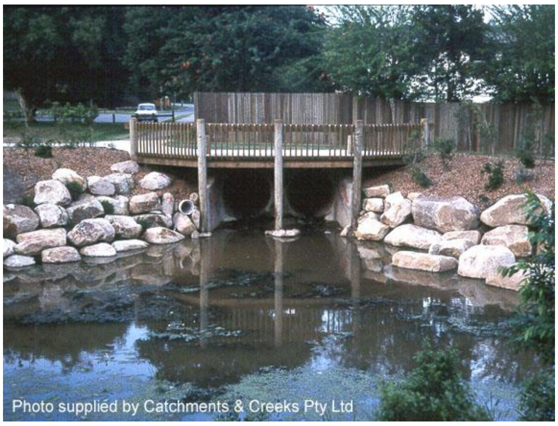
- Creativity and flexibility on behalf of the designer can result in a less intrusive stormwater outlet structure.
- Ideally, stormwater outlets should be recessed into the bank of the waterway so that the waterway channel can experience some normal erosion and migration without exposing the outlet.
- Stormwater outlets can also be hidden under other landscape features, such as walkway paths and observation decks.

No headwall (Qld)

No headwall (Qld)

No headwall (Qld)

No headwall (Qld)



Hidden outlet (Qld)

Hidden outlet (Qld)

Stormwater outlets – recessed into the creek bank

Recessed stormwater outlet (Qld)

Outlets recessed into the creek bank

- Recessing the stormwater outlet into the channel bank can allow the waterway channel to experience normal erosion processes and channel migration without exposing the outlet.
- Ideally, these recessed 'side channels' should be hidden by appropriate riparian vegetation.
- If space allows, then these side channels can be used for stormwater treatment.

Recessed stormwater outlet (Qld)

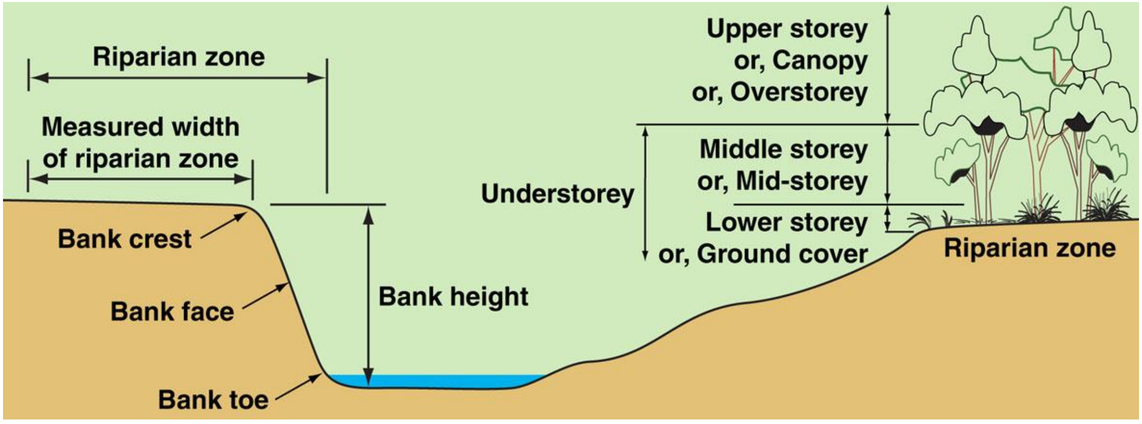
Recessed stormwater outlet (NSW)

Recessed stormwater outlet (Qld)

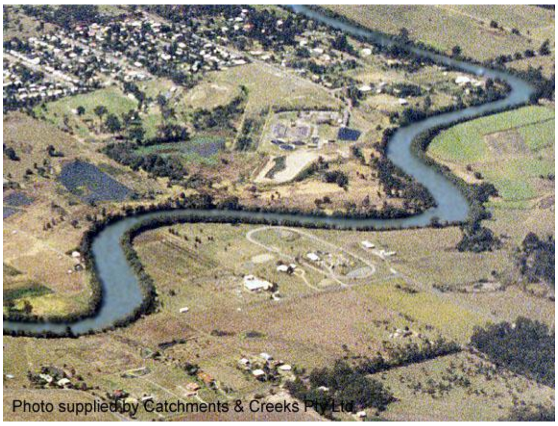
Recessed stormwater outlet (Qld)

Recessed stormwater outlet with water quality treatment swale (Qld)

Width of riparian zones (desirable)



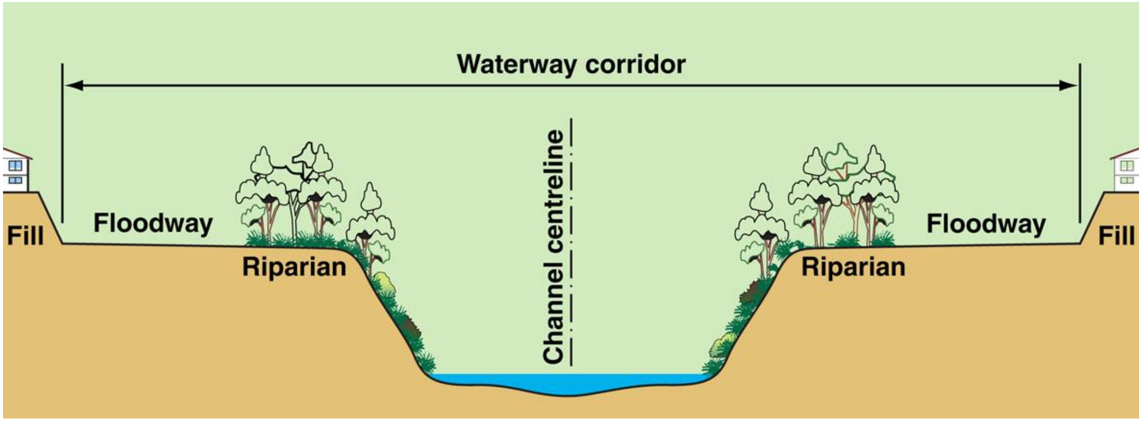
Defining the riparian zone and riparian 'width'



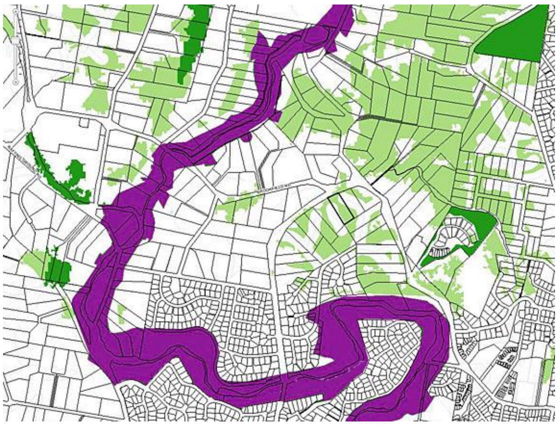
Narrow riparian corridor

The required width of riparian zones

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



Waterway corridor



Corridor mapping

Corridor mapping

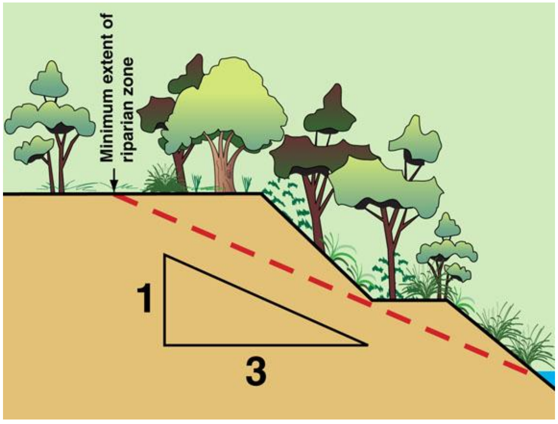
- Some authorities prepare *Waterway Corridor Maps* that identify which land must be excluded from development.
- The nominated corridor width is often measured from the centre of the creek (but may be a different distance each side of the creek)—suggested widths are:
  - 1st order streams = 15 m (each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

Width of riparian zones (desirable)

Riparian zone and grassed floodway (Qld)

Minimum width of riparian zone

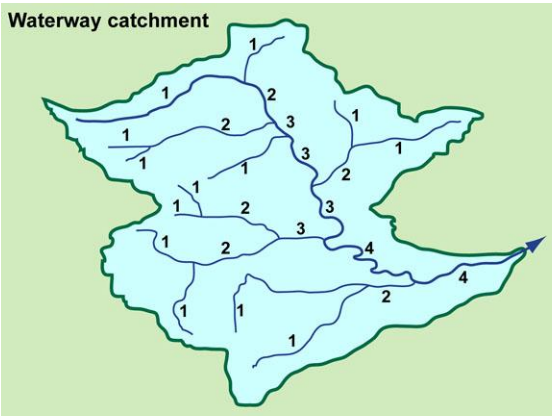
- The suggested minimum width is 5 m.
- However, specifying a minimum width can become problematic if it results in only this minimum width ever being provided.
- In order to filter pollutants from stormwater inflows (sheet flow runoff) the minimum width of the combined riparian zone and grassed floodway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



Minimum width based on bank stability

Riparian width based on bank stability recommendations

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



Horton's stream order system

Width based on waterway classification

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

Bank revegetation (Qld)

Additional allowance based on the time required to establish new vegetation

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

16. Management of Riparian Zones

Bush regeneration

Bushland education centre (Qld)

The aim

- The aim of bush regeneration is to rehabilitate the bushland from a degraded condition to a healthy plant community that works for the betterment of the area.
- This chapter focuses on the management of riparian bushland.
- Riparian bushland has a direct connection to the waterway that it surrounds, and that connection must be to the betterment of the aquatic, terrestrial, arboreal and human communities.

Weed removal (Qld)

Ecosystem resilience

- Ecosystem resilience refers to the ability of an ecosystem to recover from disturbances.
- Threats to riparian bushland can come from wind storms, fire, human impacts, flooding, and weed invasion.
- Ideally, this resilience should comes from the bushland's natural resilience, and where possible the aim should be to restore or enhance the natural resilience of the riparian bushland.

High-use pedestrian pathway (Qld)

Fire trail closed for rehabilitation (Qld)

Ecosystem resilience

- Ecosystem resilience is best achieved by recognising the natural resilience of the riparian bushland, and enhancing these natural features, rather than building a bushland community that requires ongoing human input (maintenance).
- This approach should also apply to the design and management of access pathways.
  - Soil compaction, including ongoing pedestrian foot compaction, can be used to control weed growth on unsealed pedestrian pathways (rather than herbicides, or the placement of gravel).
  - Vehicular access tracks (not fire trails) can be covered with non-woody species to slow weed invasion.
  - These non-woody species must consist of species that can readily recover from occasional vehicular damage, and are able to compete against the invasion of weed species.

Bush regeneration

Removal of weed tree (Qld)

Introduction

- Ecosystem rehabilitation can be approached in four different ways:
  - natural regeneration
  - assisted bush regeneration
  - reconstruction
  - fabrication.
- Natural regeneration involves weed removal and native plant regeneration from the existing in-soil seed bank.

Assisted bush regeneration (Qld)

Assisted bush regeneration

- Assisted bush regeneration is most useful when the in-soil seed bank has been depleted and the existing species diversity is low.
- These programs involve weed removal and seed collection, which is used to propagate seedlings for later planting.
- After initial weeding, time is given to see if natural regeneration will occur, possibly over 12 months—if unsuccessful, then assisted planting can occur during ideal months.

Reconstruction of a riparian zone (Qld)

Bush reconstruction

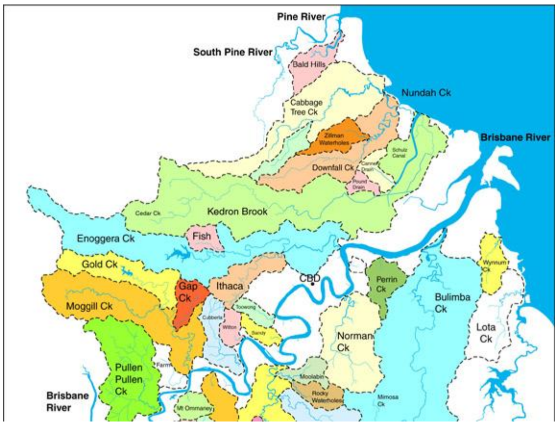
- Bush reconstruction occurs when the site is heavily modified, but the remaining soil and hydrological conditions are suitable for the original plant communities.
- The original plant communities can be identified through tree surveys of the site, and adjacent plant communities.
- Tree surveys of nearby bushland can be useful, but expert advice will be required to modify these plant communities for the needs of the waterway.

New drainage channel (Qld)

Bush fabrication

- Bush fabrication is the process that is often adopted when:
  - constructing a new drainage channel
  - replacing a concrete-lined drain with a vegetated drainage channel.
- Wherever possible, the fabrication process should mimic the above 'reconstruction' approach.
- It should be noted that seed from new drainage channels will migrate downstream into existing riparian zones.

Bush regeneration



Creek catchments in north Brisbane

Know your catchment

- Bush regeneration should not be performed without knowledge of how the riparian zone fits into the rest of the catchment.
- Bush regeneration needs to be compatible with:
  - the type of waterway (clay-based, sand-based, gravel-based, rocky, etc.)
  - the waterway's connectivity with adjacent non-riparian bushland
  - recognised fauna movement corridors.

Weeds moved by a flood event

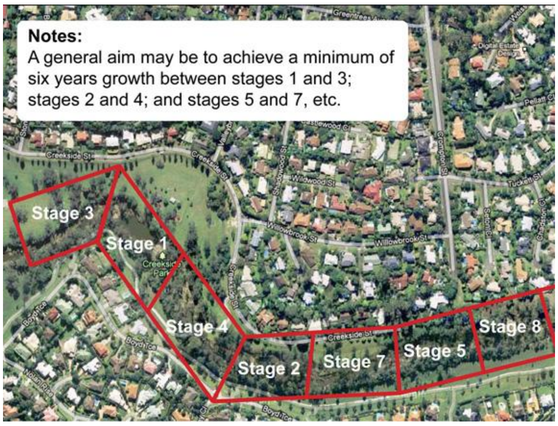
Understand the movement of weeds

- Riparian zones are highly susceptible to the movement of weeds down a waterway, particularly during flood events.
- Regeneration teams need to be aware of:
  - the potential for weed species to move into a regeneration area from upstream
  - the potential for weed seed to move downstream from the regeneration area.
- Ideally, weed removal should commence within the upper catchment.

Grasses providing erosion control

Understand the roles that weeds are currently performing

- Weed removal is an admirable task, but like all tasks, it must be performed correctly.
- Weeds, while being undesirable plants, are still 'plants', which means they can perform important tasks within a waterway.
- YOUR task is to be aware of tasks the weeds are performing, and then to make sure the replacement plants are able to perform these same essential tasks.



Staging of weed removal

Staging of weed removal

- The more weeds that are removed from a waterway at a given time, the thinner the vegetation density becomes, and the faster floodwaters will be able to pass along the waterway—potentially leading to increased erosion and vegetation damage.
- If weed removal extends over a significant distance, or a bed fall that exceeds, say one (1) meter, then consider staging the weed removal so that excessive flood flow velocities will not be generated—flood modelling can aid this process.

Weed control practices

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

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

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

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

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

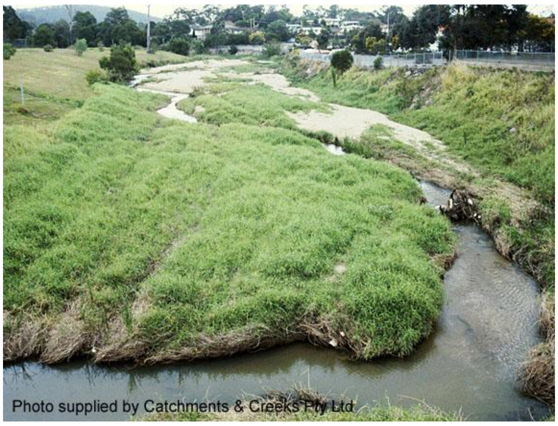
Local community groups are an effective way of achieving ongoing weed removal from urban waterways, but such activities must be appropriately managed by people that understand what potential hydraulic and erosion impacts can result from weed control practices.

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

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

(i) seek expert advice before you start
(ii) remove the target weeds
(iii) temporarily stabilise the area with a fast-growing, non-aggressive weed that is known to be easy to control (such as certain grasses)
(iv) progressively establish the chosen natives within the temporary grass (this may involve progressively removing or poisoning small areas of the introduced grass)
(v) once the natives are established, remove all remaining elements of the temporary grass.

How weeds can contribute to creek erosion



Bed sediment stabilised with grasses

Stabilisation of sediment slugs

- Sand slugs and sediment slugs are terms used to describe the mounds of loose bed sediment that slowly migrate down many of our creeks and rivers.
- In certain conditions, these sediment slugs can become overgrown with weeds, which can prevent the slugs from continuing their migration.
- Excessive weed growth within the sediment can cause the low-flow channel to be diverted around the sediment, possibly causing bank erosion.

Blockage of a creek with wetland plants

Blockage of narrow channels by reeds and other stiff grasses

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

Vine growth over native trees (Qld)

Suppression of native plants

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

Bank erosion following weed removal

Increased erosion risk during weed removal

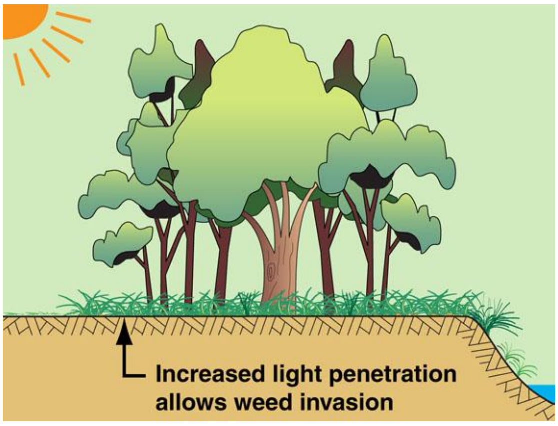
- A weed problem often results in the need for a ‘weed control program’, which can:
  - temporarily denude the creek bank, which . . .
  - can increase the risk of bank erosion, which . . .
  - can increase the opportunities for more weed growth (because weeds are often a fast-response plant that quickly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

Planting to control edge effects

Intrusion of light into a riparian area

Introduction

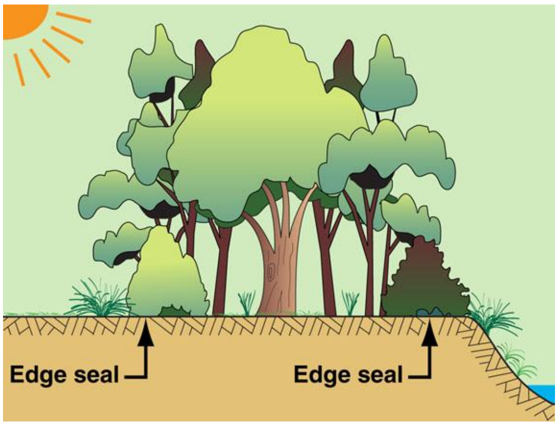
- In both rural and urban areas, riparian zones may consist of just a narrow strip of vegetation each side of the channel.
- Many of the functions performed by riparian vegetation will be affected by the width of the riparian zone.
- The width of the riparian zone also affects the degree of sunlight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



Weed intrusion into the riparian zone

The impact of edge effects on weed invasion

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



Controlling the edge effects

Controlling edge effects with appropriate planting

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

Forming a 'mowing edge' (Qld)

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

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

The use of mulch in riparian areas

Loose mulch applied to a creek bank

A potential source of pollution

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

Geo logs used on a steep creek bank

Retaining loose mulch on steep banks

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

Straw mulch (Qld)

Straw and cane mulch

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

Bush mulch (NSW)

Bush mulch

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

The use of erosion control blankets in riparian areas

Jute mesh (Qld)

Terminology

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

Jute erosion control blanket (SA)

Bio-degradable products

- Bio-degradable erosion control blankets are typically manufactured from:
  - jute (made from specific Asian plants), which have a useable life of a few months, or
  - coir (made from coconut fibre), which is more durable, making it better suited for use within waterways.
- Meshes are the type of 'blankets' best suited for use on waterway banks.

Hydraulically-applied blanket (Qld)

Hydraulically-applied blankets

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

Plastic-reinforced erosion control mat

Problems associated with plastic-reinforced mats

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

Stock management

Dairy cows returning home for milking

Introduction

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

Bank erosion at stock access point (Qld)

Bank erosion issues

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

Stabilised stock access ramp (Qld)

Stabilised access points

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

Livestock underpass (NSW)

Livestock friendly culvert underpasses

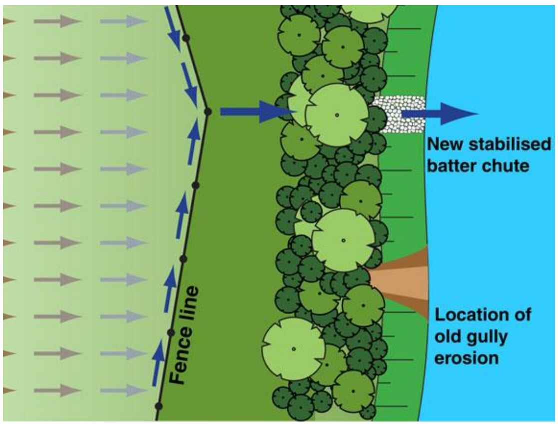
- In circumstances where livestock need to regularly pass through a culvert, road authorities should work with the landowner to convert one or more of the cells into a terrestrial corridor (also known as a 'dry' cell).
- Stabilised access ramps (formed from a vegetated mix of soil and rocks) can be used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

Fencing

Fencing of riparian zone (SA)

Fencing of riparian zone (Qld)

Gully erosion along a fence line (Qld)



Managing stormwater runoff

Introduction

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

The redirection of stormwater runoff

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

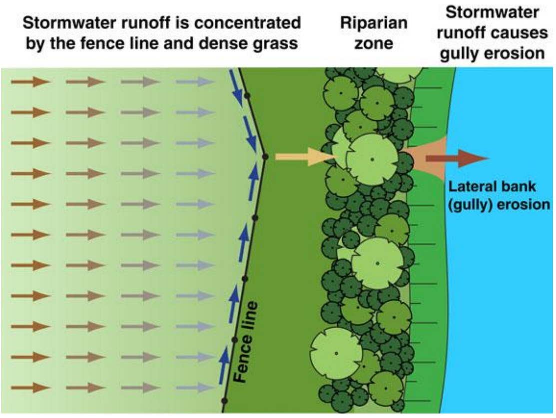
Gully erosion along fence lines

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

Designing fence lines adjacent to creeks

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

Stormwater management through riparian zones



Potential cause of lateral bank erosion

Introduction

- Stormwater runoff can contribute to creek erosion problems in three ways:
  - initiating and/or aggravating lateral bank erosion
  - initiating and/or aggravating tunnel erosion problems
  - aggravating soil erosion along pedestrian or livestock access tracks.

Stormwater-induced lateral bank erosion

Controlling lateral bank erosion

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

Tunnel erosion adjacent a creek (Qld)

Controlling tunnel erosion

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

Pedestrian access to a creek (Qld)

Controlling stormwater movement along access tracks

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