



# Fish Passage Culvert Design

## Part 3: Appendices G to M

Version 2, February 2026

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Published by: Catchments and Creeks, Bargara, Queensland

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Witheridge, G.M. 2026, *Fish Passage Culvert Design – Part 3: Appendices G to M*. Catchments & Creeks, Bargara, Queensland.

Cover image: Drawing of single cell culvert emphasising terrestrial passage features.

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### Note to Reader:

Readers should note that this document has been prepared by a civil engineer, and the focus is on the engineering aspects of fish passage at engineering structures. The document has not been reviewed by a fisheries biologist.

### Disclaimer

To be effective, fish passage requirements at waterway crossings must be appropriately investigated, planned, and designed in a manner appropriate for the given work activity and site conditions.

Adoption of the recommendations and procedures presented within this document will not guarantee:

- (i) compliance with any statutory obligations
- (ii) compliance with fish passage outcomes
- (iii) compliance with the structural or flood control requirements of the culvert
- (iv) avoidance of environmental harm or nuisance
- (v) appropriate outcomes for waterways located outside of Australia.

## Principal reference documents



AR&R Project 11, Stage 2 (2012)

### **Project 11: Blockage of Hydraulic Structures**

Australian Rainfall and Runoff (AR&R), Report Number P11/S2/007, March 2012, Engineers Australia, Barton, ACT

W. Weeks, G. Witheridge, E. Rigby, A. Barthelmess and G. O'Loughlin



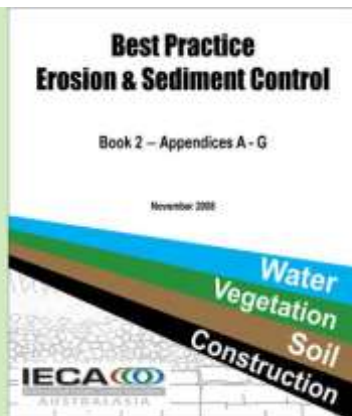
Queensland Urban Drainage Manual

### **Queensland Urban Drainage Manual (QUDM)**

Institute of Public Works Engineering Australia, Queensland Division and the Department of Energy and Water Supply. Brisbane, Australia, 4th edition, 2017.

Chapter 10. Waterway Crossings

Chapter 12. Safety Aspects



IECA Australasia, 2008

### **Best Practice Erosion & Sediment Control. International Erosion Control Association, (IECA) Australasia Chapter, 2008, Book 2: Appendices**

A. Construction site hydrology and hydraulics

B. Sediment basin design and operation

**C. Soils and revegetation**

D. Example plans

E. Soil loss estimation

F. Erosion hazard assessment

G. Model code of practice



Queensland Transport, 2024

### **Fauna Sensitive Transport Infrastructure Delivery – Chapter 6: Mitigation**

The State of Queensland (Department of Transport and Main Roads), June 2024.

Specifically:

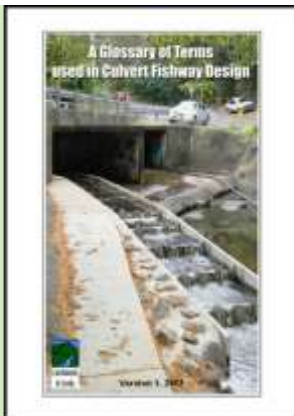
[4.4 Multi-use culverts](#)

[13.0 Fauna exclusion fencing](#)

[16.0 Biodiversity enhancement](#)

[16.6 Fauna furniture for crossing structures](#)

## Related *Catchments and Creeks* field guides

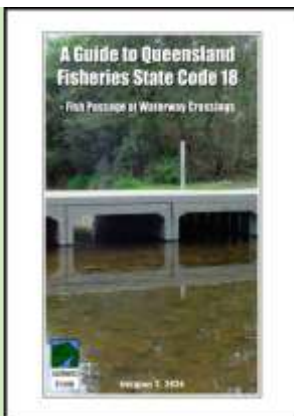


**Glossary of Terms, 2017**

### ***A Glossary of Terms used in Culvert Fishway Design***

Catchments & Creeks Pty Ltd, 2017, Brisbane Queensland.

This field guide provides photos and definitions of terms commonly used by engineers and fish biologists in the fish passage industry with specific reference to culvert design.

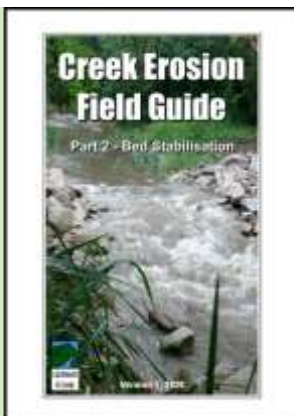


**Queensland State Code 18, 2024**

### ***A Guide to Queensland Fisheries State Code 18***

Catchments & Creeks, 2024, Barga Queensland.

Published in October 2024.



**Creek Erosion, Part 2, 2022**

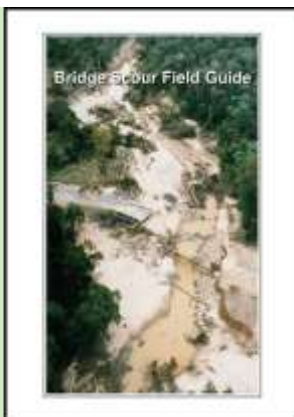
### ***Creek Erosion Field Guide Part 2 – Bed Stabilisation***

Catchments & Creeks Pty Ltd, 2022, Barga Queensland.

Version 1, April 2021

Version 2, February 2022

Part 2 discusses the planning of creek erosion treatments, fish-friendly bed treatment, common properties of rock, the hydraulics of grade control structures, fish-friendly and non fish-friendly bed stabilisation techniques.



**Bridge Scour Field Guide, 2020**

### ***Bridge Scour Field Guide***

Catchments & Creeks Pty Ltd, 2020, Barga Queensland.

Version 1, 2020

This field guide provides an overview of current design guidelines for scour control under bridges, with a focus on the use of rock.

<b>Contents</b>	<b>Page</b>
Purpose of field guide	7
About the author	7
Foreword	7
Layout of Part 3	8
Terminology	9
<b>Appendix G – Blockages</b>	
Introduction	11
Glossary of terms used in culvert blockage	12
Types of culvert blockage	14
Sediment debris	15
Floating debris	16
Urban flood debris	17
Potential impacts of debris and sediment blockages	18
Typical source of flood debris	19
Expected sediment flow in various waterways	20
Assumed blockage conditions for flood mapping	21
Reducing the effects of debris blockages	22
The typical response of a creek to channel widening	23
Sediment control options at culverts	24
Debris traps placed upstream of culverts	26
Debris blockage of traffic barriers	27
<b>Appendix H – Safety Risks at Culvert Crossings</b>	
Introduction	33
Risk management options	34
The impact of deck thickness on ‘fish passage’ and ‘human safety’	35
Safety risk ranking system	36
Mitigating safety risks associated with waterway culverts	40
Safety systems installed upstream of culverts	41
Inlet safety screens – Design information	42
‘Parabolic’ inlet screens	44
Inlet safety screens – Alternative designs	45
Inlet safety screens – Screen slope	46
Inlet safety screens – Hydraulic analysis	47
<b>Appendix I – Culverts Located in Problem Soils</b>	
Introduction	49
Aggregate Immersion Test	50
Identifying dispersive and slaking soils	51
Soil erosion resulting from slaking soils	53
Soil erosion resulting from cracking clays (dry bank slumping)	54
Potential issues associated with recessing culverts in problem soils	55
Culverts in expansive soil areas	56
<b>Appendix J – Terrestrial Passage Requirements at Culvert Crossings</b>	
Introduction	58
Integration of aquatic and terrestrial passage features	60
Lizard runs	61
Queensland Department of Transport and Main Roads	62
Traffic calming	65
Risk of predation	66
Predators	67

<b>Appendix K – Culvert Upgrades</b>	<b>Page</b>
Introduction	69
Culvert upgrades	70
Culvert upgrades – Raising the downstream channel bed	71
K1 – Constructed riffles	72
K2 – Rock chutes and rock ramps	73
K3 – Ridge rock ramps	80
K4 – Fishways	82
<b>Appendix L – Culvert Upgrade Case Studies</b>	
Bennett Road, Enoggera Creek, Brisbane, Queensland	86
Ewingar Creek, Northern Rivers Region of NSW	88
Laura Creek, Guyra, New South Wales	90
Washpool Creek Road, Tenterfield, NSW	92
<b>Appendix M – Terminology</b>	
AEP to Apron	95
Arch bridge to Base	96
Boundary layer to Cell	97
Circular culvert to Cover	98
Culvert to Drop-inlet	99
Drop-outlet to Fish ladder	100
Fish migration to Floodplain culvert	101
Floor to Head differential	102
Headwall to Invert	103
Laminar flow to Low-flow design	104
Medium flow design to Obvert	105
Pipe culvert to Rock-based waterway	106
Sand-based waterways to Smooth-turbulent flow	107
Stream order to Terrestrial pathway	108
Turbulent flow to Wingwall	109

## Purpose of field guide

This field guide has been prepared specifically to:

- provide educational information on fish passage at waterway culverts
- provide a quick reference guide to fish passage at culvert crossings
- provide a pictorial supplement to the various State Fisheries policies and design guidelines.

It is **not** the intention of this document to define the design standards for fish passage through waterway culverts. Such standards need to be set by Fisheries representatives from the various states and territories. This document is also **not** intended to be a detailed culvert design manual. Instead it is a 'supplement' to local Fisheries codes and engineering guidelines.

This document represents the opinions and recommendations of **just one person**, the author, who is a person **without** training in fish biology. As such, the document does **not** represent a holistic or balanced opinion. Readers should seek additional advice from local experts.

The photos presented within this document **do not necessarily represent current best practice**, but are intended to represent the current topic of discussion. It would be near impossible to obtain a 'perfect' example for each 'topic'. **No** image (photo) presented in this document should be considered **best practice** without full knowledge of the site conditions.

## 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 45 years experience in the fields of hydraulics, creek engineering, and erosion & sediment control, during which time he had 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, before ended his career working through his own company Catchments & Creeks Pty Ltd.

## Foreword

If I am to be honest, the drafting of this three-part field guide has been one of the hardest documents that I have had to produce. The basic problem was that I did not (do not) have the same level of knowledge on this topic as I believe I have on the previous 60-plus field guides that I had produced.

Throughout this three-part document I have gone to great lengths to point out that the design of fish-friendly culverts is a team effort, involving several different disciplines; and here I am drafting this document with only the knowledge and experience of just one of those disciplines, civil engineering.

At the time of drafting this second edition of this field guide I had logged over 7,400 hours drafting 65 different field guides, but that does not give me the required knowledge to tell someone the complete picture of how to design a fish-friendly culvert. All I can do is present the information as best I can, and insert several notes asking readers to seek their own expert advice.

Readers should **not** blindly trust what I have written.

Readers should use their own professional judgement.

Designers should seek advice from their local or State government, and local Fisheries office, with regards to the appropriate use of the information contained within this document.

I fully realise that there are some that believe that I should not have put 'pen-to-paper' unless I was 100% certain about 100% of what I was writing; but if that were the case then none of the existing 65 field guides would ever have seen the light-of-day.

## Layout of Part 3



Photo supplied by Catchments & Creeks Pty Ltd

**Woody bridging debris (Qld)**



**Water safety**



Photo supplied by Catchments & Creeks Pty Ltd

**Lizard run and 'dry' terrestrial pathway**



Photo supplied by Catchments & Creeks Pty Ltd

**Culvert upgrade as part of road works**

### Appendix G – Blockages

- Appendix G discusses the following blockage issues:
  - types of culvert blockage
  - recommended design values of blockage for culverts
  - potential impacts of debris blockages on fauna passage
  - potential blockage control measures
  - potential impacts of debris blockage of traffic barriers.

### Appendices H & I – Safety Risks at Culvert Crossings

- **Appendix H – 'Safety Risks at Culvert Crossings'** presents an overview of culvert safety issues as first presented in the *Queensland Urban Drainage Manual* (QUDM).
- **Appendix I – 'Culverts Located in Problem Soils'** presents information on culverts located on problematic soils such as highly erodible soils, dispersive soils, slaking soils, and acid sulfate soils.

### Appendix J – Terrestrial Passage Requirements at Culvert Crossings

- Fish passage typically requires a water depth that exceeds the body-depth of the fish.
- Terrestrial passage, of native fauna, typically requires a 'dry' pathway that is elevated above the dry-weather flow.
- Both fish passage and terrestrial passage are usually required at waterway culverts, and these design requirements must be appropriately integrated.

### Appendices K, L & M

- **Appendix K – 'Culvert Upgrades'**, this appendix discusses how problematic culverts can be upgraded.
- **Appendix L – 'Culvert Upgrade Case Studies'**, this appendix provides examples of both new and upgraded culverts.
- **Appendix M – 'Terminology'**, this appendix provides a glossary of technical terms as used within this three-part document.

## Terminology



**A culvert containing both wet and dry cells**



**Corrugated pipe culvert (NSW)**



**Australian Smelt (Queensland Museum)**



**Waterway, watercourse, creek or stream**

### Wet and dry cells

- Nominated 'wet' and 'dry' cells exist in order to promote the passage of both terrestrial and aquatic fauna.
- **Wet cells** have a floor level set below the normal dry-weather water level.
- **Dry cells** are designed to have a dry floor during low-flow conditions, which helps to promote native fauna movement.
- Each individual cell in a multi-cell culvert can be called a **conduit**, **cell**, **barrel**, or even a **culvert**.

### Box, pipe and corrugated culverts

- A **box culvert** contains a rectangular conduit.
- A **pipe culvert** contains circular (pipe) conduits.
- A **corrugated pipe culvert** contains corrugated, circular, metal conduits.
- An **arch bridge** is not considered to be a 'culvert' because it is not a fully-enclosed conduit (i.e. the structure does not enclose the channel bed).

### Fish

- With respect to fisheries legislation, the term '**fish**' typically means any animal species that, throughout its life cycle, lives:
  - in water (whether freshwater or saltwater)
  - in or on foreshores
  - in or on land under water.
- Readers should refer to their local fisheries legislation for their State or Territory definition of 'fish'.

### Waterway and fishways

- The term '**waterway**' typically includes a river, creek, stream, watercourse, drainage feature, or inlet of the sea.
- Readers should again refer to their local Fisheries legislation.
- The term '**fishway**' refers to a constructed fish ladder, structure or device, by which fish can pass through, around, or over, a fish barrier—the term is more commonly associated with structures not defined as fish ladders.

# **Appendix G: Blockages**

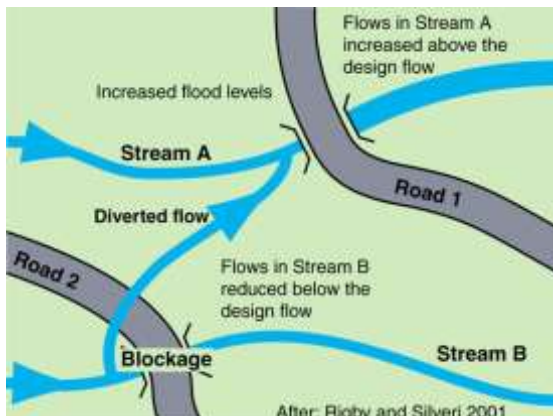
## Introduction



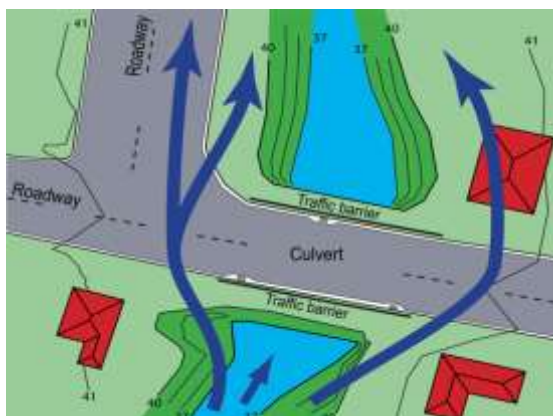
AR&R Project 11, Stage 2 (2012)



Debris blockage (Qld)



Flow bypass caused by blockages



Flow bypassing caused by blockages

### Reference document:

*Project 11: Blockage of Hydraulic Structures, Australian Rainfall and Runoff (AR&R), Report Number P11/S2/007, March 2012, Engineers Australia, Barton, ACT*

W. Weeks, G. Witheridge, E. Rigby, A. Barthelmess and G. O'Loughlin

This study resulted in Chapter 6 (*Blockage of Hydraulic Structures*) of Book 6 (*Flood Hydraulics*) of Australian Rainfall & Runoff (2019).

### Fish passage issues

- From a [fish passage](#) perspective, the critical issues are likely to be:
  - potential blockage of essential fish migration during those limited times when fish migration is likely to occur
  - potential blockage of day-to-day fish movement if flood debris is not removed in a timely manner after each flood event
  - the design of debris control structures that can benefit fish passage.

### Flood estimation issues

- From a [flood estimation](#) perspective, the critical issues are likely to be:
  - the quantity and type of debris that would reach the structure in the design event
  - the type, location, porosity, and timing of a blockage at the structure
  - the likely extent and coincidence of such blockages across the catchment
  - the impacts of the blockage on the hydraulic performance of the structure
  - potential impacts on adjacent waterways if the blockage causes a redirection of flows
  - the impacts of the blockage on the catchment, community assets, and public safety
  - the cost of post-flood maintenance.
- The occurrence of all of these issues is not a certainty, which means flood modelling needs to consider the combined probability (likelihood) of such events.

## Glossary of terms used in culvert blockage



Severe sediment blockage (Western Qld)



Blockage material (Qld)



Log 'bridging' across the culvert inlet



Readily available urban debris (Qld)

### Blockage

- 'Blockage refers to the presence of debris within or immediately adjacent to a waterway and drainage structure that reduces that structure's hydraulic capacity.' (AR&R, 2012)

### Blockage matter

- 'Blockage matter refers to the material that is likely to form the primary 'blockage', i.e. the material primarily causing the interference to hydraulic flow.' (AR&R, 2012)
- 'Such material is unlikely to cause full blockage of a structure without the presence of suitable bridging matter.' (AR&R, 2012)

### Bridging matter

- 'Bridging matter refers to the material of sufficient size and strength to bridge across the opening (inlet) of a structure and on which blockage matter can collect, thus potentially resulting in the full or partial blockage of a structure.' (AR&R, 2012)
- 'Bridging matter can be as small as leaves caught on a debris screen, or as large as logs, cars and mattresses trapped at culvert inlets.' (AR&R, 2012)

### Debris availability

- 'Debris availability refers to the presence and quantity of particular types of debris within the source area.' (AR&R, 2012)
- 'The critical types of debris are related to the geometry of the various hydraulic structures located within the catchment and more than one type of debris may need to be considered.' (AR&R, 2012)

## Glossary of terms used in culvert blockage



Easy transportation of floating matter

### Debris transportability

- 'Debris transportability refers to the ease with which the mobilised debris is transported down a stream or along a drainage channel to the structure.' (AR&R, 2012)



Design plans

### Design blockage

- 'Design blockage refers to the most likely blockage conditions that can be expected to occur during a design storm of a given frequency.' (AR&R, 2012)
- 'It is noted that the assessed level of blockage for a 10 year ARI storm may be different from that expected during a 100 year ARI storm.' (AR&R, 2012)
- 'This amount of blockage can be applied in calculation of design flood levels.' (AR&R, 2012)



100 percent blockage of a culvert (Qld)

### Severe blockage

- 'Severe blockage refers to the extent of infrequent blockage that is considered possible during the design life of a given structure, say during exceptionally large floods, but is unlikely to occur on a frequent basis.' (AR&R, 2012)
- 'Though termed 'severe', such blockage may not necessarily represent total blockage of the structure, or even a condition likely to result in severe consequences.' (AR&R, 2012)



Partial blockage of a thin-deck culvert

### Structure interaction

- 'Structure interaction refers to the interaction between debris arriving at a structure and the structure itself.'
- 'It is highly influenced by the quantity and quality of debris arriving at the structure and specific aspects of a structure, such as inlet diameter or waterway width, as these govern the propensity of the structure to block.' (AR&R, 2012)
- 'This is also affected by specific designs of any countermeasures such as debris deflectors that are planned to limit the impact of blockage.' (AR&R, 2012)

## Types of culvert blockage



**Culvert blocked by flood debris (Qld)**



**Woody bridging debris (Qld)**



**100% blockage of a road culvert (Qld)**



**Partial sediment blockage of a culvert**

### Introduction

- Sediment and debris blockages are important because they can:
  - reduce water flow through a culvert
  - reduce fish passage
  - reduce movement of terrestrial fauna.
- Flood debris can consist of:
  - long grasses and leaves
  - woody debris
  - urban litter
  - large floating objects.

### Bridging debris (not the blockage of bridges)

- Even though most flood debris is small enough to pass through a culvert, this material can become trapped at the culvert inlet because:
  - the material wraps around the legs of a multi-cell culvert
  - the material wraps around, or is captured by a network of large woody debris that 'bridges' the culvert opening.
- **Bridging debris** primarily consists of logs and branches.

### Top-down blockages

- Top-down blockages are primarily generated by floating debris, which mainly collects around the top of the culvert cells.
- This can mean that floodwater and fauna can continue to pass under the debris blockage.
- If the flood level rises above the culvert deck, the debris raft can become trapped under traffic barriers, or captured by a fencing/railing system, which can further exacerbate local flooding.

### Bottom-up blockages

- Bottom-up blockages are generated by:
  - the natural migration of bed sediments that have been interrupted by the culvert hydraulics
  - introduced rural or urban sediment runoff.
- If the culvert is correctly sized, then the natural migration of bed sediment should pass freely through the culvert; however, blockages can occur if the culvert is designed to function as a 'pool'.

## Sediment debris



**Natural migration of bed sediment (NSW)**



**Natural migration of bed sediment (NSW)**



**Blockage by clayey sediments (Qld)**



**Blockage by clayey sediments (Qld)**



**Blockage by gravel sediments (Qld)**



**Blockage by sandy sediments (USA)**



**Blockage by boulders (Qld)**



**Blockage by boulders (Qld)**

## Floating debris



**Debris wrapped around culvert legs (Qld)**



**Debris trapped by traffic barriers (Qld)**



**Woody bridging debris (Qld)**



**Woody bridging debris (Qld)**



**Large woody debris (NSW)**



**Woody bridging debris (Qld)**



**Debris trapped by handrails (Qld)**



**Debris trapped by traffic barriers (Qld)**

**Urban flood debris**



**Plastic storage box (Qld)**



**Residential garbage bin (Qld)**



**Residential garbage bins (Qld)**



**Plastic water tank (Qld)**



Photo supplied by Qld. Dept. Environment and Resource Management

**Steel shipping container (Qld)**



**Steel shipping container (Qld)**



Photo supplied by Brisbane City Council

**Commercial rubbish and recycle bins**



**Cars (NSW)**

## Potential impacts of debris and sediment blockages



**Debris caught on experimental baffles**

### Blockage of fish passage baffles

- Depending on the design of the fishway, flood debris can wrap around parts of the fishway:
  - causing debris to become trapped inside the culvert, which increases the difficulty and cost of maintenance
  - interfering with fish passage.



**Low-level blockage of a road culvert**

### Blockage of the culvert entrance

- The partial blockage of a culvert may, or may not, be a significant issue with regards to local flooding.
- Such minor blockages may not attract a high priority for maintenance personnel, but such blockages can stop 100% of the day-to-day movement of fish.
- Fish passage can be improved if the trapped debris can be held in an elevated position above the low-flow water level.



**Sediment blockage of road culvert**

### Impact of fine sediments

- It is typical for sediment blockages not to adversely affect fish passage; however, excessive sediment deposition can:
  - reduce the penetration of sunlight into the culvert
  - increase the concentration of sediment suspended in the water column that fish are expected to swim through
  - smother baffle installed on the culvert floor.



**Sediment and boulders in a fishway**

### Impact of coarse sediments

- Coarse sediment, such as cobbles and boulders, can:
  - cause this material to become trapped within a fishway, both inside and outside of the culvert, which increases the difficulty and cost of post-flood maintenance work
  - interfering with fish movement along the fishway.

## Typical source of flood debris



Photo supplied by Brisbane City Council

**Urban flood debris (Qld)**

### Urban flood debris

- Urban flood debris can include: fence palings, building materials, mattresses, garbage bins, shopping trolleys, fridges, large industrial containers and vehicles.
- Floating bins can vary in size from small domestic bins to large metal containers.
- The availability of organic debris can be linked to the severity of the winds during a storm event, or during the weeks leading up to a storm.



Photo supplied by Catchments & Creeks (2013)

**Deposition of large rocks at culvert inlet**

### Categories of urban flood debris

- The author questions the value of categorising flood debris according to its size because, what is considered large debris for a 300 mm conduit, would likely be considered small debris for a 3000 mm conduit.
- It is important to note that 'large' boulders (> 450 mm) can originate from both rural and urban catchments.

**Table G1 – Types and sources of debris**

Type of debris	Typical sources of debris
Litter	<ul style="list-style-type: none"> <li>• General urban litter (e.g. cans, plastic bags, takeaway food containers).</li> <li>• Loose material blown off building sites.</li> </ul>
Leaves	<ul style="list-style-type: none"> <li>• Local trees as a result of strong winds.</li> <li>• In the 16 November 2008 storms in western Brisbane suburbs were littered with green gum leaves stripped from Brisbane Forest Park and associated bushland.</li> </ul>
Grass	<ul style="list-style-type: none"> <li>• Cut grass washed from rural and urban properties.</li> <li>• Cut grass from the mowing of public open spaces.</li> <li>• Tall grasses associated with weed infested creeks.</li> </ul>
Garden mulch	<ul style="list-style-type: none"> <li>• Garden mulch from overland flow paths within urban areas.</li> <li>• Natural mulch from bushland areas.</li> </ul>
Reeds	<ul style="list-style-type: none"> <li>• Aquatic reeds from urban and rural creeks.</li> </ul>
Woody debris	<ul style="list-style-type: none"> <li>• Storm damage of trees and shrubs from urban areas.</li> <li>• Flood damage of riparian vegetation.</li> </ul>
Sediment	<ul style="list-style-type: none"> <li>• Building and construction sites.</li> <li>• Road surfacing material.</li> <li>• Erosion of gullies and watercourses.</li> </ul>
Building material	<ul style="list-style-type: none"> <li>• Loose material blown off building sites.</li> <li>• Large debris from flood damaged buildings – typically affects larger culverts and bridges.</li> </ul>
Cars	<ul style="list-style-type: none"> <li>• Cars and other vehicles swept down waterways by floodwaters.</li> </ul>

## Expected sediment flow in various waterways



Urban sediment runoff (Qld)

### Clay-based **minor** waterways (creeks)

- High sediment flows are generally not natural in clay-based creeks, but can be in clay-based rivers.
- High sediment flows can result from changing catchment conditions (land clearing or bushfire), and urban development.
- A high sediment inflow can completely smother the low-flow channel, and cause the culvert's bed to become permanently saturated, thus inhibiting terrestrial movement.



Sediment slugs in the Hunter River (NSW)

### Clay-based **major** waterways (rivers)

- High sediment flows (i.e. silt and mud) should be expected in large clay-based waterways during flood events.
- Aquatic and terrestrial passage designs must allow for the high sediment flow.
- Fortunately, most waterway crossings over large waterways consist of bridges, which by their very nature are usually compatible with high sediment flows.



Deposition of sand in a culvert (USA)

### Sand-based waterways

- High sediment (sand) flow should be expected in sand-based waterways.
- Rock lined low-flow channels are generally not compatible with these waterways.
- Sediment flows are best managed by varying the invert levels of multi-cell culverts to simulate the waterway's natural bed profile.

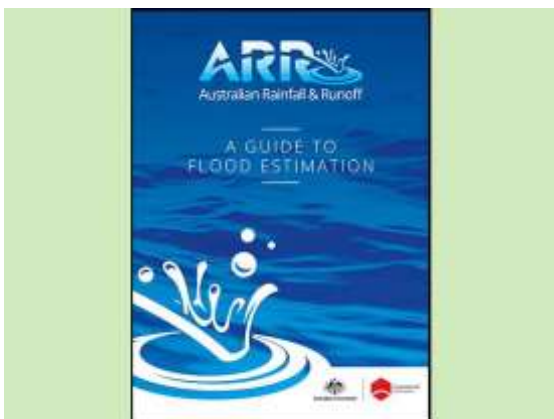


Deposition of natural bed gravel (Qld)

### Gravel-based waterways

- Significant sediment (rock/gravel) movement normally occurs during the more severe flood events.
- Low-flow channels are usually able to survive in these waterways, but expect the waterway to form its own channel.
- Urban development of the catchment **must** incorporate adequate sediment controls to prevent the deposition of silt and mud into these waterways.

## Assumed blockage conditions for flood mapping



Australian Rainfall & Runoff, 2019

### Reference document:

*Australian Rainfall and Runoff (AR&R)*, Engineers Australia, ACT. 2019.

The primary reference document for flood estimation investigations should be:

- **Chapter 6** (*Blockage of Hydraulic Structures*) of Book 6 (Flood Hydraulics)



Photo supplied by Catchments & Creeks Pty Ltd

Example of a low level of debris blockage

### Smaller, more frequent floods (AEP > 5%)

- Recommended design conditions are:
  - If the catchment has been assessed as having a **high risk of debris production**, then adopt medium level of debris blockage.
  - **Medium risk of debris production**, then adopt low level of debris blockage.
  - **Low risk of debris production**, then adopt low level of debris blockage, say 10%.



Photo supplied by Catchments & Creeks Pty Ltd

Medium level of debris blockage

### Medium floods (AEP 5% to 0.5%)

- If the catchment has been assessed as having a **high risk of debris production**, then adopt high level of debris blockage.
- **Medium risk of debris production**, then adopt medium level of debris blockage, say 20%.
- **Low risk of debris production**, then adopt low level of debris blockage.



Photo supplied by Catchments & Creeks Pty Ltd

High level of debris blockage

### Major floods (AEP < 0.5%)

- If the catchment has been assessed as having a **high risk of debris production**, then adopt high level of debris blockage.
- **Medium risk of debris production**, then adopt high level of debris blockage.
- **Low risk of debris production**, then adopt medium level of debris blockage.
- The adoption of 100% blockage is only used to set upstream flood levels, not downstream flood levels.

## Reducing the effects of debris blockages



Floodplain culvert with well-spaced cells

### All culverts

- Steps that can be taken to reduce the risk of debris blockage include:
  - maximise the clear height of the culvert cells, even if this results in the culvert having a hydraulic capacity that exceeds the design standard
  - maximise the clear width of the culvert cells
  - separating individual culvert cells to reduce the risk of debris wrapping around the connecting culvert leg.



Debris deflection walls, 1995 (Qld)

### Debris deflection walls

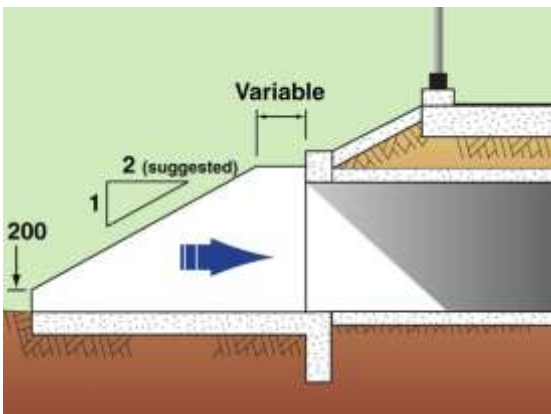
- One means of maintaining the hydraulic capacity of culverts in high debris streams is to construct [debris deflector walls](#).
- The purpose of these walls is to allow the debris raft:
  - to be held away from the culvert entrance
  - to rise with the flood, and ultimately to rest high on these walls, thus allowing fish passage to continue.



Post-flood condition, 1995 (Qld)

### Fish passage benefits

- If the debris raft can be lifted above the channel bed, then fish passage can occur under the debris raft.
- If the debris raft remains held above the channel bed after the flood, then this critical period of fish passage can continue while the culvert waits for post-flood maintenance.

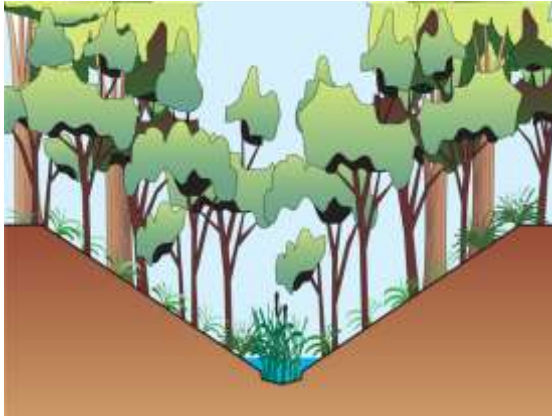


Typical debris deflection wall dimensions

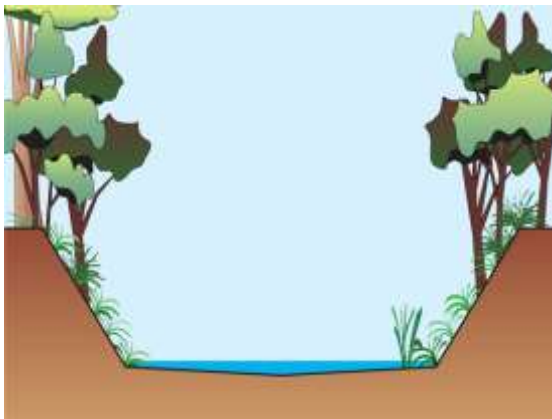
### Design details

- Debris deflector walls typically have a leading edge slope of (1V:2H).
- If conditions allow, a ledge can be formed at the top of the walls to hold the debris raft once the flood peak has passed.

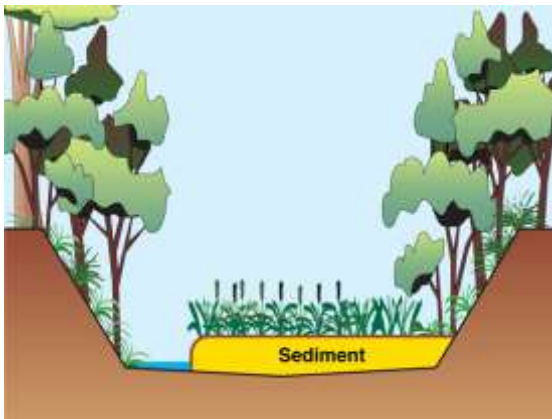
## The typical response of a creek to channel widening



The creek's natural cross-section



Flood mitigation channel widening



Response of the creek



Creek's response to channel widening

### Introduction

- In order to understand why sediment blockages often occur in wide, multi-cell culverts, we can study how a creek responds to a widening of its channel.
- Clay-based waterways generally have a V-shaped profile (cross-section), while sand and gravel-based waterways are likely to have a wide flat bed, which gives these waterways more of a U-shaped profile.

### Flood mitigation works

- If a region experiences significant property flooding, then community pressure can force authorities to carry-out flood mitigation works, such as the widening on the waterway channel.

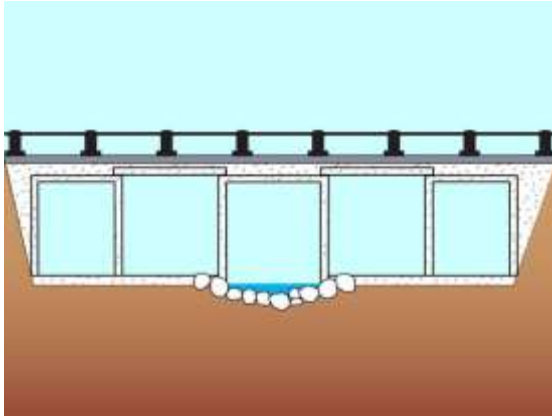
### Long-term outcome of channel widening

- The long-term outcome of such channel widening is usually the accumulation of a sediment on the bed of the channel.
- What the creek is trying to do is return itself back to a 'stable' cross-section, with a narrow low-flow channel.
- Examples of this sediment-filled benching can be seen in the photos below, which are both examples of past flood mitigation activities (i.e. channel widening).

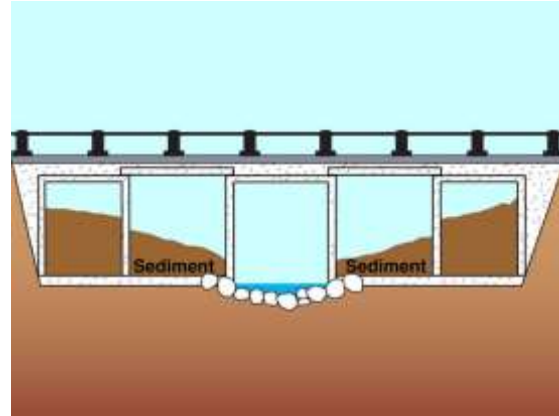


Sediment benching in a widened creek

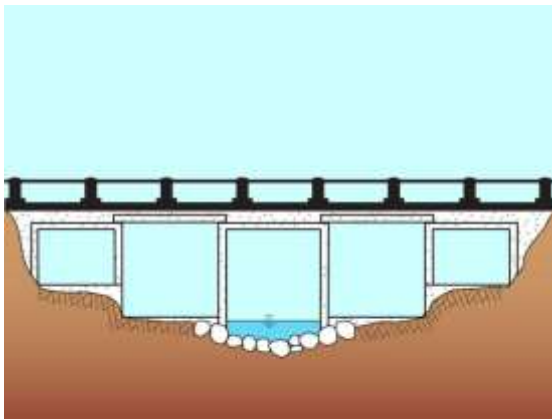
## Sediment control options at culverts



Wide-bed culvert (as built!)



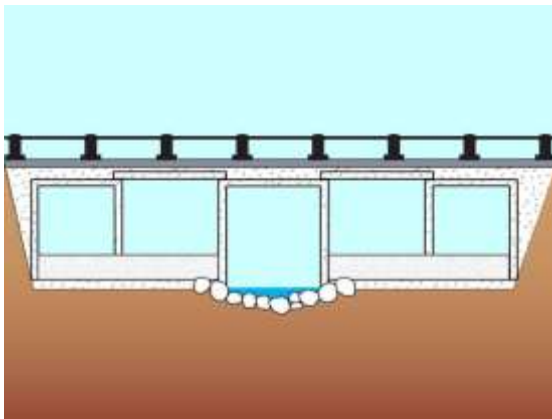
Wide-bed culvert (with sedimentation)



Complex multi-cell culvert

### Variable floor level multi-cell culverts

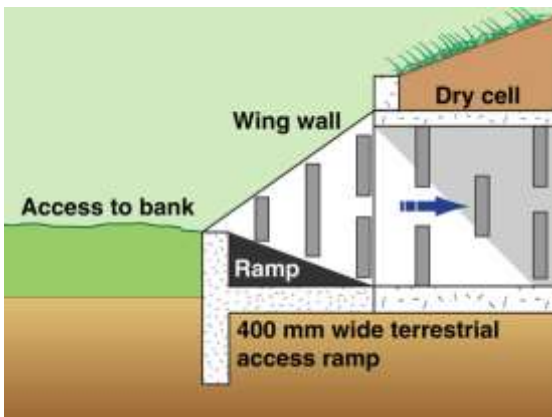
- Creeks respond to a wide multi-cell culverts in the same way they respond to channel widening—they allow the outer cells to fill with sediment.
- One solution to this problem is to construct the culvert with **variable invert levels** such that the profile of the base slab simulates the natural cross-section of the channel.
- However, this option may not provide the culvert with sufficient flow area for flood control, or fish passage.



Sediment training walls

### Wide-bed culverts with sediment training walls

- An alternative solution is to construct a **sediment training wall** in front of the nominated dry cells.
- These low walls must completely isolate the dry cells from any dry-weather flows.
- Debris deflection walls can be integrated into the design of these sediment training walls.

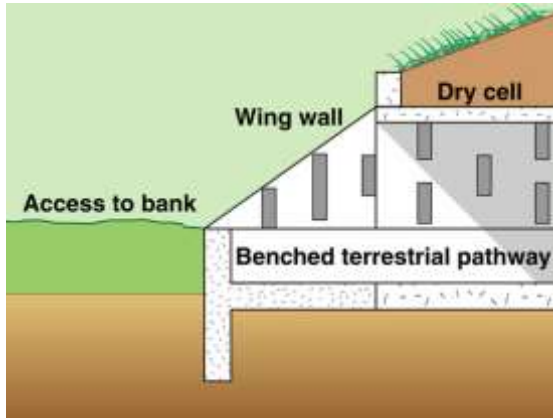


Terrestrial passage features

### Allowance for terrestrial passage

- Sediment training walls and debris deflector walls can be combined to solve a number of common culvert maintenance problems.
- Sediment training walls allow sediment to be deposited upstream of the culvert where it can be removed.
- Various designs can be used to allow terrestrial passage over these low walls.

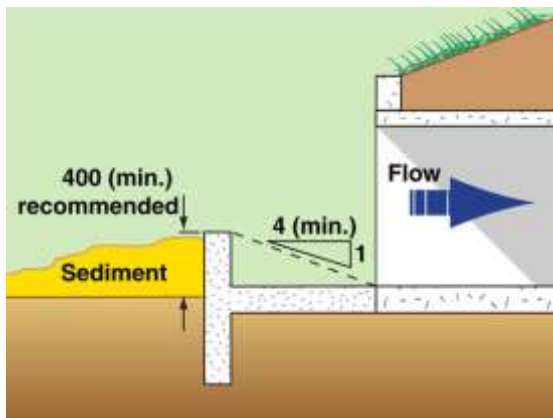
## Sediment control options at culverts



Terrestrial passage features

### Terrestrial passage features

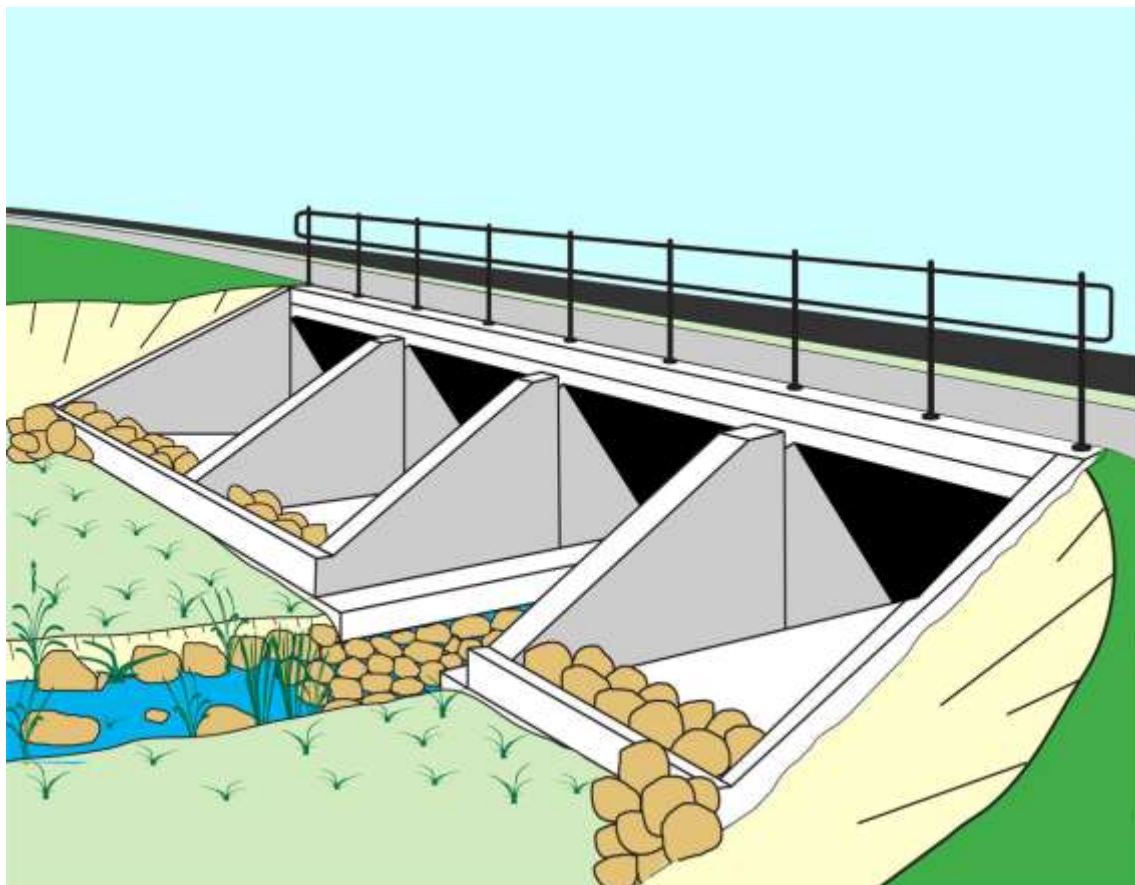
- Terrestrial passage, specifically the movement of turtles, can be aided with the inclusion of:
  - concrete ramp (previous page)
  - a raised terrestrial pathway bench (left)
  - grouted rock ramps (below).
- It is essential for the terrestrial pathway to join with the creek bank.



Hydraulic design

### Design of sediment training walls

- Sediment training walls need to be placed well-away from the culvert's entrance in order to allow for the free passage of flood waters into the culvert.
- The walls need to be at least 300 to 500 mm high (the author recommends a minimum height of 400 mm).



Multi-cell culvert with debris deflection walls and sediment training walls

## Debris traps placed upstream of culverts



**Safety poles (NSW)**



**Pile field (NSW)**



**Trash rack (ACT)**



**Debris impact pole (SA)**

### Introduction

- Various debris capture systems can be installed upstream of high-risk culverts.
- A 'high-risk' culvert is a culvert where any form of debris blockage would adversely affect flooding that has the potential to enter buildings.

### Pile fields

- Pile fields can be used for a variety of purposes in waterways, including:
  - debris collection
  - debris impact poles
  - human safety (to reduce the risk of a person being swept into a culvert)
  - flow diversion system (to guide flows around a channel bend)
  - a buried erosion control system (to limit the extent of bed erosion)
  - outlet energy dissipation (image left).

### Trash racks

- Trash racks of various designs have been used in urban waterways as part of an overall stormwater quality system.
- Trash racks can be used to keep debris away from culverts.
- These trash racks are used in non-fish habitat regions of urban waterways (typically constructed stormwater drains).

### Debris impact poles

- Debris impact poles can be used to:
  - prevent debris rafts collecting around bridge piers
  - reduce the risk of high-energy impacts on bridge piers (a structural engineering issue).

# Debris Blockage of Traffic Barriers



Photo supplied by Catchments & Creeks Pty Ltd

**Floodwater passing over approach road**

## **Pavement damage during overtopping flows**

- Floodwaters overtopping culverts can cause damage to road pavements.
- In some cases this damage can be the result of excessive hydraulic pressure gradients, rather than excessive flow velocities.



**Road pavement lifted by floodwater (Qld)**

## **Pavements lifted by pressure gradients**

- It takes a large force to lift a road pavement, which can be achieved by a small pressure applied to a large area.
- The pressure differential acting on a flooded pavement may be small, but because a 'new' pavement is a continuous surface (i.e. not cracked), the area over which this pressure acts can be very large.
- If the weight of water pushing down on a pavement is exceeded by the hydraulic force pushing up on the pavement, then the pavement can lift.



Photo supplied by Catchments & Creeks Pty Ltd

**Flood damage to grouted stone-pitching**

## **Failure of scour protection on abutments**

- We know that adverse hydraulic pressures can cause, or at least contribute to, the failure of hard-skin scour control measures such as grouted stone-pitching.
- The adverse pressure gradients result from the fact that the water pressures on the outside of the stone-pitching vary with the flow velocity; however, the water pressure under the stone-pitching is dependent on the water pressure adjacent to the nearest weep hole or surface crack.
- The same issues can apply to pavements.

## Potential pressure changes under flooded pavements

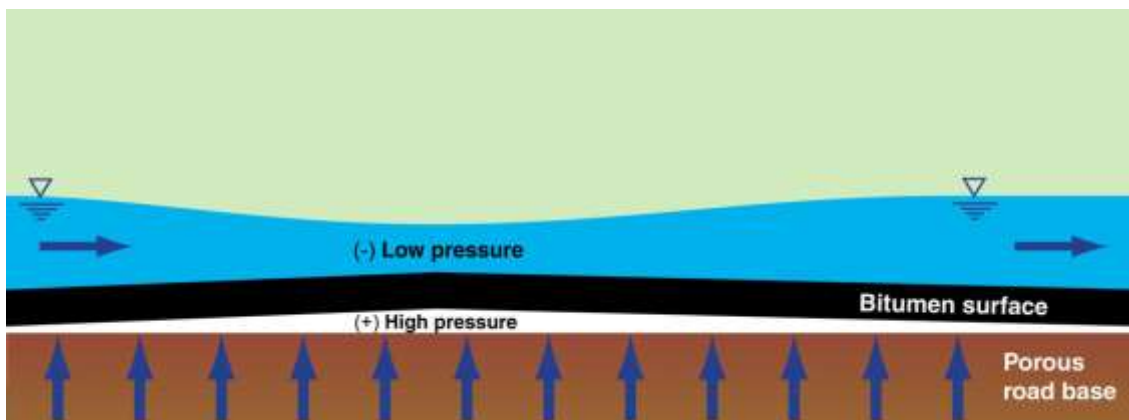


Photo supplied by Catchments & Creeks Pty Ltd

Floodwaters passing over a road (Qld)

### Flooded roads

- As shallow floodwaters pass over the crown of a floodway there can be an acceleration in flow velocity above the crown, which causes a reduction in water level, and the weight of water bearing down on the pavement.
- The upward water pressure in the **porous road base** under the pavement can be governed by the water pressure at the edge of the road (where the road base is in contact with the floodwater), which is greater than the downward weight of the water above the pavement.



Variations in hydraulic pressure during minor overtopping of a roadway



Gowrie Creek, Toowoomba, Qld, 2011

### Highly variable flow conditions

- When high-velocity floodwaters overtop a culvert, both the flow velocity and flow depth can be highly variable if standing waves are formed on either side of the road.
- Standing waves can be generated by the edge of the culvert, or as a result of rapid changes in flow velocity.

(The example of standing waves shown below is on a bridge crossing rather than a culvert crossing.)



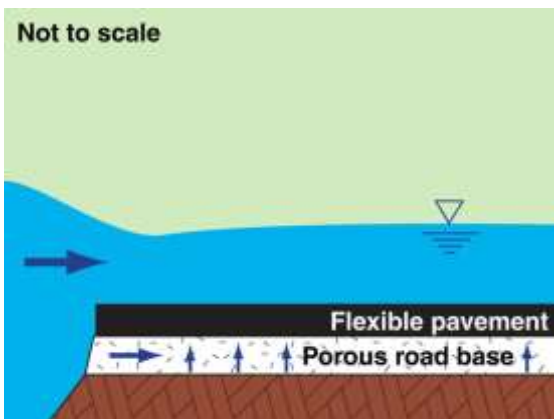
Mount Sylvia Rd, East Haldon, Qld, 2010



Photo supplied by Catchments & Creeks Pty Ltd

Same bridge (left) post flood, 2011

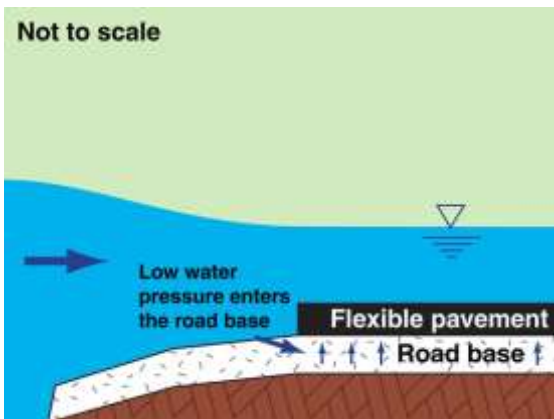
## Potential pressure changes under flooded pavements



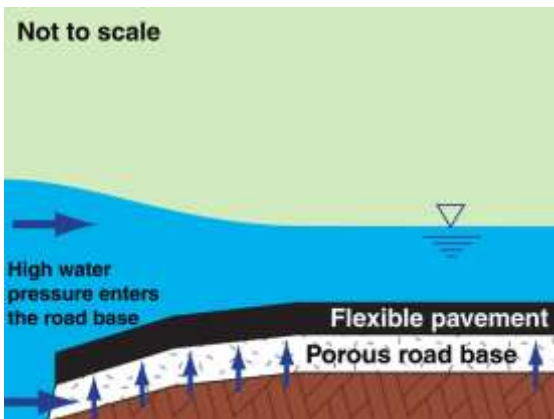
Hydraulic uplift pressures



Displaced pavement (Qld)



Open shoulder on a road floodway



Sealed shoulder on a road floodway

### Hydraulic uplift pressures

- As previously discussed, if the weight of water pushing down on a pavement is exceeded by the hydraulic pressure pushing up on the pavement through the road base, then the pavement can lift.
- Once the pavement lifts, pressures above and below the pavement quickly equalise, resulting in the pavement quickly falling back onto the road; however, in that short period, fast-flowing floodwaters can move the pavement a few metres downstream.

### Age of the road pavement

- This type of pavement damage requires large areas of the pavement to be free of cracks that would otherwise help to equalise pressure gradients.
- This means pavement failures are more likely to occur when a flood event occurs **just after** a road is constructed, or after a new pavement has been laid.

### Open road shoulder

- If the edge of the pavement is located away from the edge of an elevated road, then the water depth at the edge of the pavement may have already reduced in depth as a response to the increased flow velocity.
- This means the hydraulic pressure under the pavement may be close to the pressure above the pavement, which means pavement failure is **unlikely** to occur.

### Sealed road shoulder

- If the edge of the pavement extends to the edge of an elevated road, then the water depth at the edge of the pavement may be significantly higher than the water depth passing over the road.
- This means the hydraulic pressure under the pavement may be significantly greater than the pressure above the pavement, which means pavement failure is more likely to occur during a flood event.
- Of course it can take some time for these hydraulic pressures to build-up under the pavement.

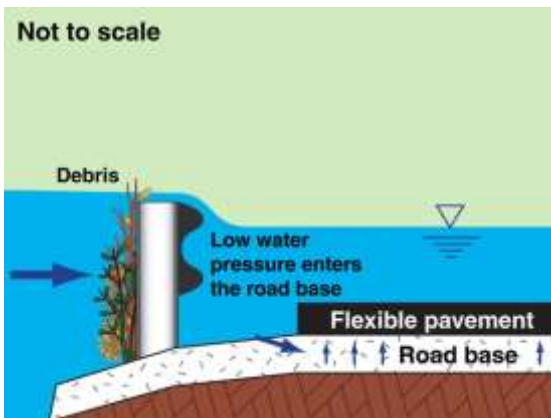
## The potential effects of guardrails on pavement failures



Floodwater passing under a guardrail

### The potential impact of a guardrail on a pavement failure

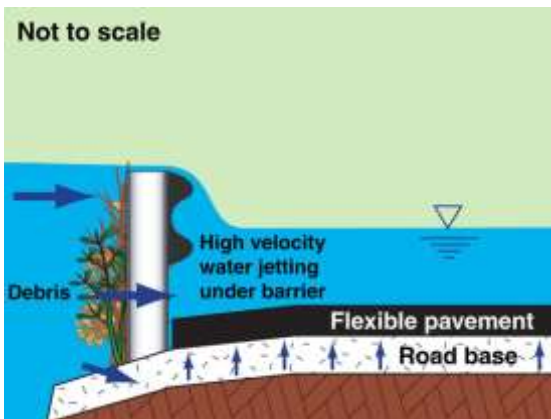
- The author has had discussions with road maintenance personnel that have claimed that a particular pavement failure occurred just after a guardrail was installed along the floodway.
- Prior to the installation of the guardrail, the road had experienced several flood events without pavement failure.
- Of course the failure may also be linked to any resurfacing of the pavement.



Pavement edge away from a guardrail

### Pavement edge away from a guardrail

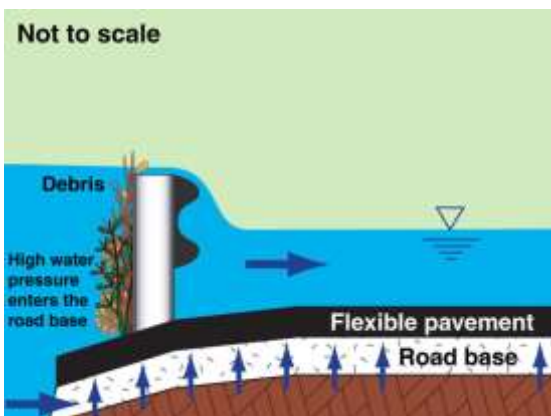
- If the edge of the pavement is located away from the guardrail, then the water depth at the edge of the pavement may have already reduced.
- This means the hydraulic pressure under the pavement may be close to the pressure above the pavement, which means pavement failure is unlikely to occur.



Pavement edge near a guardrail

### Pavement edge near a guardrail

- If the edge of the pavement is located near the guardrail, then the water depth at the edge of the pavement may be higher than the water depth passing over the road.
- This means the hydraulic pressure under the pavement may be significantly greater than the pressure above the pavement.
- Water 'jetting' under the guardrail can also help to lift the edge of a weakened pavement.



Pavement edge beyond a guardrail

### Pavement edge beyond a guardrail

- If the edge of the pavement extends beyond the guardrail, then the water depth at the edge of the pavement will likely be significantly higher than the water depth passing over the road.
- This means pavement failure is more likely to occur during a flood event.
- Debris blockage of the guardrail will likely increase the adverse pressure gradient acting on the pavement.

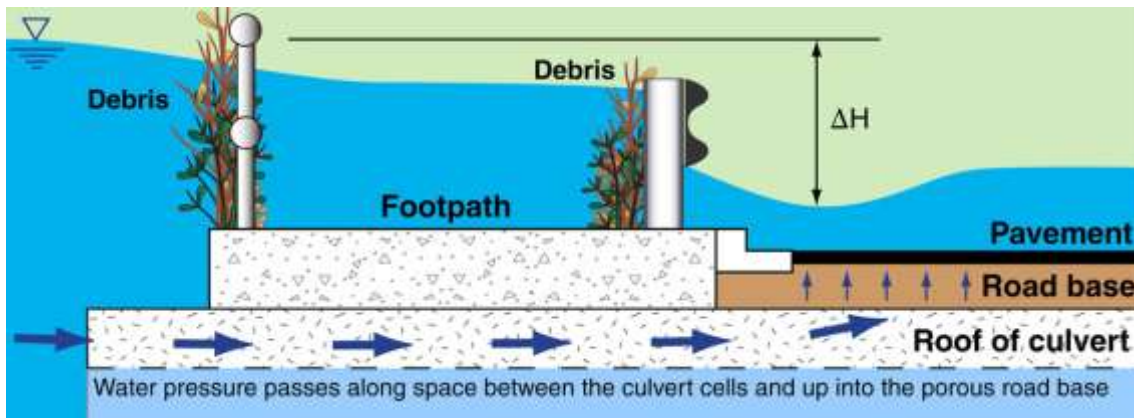
## Pavement failure at culvert crossings



### Porous road base placed on a road culvert

- In this case (left) a concrete deck was not formed over the box culverts because a minimum deck thickness was desired for reasons of flood control.
- Instead, a porous road base was placed directly on the box culverts, and then the pavement was placed on the road base.
- During an overtopping flood, high water pressure passed between the legs of the box culverts, and up into the road base, lifting the newly laid pavement.

### Pavement failure over a culvert (Qld)



### High water pressure passes between the culvert legs and up into the porous road base



### Open gap between culvert legs

### Open gap between the culvert legs

- The above mentioned pavement failure was caused by the fact that the gap between the legs of a box culvert was not filled with grout (as required by some organisations).
- If the box culverts are covered with a concrete deck, then such an impervious deck can prevent high water pressures passing up into the road base.



### Gap between culvert legs filled with grout

### The gap between the culvert legs filled with grout

- Some construction drawings specify that a 50 mm gap must exist between each culvert leg, and that this gap must be filled with pumped grout.
- As discussed above, this construction detail prevents water pressures passing between the culvert legs.

# **Appendix H: Safety Risks at Culvert Crossings**

## Introduction



Queensland Urban Drainage Manual

### Reference document:

*Queensland Urban Drainage Manual (QUDM)*

Institute of Public Works Engineering Australia, Queensland Division and the Department of Energy and Water Supply. Brisbane, Australia, 4th edition, 2017.

Particularly:

### Chapter 12 – Safety Aspects



Broken arm

### Safety hazards

- The potential injuries a person may experience if swept through a culvert can include:
  - physical harm, such as broken bones
  - short or long-term psychological trauma
  - brain damage
  - drowning
  - death.



Unstable ground

### Factors of influence

- The hazards experienced by persons passing through a culvert can be influenced by factors such as:
  - ambient lighting conditions (time of day)
  - depth and velocity of flow
  - the rate of rise in water level
  - stability of the ground surface upstream of the culvert, such as the edge of a bank
  - the presence of large, submerged, or sharp debris trapped at the entrance to the culvert
  - the presence of large, submerged, or sharp objects within the culvert, such as fish passage baffles
  - the presence of large, submerged, or sharp objects at the culvert outlet, possibly associated with energy dissipation measures
  - the person's footwear and clothing (e.g. the drag caused by loose or heavy clothing).



Dangerous waters

## Risk management options



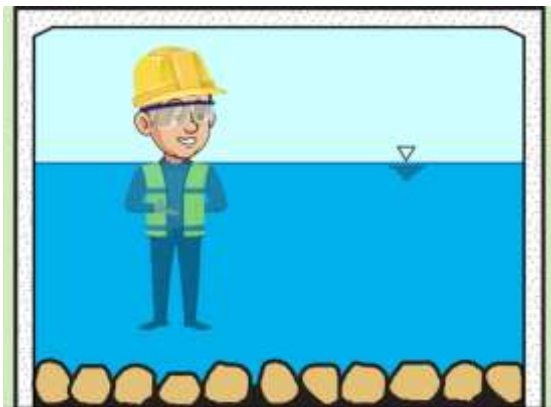
Safe waters (NSW)



Safe creek banks (constructed channel)



Warning sign (NSW)



Good headroom

## Risk management options

- The safety risks associated with waterway culverts can be managed, but not necessarily eliminated, through the use of appropriate design and management techniques, including:
  - designing flow conditions so that the waters do not present a risk of injury or death (**first priority**)
  - shaping the waterway banks in a manner that minimises the risk of a person accidentally falling or slipping into the waters (**high priority**)
  - designing or shaping the land and environments, in and around a culvert, in a manner that discourages an adult or child wanting to enter, or play in, the waterway during a storm or flood event (**high priority**)
  - designing systems that allow a person to readily exit a drain or waterway before they are swept into a culvert
  - designing long culverts in a manner that maximises the likelihood of the culvert flowing partially full (i.e. not submerged) during a storm or flood event
  - erecting warning signs to alert people of potential dangers
  - erecting external barriers (e.g. fencing) to limit the entry of persons into the upstream waters
  - erecting in-channel screens, or catch-poles, upstream of the culvert
  - erecting inlet safety screens on the culvert (**generally considered the least preferred option due to increased flooding risks, and the safety hazards associated with the increased flood risk**)
  - public education programs.

## Long culverts

- Unless otherwise agreed, a '**long culvert**' is a culvert with a flow travel time in excess of 10 seconds.
- Wherever possible, the potential 'headroom' within a flowing culvert should be maximised for the purpose of reducing the risk of a person being fully submerged as they pass through a culvert.
- Unfortunately, existing services, such as sewerage and water supply pipes, passing over the culvert often limits the height of the culvert's obvert (roof).

## The impact of deck thickness on ‘fish passage’ and ‘human safety’



Box culvert with deep deck (Qld)

### Potential problems caused by deep deck profiles

- The potential problems caused by a deep culvert deck include:
  - reduced hydraulic capacity
  - increased hydraulic entrance losses (in real terms)
  - potential changes in flow velocity when the culvert is flowing full
  - increased probability of the culvert operating in a full, or near-full condition, during storm events.



Culvert with exposed services (Qld)

### Possible reasons why a culvert may be forced to have a deep deck

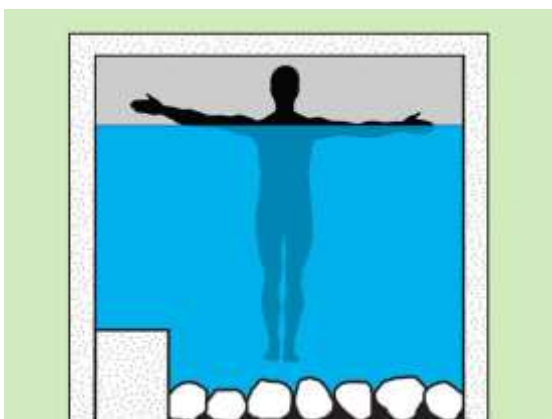
- The most common reason for a deep deck is the need for the culvert cells to pass under existing services (pipes and cables) that run along the road reserve.
- The image shown left is a rare example of a culvert with non-related pipe work passing through the culvert.



Rural, multi-cell box culvert (NSW)

### Typical culvert deck thickness/depth

- The average deck thickness is around 1 m, which consist of:
  - roof thickness of the pre-cast cells
  - thickness of a bridging slab (if used)
  - the covering concrete slab
  - road kerb, footpath and/or the foundation beam for a handrail or guardrail.
- Some designers have gone to extremes to minimise the thickness of the top deck (as shown left).



Safer flow condition relative to flowing full

### Public safety issues

- The taller the culvert cell, the greater the probability of the culvert flowing partially-full during storm events.
- Having a reasonable air gap between the flood level and the culvert's obvert gives any person swept through the culvert the greatest chance of survival.
- For trapped humans, the most dangerous flow condition is when the culvert is flowing full.

## Safety risk ranking system

The following safety risk ranking system was initially developed for Brisbane City Council, and later presented within the *Queensland Urban Drainage Manual* (2017).

**Table H1 – Contact classification**

Contact class	Location description
<b>Class A1</b>	Within or immediately adjacent to a school or childcare centre, including the adjoining road reserve, where access to the inlet or upstream channel is unrestricted and/or there is reasonable risk of a person being swept towards the inlet during a storm or flood.
<b>Class A2</b>	As above except access to potentially dangerous waters or inlets is unlikely and/or severely restricted. If full exclusion fencing exists, then Class D applies.
<b>Class B1</b>	Within 100 metres of an existing or future urban residential area, or public gathering area, such as a park, shopping centre, entertainment or sporting facility. Access to the inlet or upstream channel is unrestricted and/or there is reasonable risk of a person being swept towards the inlet during a storm or flood.
<b>Class B2</b>	As above except access to potentially dangerous waters or inlets is unlikely and/or severely restricted. If full exclusion fencing exists, then Class D applies.
<b>Class C1</b>	More than 100 metres from a school, park, childcare centre, or existing or future urban residential area. Access to the inlet or upstream channel is unrestricted and/or there is reasonable risk of a person being swept towards the inlet during a storm or flood.
<b>Class C2</b>	As above except access to potentially dangerous waters or inlets is unlikely and/or severely restricted. If full exclusion fencing exists, then Class D applies.
<b>Class D</b>	Within an area surrounded by heavily trafficked arterial roads, childproof fencing, or is otherwise considered inaccessible (legally or illegally) to the general public.

**Table H2 – Potential safety risks associated with a conduit flowing full** <sup>[1]</sup>

Ranking	Hydraulic capacity of pipe/culvert
<b>Low</b> (score 1)	<i>Intent: Site conditions mean that the conduit is <b>unlikely</b> to be flowing full or near-full during an incident, thus a trapped person is likely to be able to breathe freely while passing through the conduit.</i> <b>Typical assessment condition:</b> Conduit capacity is greater than or equal to 2% AEP.
<b>Medium</b> (score 3)	<i>Intent: Site conditions mean that there is a reasonable chance that the conduit will not be flowing full or near-full during an incident.</i> <b>Typical assessment condition:</b> Conduit capacity is greater than 39% AEP (2 year ARI) and less than 2% AEP.
<b>High</b> (score 6)	<i>Intent: Site conditions mean that the conduit is <b>likely</b> to be flowing full or near-full during an incident resulting in a trapped person being submerged while passing through the conduit.</i> <b>Typical assessment condition:</b> Conduit capacity is less than or equal to 1 in 2 years ARI.

[1] This table may be considered to represent likely consequences if it is accepted that the risk of drowning is directly related to the probability of the pipe or culvert flowing full.

**Table H3 – Potential safety risks associated with the length of the conduit**

Ranking	Hydraulic capacity of pipe/culvert
<b>Low</b> (score 1)	<p><i>Intent: Site conditions mean that a trapped person is likely to take less than 10 seconds to pass through the conduit.</i></p> <p><b>Typical assessment condition:</b>                      Conduit length is less than or equal to 30 metres.</p>
<b>Medium</b> (score 3)	<p><i>Intent: Site conditions mean that a trapped person is likely to take 10 to 20 seconds to pass through the conduit.</i></p> <p><b>Typical assessment condition:</b>                      Conduit length is greater than 30 and less than 60 metres.</p>
<b>High</b> (score 6)	<p><i>Intent: Site conditions mean that a trapped person is likely to take more than 20 seconds to pass through the conduit.</i></p> <p><b>Typical assessment condition:</b>                      Conduit length is greater than or equal to 60 metres.</p>

**Table H4 – Potential safety risks associated with flow conditions within a conduit <sup>[1]</sup>**

Ranking	System	Example flow and conduit conditions <sup>[2]</sup>
<b>Low</b> (score 1)	Any system	<ul style="list-style-type: none"> <li>Conduit containing junction pits without a change-of-direction.</li> </ul>
<b>Medium</b> (score 3)	Any system	<ul style="list-style-type: none"> <li>Low velocity (&lt; 1 m/s) stormwater pipe or culvert containing an internal split-flow chamber, change-of-direction junction pit, or drop-pit less than 1 m in fall.</li> <li>Conduit discharging to a low-risk (non-impact) energy dissipater.</li> </ul>
<b>High</b> (score 6)	Culvert	<ul style="list-style-type: none"> <li>High velocity (&gt; 1 m/s) culvert containing an internal split-flow chamber.</li> <li>Culvert discharging to a high-risk energy dissipater (e.g. impact structure).</li> </ul>
	Stormwater pipe	<ul style="list-style-type: none"> <li>Conduit containing a covered deepwater chamber (e.g. enclosed GPT) accessible to a person being washed through the pipe.</li> <li>High velocity (&gt; 1 m/s) conduit containing a split-flow chamber, change-of-direction junction pit, or drop-pit.</li> <li>Conduit discharging to a high-risk energy dissipater (e.g. impact structure).</li> </ul>

**Notes:**

- [1] The intent of this table is to assign the risks associated with a person experiencing serious head or otherwise fatal injuries while passing through a conduit, or as a result of a person exiting the conduit onto an energy dissipater.
- [2] In this case it is assumed that an outlet energy dissipater is part of the internal flow conditions of the conduit.

**Table H5 – Potential risks associated with flow conditions at the outlet of a conduit <sup>[1]</sup>**

Ranking	Flow conditions
<b>Low</b> (score 1)	<p><i><b>Intent:</b> Outlet conditions represent a low risk of drowning or head injuries and favourable conditions for rescue.</i></p> <p><b>Examples:</b></p> <ul style="list-style-type: none"> <li>• Open water, low velocity channel with good egress.</li> </ul>
<b>Medium</b> (score 3)	<p><i><b>Intent:</b> Outlet conditions represent a low risk of drowning or head injuries, but egress may be difficult and/or questionable conditions exist for rescue.</i></p> <p><b>Examples:</b></p> <ul style="list-style-type: none"> <li>• Deep and/or high-velocity water downstream of the outlet.</li> <li>• Outlet to turbid waters more than 1200 mm deep.</li> <li>• Outlet to waters not in clear sight of a potential rescuer.</li> </ul>
<b>High</b> (score 6)	<p><i><b>Intent:</b> Outlet conditions represent a high risk of drowning or head injuries, and/or egress may be difficult, and/or adverse conditions exist for rescue.</i></p> <p><b>Examples:</b></p> <ul style="list-style-type: none"> <li>• Outlet to waters with no egress.</li> <li>• Outlet to waters not accessible to a potential rescuer.</li> </ul>

**Note:**

[1] The intent of this table is to assign the risks associated with a person (after passing through a conduit) entering dangerous waters where the person may drown or be placed in a position where rescue will be difficult.

**Table H6 – Risk ranking matrix**

	Cumulative consequence score <sup>[1]</sup>				
	1 – 4	5 – 9	10 – 14	15 – 19	20 – 24
Contact class	Risk ranking <sup>[1]</sup>				
A1	13	7	4	2	1
A2, B1	16	12	8	5	3
B2, C1	18	14	11	9	6
C2, D	20	19	17	15	10

**Notes:**

- [1] The cumulative consequence score is determined by summing the values from Tables H2 to H5.
- [2] A ranking of '1' represents the highest risk. A ranking of '20' represents the lowest risk. Within each ranking allotment a secondary ranking may be achieved based on the cumulative consequence score (i.e. a ranking of 8 with a Cumulative Consequence Score of 14 would rank higher than a ranking of 8 with a score of 10).

Table H7 provides a guide to the selection of site mitigation works of various safety risks at culverts and stormwater inlets.

**Table H7 – A guide to mitigation options for various safety risks** <sup>[1]</sup>

Class	Cumulative consequence score				
	1 – 4	5 – 9	10 – 14	15 – 19	20 – 24
A1	Case 2	Case 1			
A2, B1		Case 3			
B2, C1	Case 6	Case 5	Case 4		
C2, D	Case 9	Case 8	Case 7		

[1] This table is presented as a guide only. Indicated outcomes do not represent mandatory practices. Each site must be assessed on a case-by-case basis to determine appropriate treatment measures.

**Case 1** It would be difficult to justify not placing appropriate inlet screens on culverts or stormwater inlets with openings exceeding a diameter of 300 mm or a slot width of 125 mm.

**Case 2** Stormwater inlets would be treated as per Cases 1 & 3. Culverts would unlikely require inlet screens, however, the need for fencing of the upstream channel should be assessed on a case-by-case basis based on the risk of drowning or injuries caused by accidental falls.

**Case 3** Appropriate inlet screens should ideally be placed on stormwater inlets with openings exceeding a diameter of 300 mm, or a slot width of 125 mm, wherever practical. However, the appropriate management of debris blockage issues and associated flooding risks could prevent the use of inlet screens in some cases. In such cases, consider the use of fencing (i.e. exclusion fencing or barrier fencing) to restrict access to the upstream channel.

The placement of inlet screens on culverts and large stormwater pipes should generally only be considered as a last option if access to the upstream channel cannot be severely restricted and/or the safety risks associated with the culvert/pipe cannot be otherwise mitigated.

Warning signs should be used liberally.

**Case 4** Treatment is likely to be similar to Case 3. The focus should generally be on restricting access to dangerous waters instead of using inlet screens that could potentially cause flooding problems.

**Case 5** The focus should generally be on restricting access to dangerous waters and the use of warning signs.

**Case 6** Placement of warning signs where appropriate.

**Case 7** In Class C2 areas, treatment is likely to be similar to Case 4. In Class D areas, exclusion fencing should generally be used in preference to barrier fencing.

**Case 8** In Class C2 areas, treatment is likely to be similar to Case 5. In Class D areas the choice of fencing should be appropriate for the assessed safety risk.

**Case 9** In Class C2 areas, treatment is likely to be similar to Case 6. In Class D areas the choice of fencing should be appropriate for the assessed safety risk.

In all cases, the use of inlet or outlet screens on hydraulic structures, such as stormwater pipes and culverts, should be assessed on a case-by-case basis. It is important to acknowledge and assess both the beneficial and adverse consequences of such screens, including the potential impacts on local flooding and wildlife migration.

## Mitigating safety risks associated with waterway culverts



Safety message



Teaching engineering solutions



Pile field (NSW)



Safety poles (NSW)

### Introduction

- The first rule of safety management is:  
**If you cannot make it safe, then make the safety risks obvious**
- Most water safety events result from an 'unexpected event', whether that 'event' is a change in flow conditions, or an action that caused the person to enter or fall into the water.
- Management aims should be (i) to remove the risk, if practical, or (ii) to prevent an event from being unexpected.

### The four ways of solving a problem

- When looking for a solution to a safety risk, consideration should be given to the four basic options:
  - Remove yourself from the problem.
  - Remove the problem from yourself.
  - Change the outcome of the problem.
  - Change your response to the problem.
- The placement of an inlet safety screen on a waterway culvert should be considered one of the **least preferred** design options due to debris and flooding risks.

### Pile fields

- Pile fields have been used for a variety of purposes in waterways, including:
  - debris collection
  - debris impact poles
  - **human safety (to reduce the risk of a person being swept into a culvert)**
  - flow diversion system (to guide flows around a channel bend)
  - a buried erosion control system (to limit the extent of bed erosion)
  - outlet energy dissipation.

### Safety poles

- Safety poles are similar to a pile field, but simply placed in an arc around the culvert entrance.
- The purpose of safety poles is to give a person something to grab and hold onto, instead of being swept into the culvert.
- Consequently, the diameter of the poles should not exceed 300 mm.

## Safety systems installed upstream of culverts



**Safety rope (Tas)**

### Safety ropes

- Safety ropes can be placed across a waterway upstream of a culvert.



**Anchor point for a floating curtain (NSW)**

### Floating debris curtains

- Floating debris curtains can provide the same benefits as safety ropes, but they can also:
  - trap floating debris
  - direct floating debris into a gross pollutant trap (SQID) located on one side of the channel
  - help guide a floating person to one side of the channel.



**Trash rack (ACT)**

### Trash racks

- Trash racks of various designs have been used in urban drains for many years as part of stormwater treatment systems.
- These trash racks are used in non-fish habitat regions of the urban drainage system.



**Inspection of an inlet safety screen (Qld)**

### Inlet safety screens

- Inlet safety screens should, in most cases, be considered as a last resort treatment option.
- However, if the safety risks are high, then such screens may be considered essential.
- Ideally, the screen should not be placed flush with the headwall.

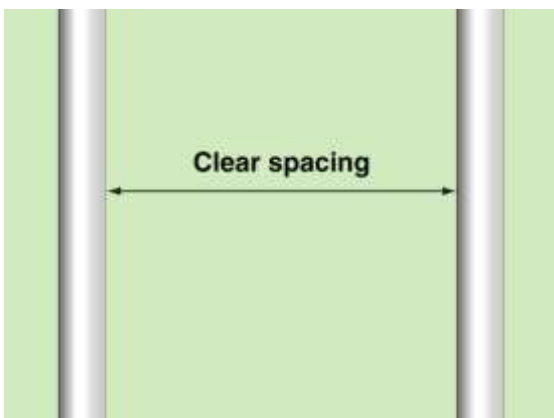
## Inlet safety screens – Design information



Parabolic inlet screen (Qld)

### Inlet safety screens

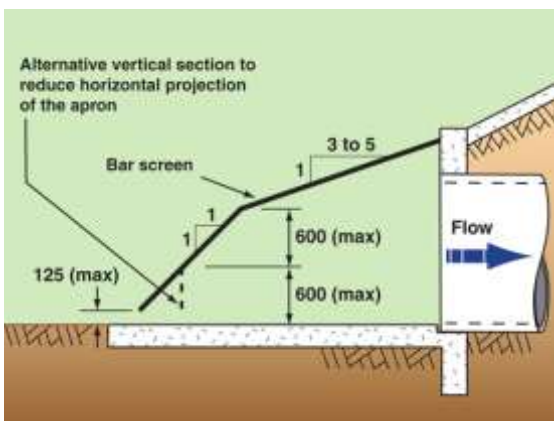
- Several studies have been performed on inlet screens and their design.
- Critical design features are:
  - variable slope of the screen with elevation
  - clear spacing of bottom edge from the apron bed
  - clear bar spacing
  - regular horizontal bar to allow egress of a trapped person (maximum 600 mm spacing).



Clear bar spacing

### Clear bar spacing

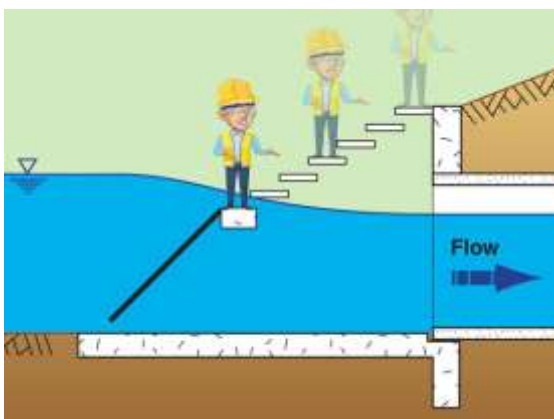
- The clear spacing of bars is based on the head size of the youngest child that is likely to interact with the bars.
- The recommended maximum clear spacing of vertical bars is:
  - 100 mm for pool safety fencing (a crawling child)
  - 125 mm for inlet screens (older than a crawling child)
  - 150 mm for outlet screens (a pre-teen child).



One possible screen profile ( $V < 1 \text{ m/s}$ )

### Slope of the screen

- Vertical (less than, or equal to, 600 mm with an approach velocity  $< 1 \text{ m/s}$ )
- 45-degrees (600 to 1200 mm with an approach velocity  $< 1 \text{ m/s}$ )
- 1:3 to 1:5 (V:H) ( $> 1200 \text{ mm}$  with an approach velocity  $< 1 \text{ m/s}$ )
- 45-degrees (less than, or equal to, 600 mm with an approach velocity  $> 1 \text{ m/s}$ )
- 1:3 to 1:5 (V:H) ( $> 600 \text{ mm}$  with an approach velocity  $> 1 \text{ m/s}$ )

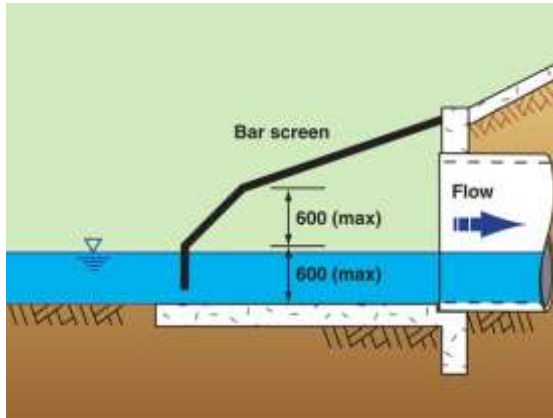


Inlet screen with step-like egress

### Providing safe egress

- An important design feature of pool safety fencing is the large spacing of the horizontal bars in order to prevent a child climbing over the pool fence and entering the pool.
- However, for inlet safety screens, the aim should be to allow a person to climb the screen, thus removing themselves from the dangerous waters.
- The recommended maximum inclined spacing of horizontal support bars is 600 mm.

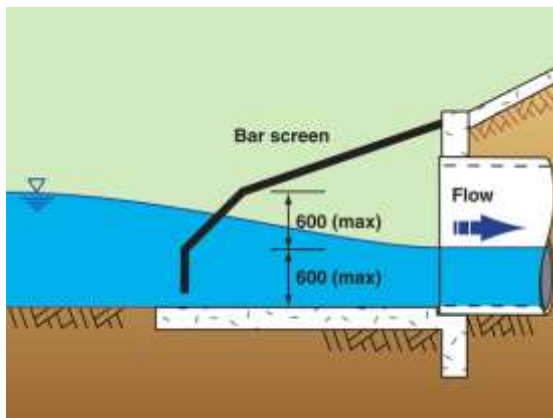
## Inlet safety screens – Design information



Low flow

### Minimal curvature of the approaching water surface

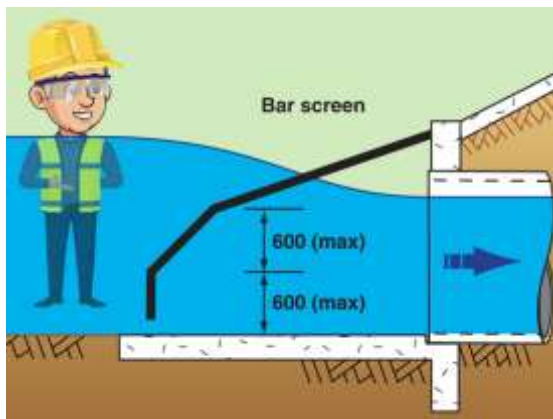
- In order to prevent a person from being held against the bar screen by high-velocity water pressure, the water surface should approach the screen at an angle far greater than 90-degrees.
- If the approach velocity is less than 1 m/s, then the water surface can approach the screen at 90-degrees up to a maximum height of 600 mm.



Medium flow

### Mild curvature of the approaching water surface

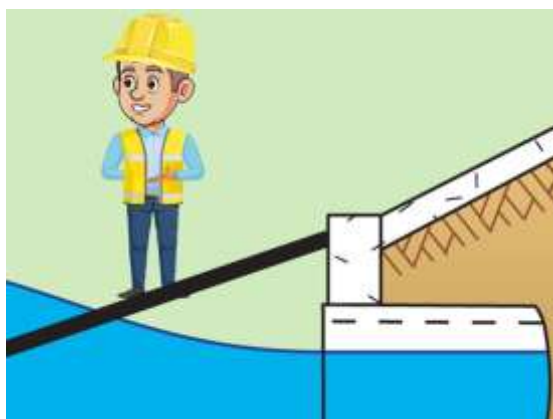
- As the inflow rate increases, there is a draw-down effect that causes the water surface to curve.
- The inlet screen should extend from the headwall such that the approach velocity does not exceed 1 m/s.
- A screen slope of 45-degrees is usually required in order to prevent the water surface from approaching the screen at 90-degrees.



High flow

### Significant curvature of the approaching water surface

- As the inflow rate increases even further, the curvature of the water surface also increases, and the slope of the inlet screen needs to flatten to 1 in 3, or even 1 in 5, in order to achieve safe conditions.

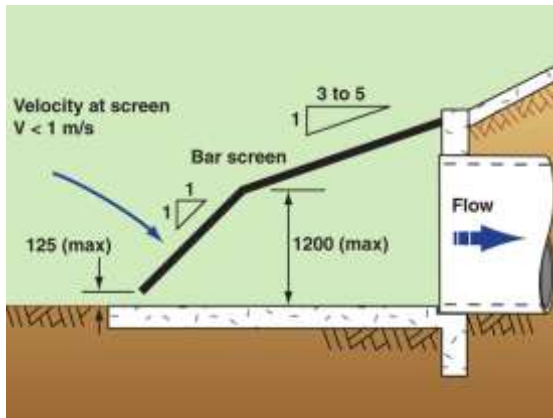


Safe approach angle of water surface

### Safe approach angle of water surface

- The water surface should not be allowed to approach the inlet screen at an angle of 90-degrees.
- An approach angle of around 135-degrees would be ideal.

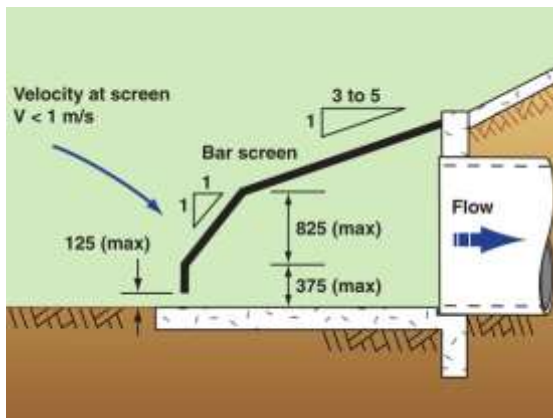
## 'Parabolic' inlet screens



Full sloping leading edge ( $V < 1 \text{ m/s}$ )

### Full sloping leading edge

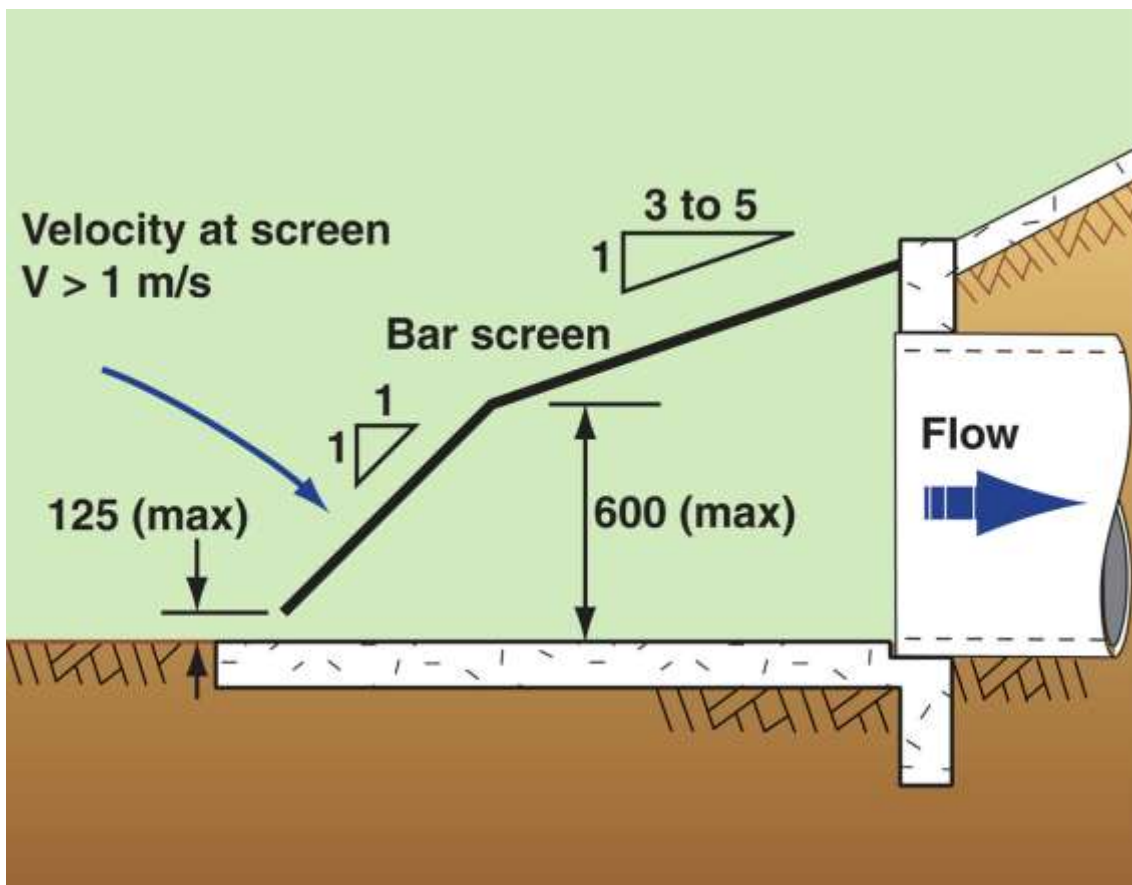
- If the approach velocity can be reduced to under 1 m/s, then a screen slope of 45-degrees can exist up to a height of 1200 mm.



Vertical leading edge ( $V < 1 \text{ m/s}$ )

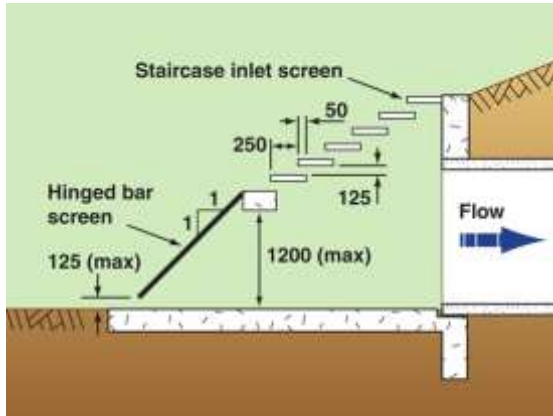
### Vertical leading edge

- If the approach velocity can be reduced to under 1 m/s, then a vertical screen can be used up to a height of 600 mm.
- Some guidelines specify a maximum vertical component of 375 mm (left).
- Designers should refer to their local design standards.

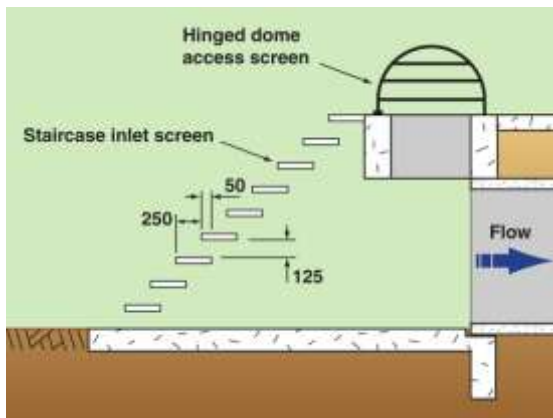


Recommended bar screen gradients for approach **velocities exceeding 1 m/s**

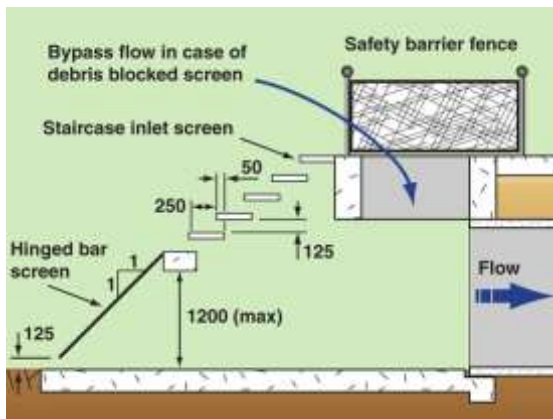
## Inlet safety screens – Alternative designs



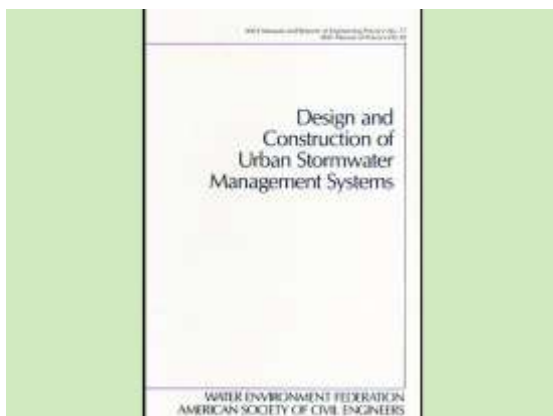
Bar screen with upper staircase screen



Staircase screen with dome inlet



Complex culvert inlet screen



ASCE, 1992

### Staircase screens

- A bit of lateral thinking can result in an inlet screen taking on the form of a staircase, which can be used by persons to egress the dangerous waters.

### Dome inlet screens

- Hinged dome inlet screens can be placed over access chambers, which can allow maintenance access behind the screen and into the culvert.

### Complex culvert inlet screens

- A variety of culvert inlet designs can be achieved in order to satisfy local issues.
- However, inlet safety screens should, in most cases, only be considered as a last resort because of:
  - the risk of the blocked screen becoming a fish barrier
  - increased flood risk
  - increased safety risk to road users due to increased risk of overtopping flows.

### Additional design reference:

Guidance on the design of trash racks is provided in '*Design and Construction of Urban Stormwater Management Systems*' (ASCE, 1992).

- Hard copy book.
- ISBN 0-87262-855-8.
- ISBN 1-881369-21-8.

## Inlet safety screens – Screen slope



**Vertical inlet screen (Qld)**

### Vertical inlet screen

- Less than 600 mm high.
- Less than 1 m/s approach velocity.



**45-degree inlet screen (Qld)**

### 45-degree inlet screen

- Less than 1200 mm high.
- Less than 1 m/s approach velocity.



**Parabolic inlet screen (Qld)**

### Parabolic inlet screen

- Approach velocity greater than 1 m/s.

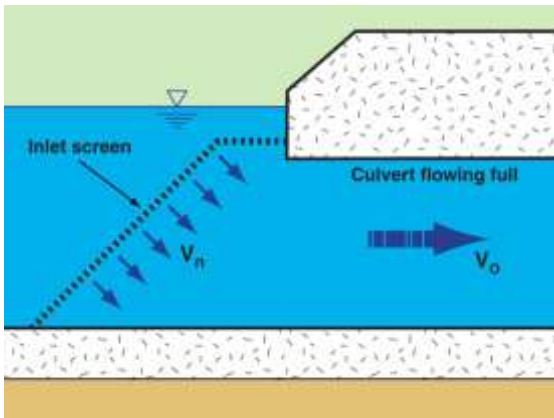


**Complex inlet screen (Gold Coast, Qld)**

### Complex inlet screen

- Emphasis on several options for safe egress given the high public access to the area.

## Inlet safety screens – Hydraulic analysis



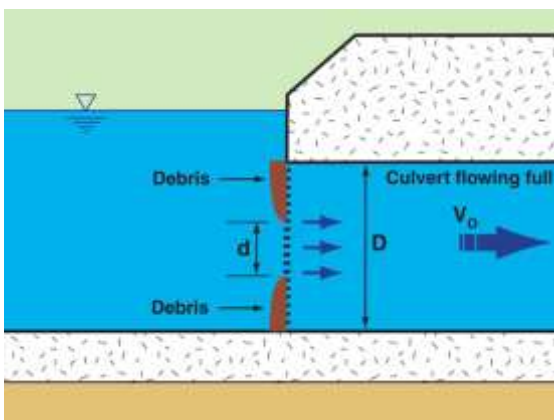
Clean inlet screen

### Clean inlet screen

$$\Delta H = K_t^* (V_n^2/2g) \quad (H1)$$

where:

$$K_t^* = 2.45 A_r - A_r^2 \quad (H2)$$



Partial debris blockage

### Partially blocked headwall screen

$$\Delta H_e = K_e \left( \frac{V_o^2}{2g} \right) \quad (H3)$$

where (H4):

$$K_e = \left( \left( \frac{1 + K_c^{1/2}}{BF} \right) - 1 \right)^2 + \frac{BF(2.45 A_r - A_r^2)}{(1 - A_r)^2}$$

Where:

$\Delta H$  = Head (energy) loss (m)

$\Delta H_e$  = combined energy loss of pipe/culvert exit including effects of screen (m)

$A$  = Gross flow area at the screen,  $A = A_b + A_n$  (m<sup>2</sup>)

$A_b$  = blockage surface area of the screen bars (including debris blockage where applicable) (m<sup>2</sup>)  
 $A_n$  = surface area of 'clean' screen bars excluding debris blockage (m<sup>2</sup>)

$A_n$  = Net flow area through screen (i.e. excluding bars and debris)

$A_r$  = Area ratio =  $A_b/A = (1 - A_n/A)$

$BF$  = blockage factor, being the ratio of the gross area of the screen not affected by debris blockage, to the internal flow area of pipe/culvert downstream of the screen =  $(d/D)^2$  for a pipe culvert

$D$  = Culvert cell equivalent diameter (m)

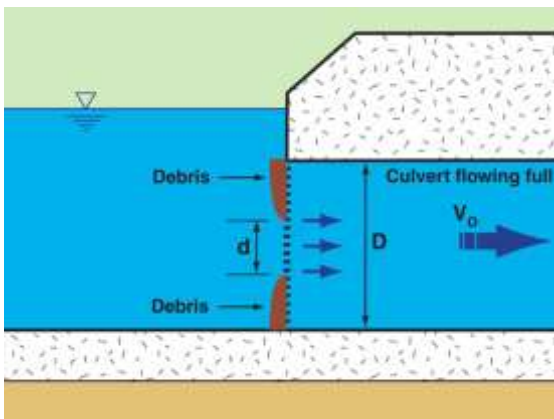
$g$  = acceleration due to gravity (9.80 m/s<sup>2</sup>)

$K_e$  = combined entry loss coefficient based on downstream pipe-full velocity head

$K_t^*$  = head loss coefficient based on velocity through screen

$V_n$  = flow velocity through the partially blocked screen (m/s)

$V_o$  = average flow velocity in the culvert (m/s).



Partial debris blockage



Fully blocked inlet screen (Qld)

# **Appendix I: Culverts Located in Problem Soils**

## Introduction

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

### Soil analysis



Photo supplied by Catchments & Creeks Pty Ltd

**Dispersive soil (Port Lincoln, SA)**



**Water testing (NSW)**



Photo supplied by Catchments & Creeks Pty Ltd

**Black cracking clay (Qld)**

### Soil data

- If the site inspection reveals 'problematic soils' (such as highly erodible soils, dispersive soils, slaking soils, or acid sulfate soils), then formal soil testing may be required.
- Some suggest there are no problem soils, just poorly managed landscapes!

### Dispersive and slaking soils

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

### Acid sulfate soils

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

### Expansive soils

- Typically soils with a Linear Shrinkage greater than 8% at OMC (based on a multi-point soaked CBR test).
- Best examples are black, grey and brown cracking clays (Ug5.1, Ug5.2, Ug5.3), also some red and yellow duplex soils can have expansive subsoils.
- Also soils range from SC/CL to CH and are not necessarily restricted to high plasticity CH clays (Unified Soil Classification).

## Aggregate Immersion Test



Slightly dispersive soil



Non-dispersive, non-slaking soil



Dispersive soil



Slaking soil

### Aggregate Immersion Test

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

### Non-dispersive soil

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

### Dispersive soils

- If the soil disperses both horizontally and vertically into the water, then the soil could be dispersive.
- Highly dispersive soils will collapse in less than 10 minutes.
- Caution; using tap, tank or groundwater can sometimes mask the dispersive reaction due to minerals and/or chemicals in the water; hence the need to use distilled water.

### Slaking soils

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

## Identifying dispersive and slaking soils



Fluting erosion (Qld)

### Fluting

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



Bank not exposed to direct rainfall (Qld)

### Textured surface

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



Deep rilling and tunnel erosion (Qld)

### Tunnel erosion

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



Rilling that extends to top of bank (Qld)

### Rilling that extends to the top of the bank

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

## Identifying dispersive and slaking soils



**Caboolture, Queensland**

### Visual indicators of dispersive soils

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



**Brisbane, Queensland**



**Ipswich, Queensland**



**Springsure, Queensland**



**Miles, Queensland**



**Covert, Queensland**



**Broken Hill, NSW**

## Soil erosion resulting from slaking soils



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



**Gully erosion through a sandy soil (Qld)**

### Bank erosion resulting from slaking soils

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



**Soil pinnacle (Qld)**



**Soil pinnacles (NSW)**

## Soil erosion resulting from cracking clays (dry bank slumping)



Photo supplied by Catchments & Creeks Pty Ltd

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



**Cracking clay (dry condition, NSW)**

### Bank erosion resulting from cracking clays

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



Photo supplied by Catchments & Creeks Pty Ltd

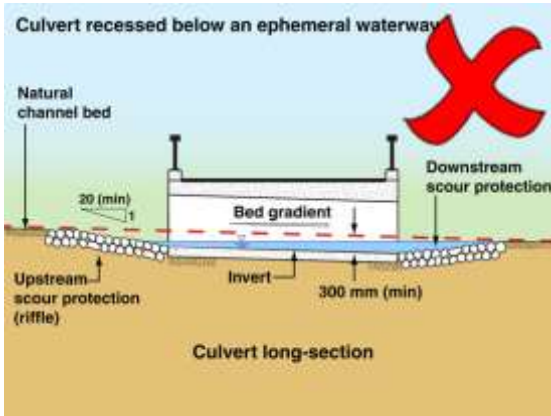
**Crumbling soil bank (Qld)**



Photo supplied by Catchments & Creeks Pty Ltd

**Crumbling soil bank (Qld)**

## Potential issues associated with recessing culverts in problem soils



Potentially problematic condition



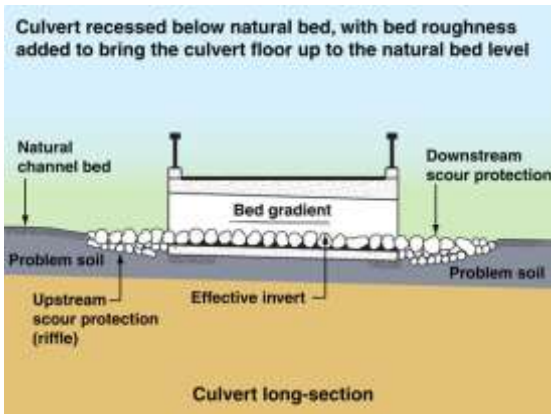
Dispersive soil (Qld)

### What **NOT** to do!

- When working in 'problem' soil areas, it is important to remember that ALL government policies must be followed, not just Fisheries policies and guidelines.
- In some highly unstable soils, a poorly-designed recessed culvert can cause severe erosion problems that can extend into adjacent properties.
- Cracking clays are dispersive, and have high 'shrink-swell' activity.



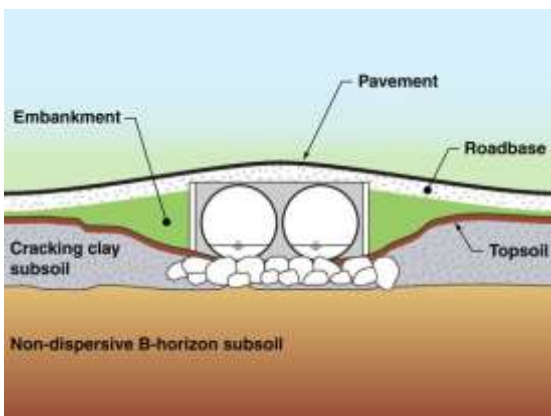
Black cracking clay (Qld)



Maximum recessing in problem soils

### Potential solution

- The local government would likely understand the soils and issues in their area.
- Expert advice can be obtained from soil conservation officers, or soil scientists.
- If allowed by local policies, the culvert may be recessed such that when rocks are grouted onto the culvert floor, the finished floor level aligns with the natural creek invert (sand or gravel-based waterways will not exist in these soil regions).



Road surface rises over a culvert

### Past practices

- Some local policies require the culvert bed to be placed no lower than the natural creek invert.
- In order to get sufficient culvert flow area under the road (to meet design standards) the road pavement must be raised over the culvert as if it were a long, gradual 'speed bump'.
- **Note:** Cracking clays can cause a recessed culvert to rise in elevation over time, causing a more abrupt 'speed bump' outcome.

## Culverts in expansive soil areas



Qld Road Drainage Manual (2019)

### Reference document:

*Road Drainage Manual, Chapter 9: Culvert Design*, The State of Queensland (Department of Transport and Main Roads), Brisbane, 2019.

### Section 9.2.7 – Culverts in expansive soil areas



Lifting of pavement (Qld)

### Identification of expansive soils

- Typically soils with a Linear Shrinkage greater than 8% at OMC (based on a multi-point soaked CBR test).
- These soils range from SC/CL to CH and are not necessarily restricted to high plasticity CH clays (Unified Soil Classification).



Lifting of pavement (Qld)

### Long-term consequences of expansive soils

- Typical outcomes include:
  - general lifting of the culvert causing a localised rise in the road surface
  - cracking and displacement of the culvert aprons
  - increased impact loads on the road pavement due to the irregular road surface.



Lifting of pavement (Qld)

### Treatment

- Designers should not use standard drawings.
- Designers should seek specialist geotechnical, soil science and structural advice.
- Over-excavation and soil treatment (lime stabilisation) of foundations.
- Heavy compaction of replaced soils.
- Adoption of a non-standard base slab.
- Note the design of nearby stable culverts.

# **Appendix J: Terrestrial Passage Requirements at Culvert Crossings**

## Introduction



Queensland Transport, 2024

### Reference document:

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

(This Queensland Transport document, and the rest of the series, contains a LOT MORE information than is provided in the appendix.)



Elevated (dry) terrestrial pathway (Qld)

### Introduction

- The policies and focus of any 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 fauna (i.e. 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 is often required within the culvert cells that are located adjacent to the waterway banks.



Alternative lizard run (NSW)

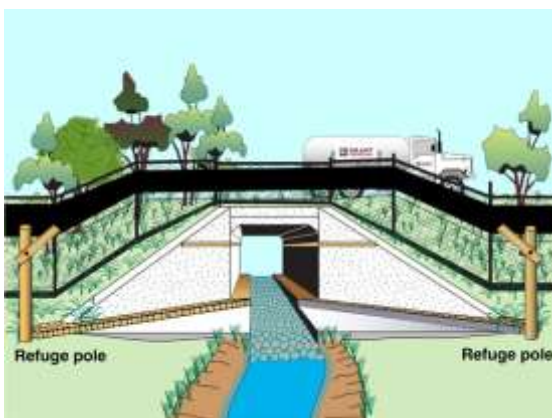
### Fauna tunnels

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

## Introduction



Single cell culvert on an ephemeral creek



Single cell culvert on a wet creek



'Wet' and 'dry' cells



Photo supplied by Catchments & Creeks Pty Ltd

Street light with shield (Qld)

### 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' (e.g. fallen trees, culverts or footbridges) that allow the target species to cross from bank to bank.

### 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).

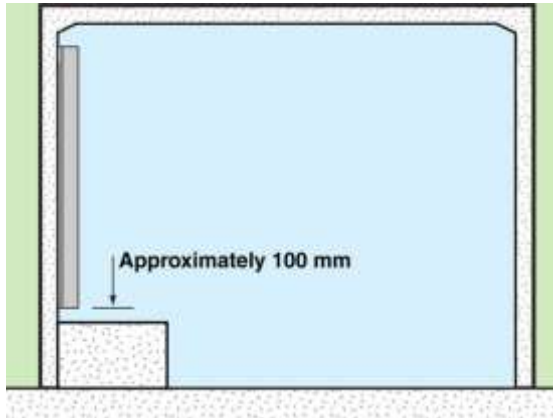
### Continuity of the 'dry' paths

- 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 to dry ground on both sides of the culvert.

### Reducing artificial light at night

- Nearby street lighting should have shields attached to minimise light spilling into sensitive areas.
- If considered necessary, the culvert's headwalls and wingwalls can be painted (typically a dark green) to reduce the impact of reflected light.
- It is noted that 'not being seen' is an important aspect/desire for most terrestrial fauna.

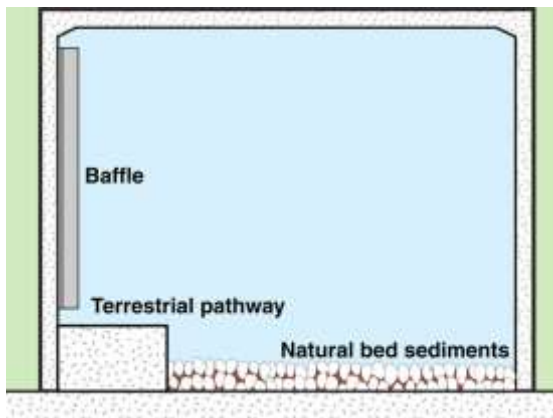
## Integration of aquatic and terrestrial passage features



Single sidewall baffle

### Basic design

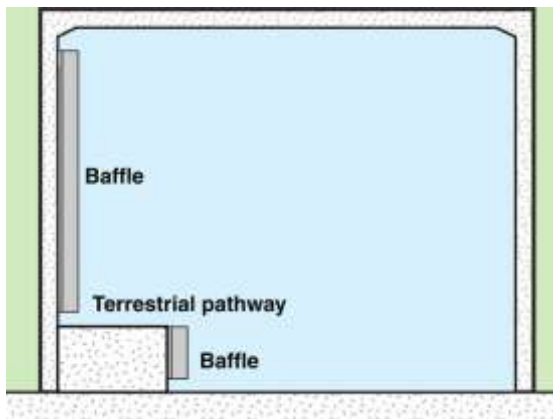
- Terrestrial pathways can be integrated into fish-friendly culverts.
- The dry terrestrial pathway should be set above the dry-weather flow.
- Minimum clear path width of 300 mm.
- Desirable clear path width of 500 mm in culvert cells at least 1800 mm wide.



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
  - sediment deposition raising the effective bed elevation.



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.



Photo supplied by Catchments & Creeks Pty Ltd

Baffles attached to the terrestrial pathway

### Example

- An example of fish passage baffles attached to the side of the dry terrestrial fauna pathway.



## Queensland Department of Transport and Main Roads



Queensland Transport, 2024

### Reference document:

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

Specifically sections:

[4.4 Multi-use culverts](#)

[13. Fauna exclusion fencing](#)

[16. Biodiversity enhancement](#)

[16.6 Fauna furniture for crossing structures](#)

[19.6 Traffic calming.](#)



Fauna culvert (Qld)

### Introduction

- This Queensland Main Roads' document features discussion on both bridge and culvert-based fauna corridors.
- The culvert-based fauna tunnels include waterway and non-waterway culverts.
- The non-waterway culverts may be located within elevated floodplains, or on land not prone to flooding.
- These non-flood prone fauna culverts (tunnels) may still be subject to drainage issues.



Single cell waterway culvert (Qld)

### Multi-use culverts

- Multi-use culverts are designed to allow the movement of various 'users' including fauna, people, livestock, drainage water and floodwater.
- The use of multi-cell culverts is usually preferred over the use of single cell culverts, which must otherwise incorporate all necessary features in one tunnel.

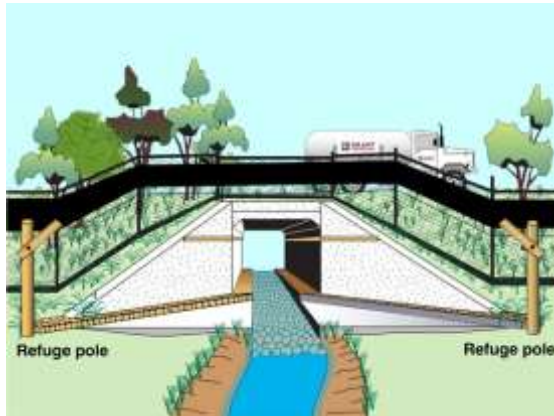


Stock (cattle) crossing (NSW)

### Stock crossings

- Stock crossings have different design features to terrestrial passage features (furniture) fitted into waterway culverts.
- In stock crossings, it is not essential to maintain a dry passageway.
- For terrestrial pathways, it is highly desirable for the pathway to be elevated above normal dry-weather flow.
- Of course, larger animals, such as kangaroos and wallabies will use a wet pathway.

## Queensland Transport and Main Roads – 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

- 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 digging underneath or secured to the ground with a concrete strip.
- Fauna fencing should typically include a 'return'—an angled section of fence (the last 10-20 m of fencing) to encourage fauna to turn back towards their habitat rather than move around the fence end and onto the transport infrastructure.
- 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 using the plants to climb 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 climbing over and onto the road, while also providing noise control benefits.

## Queensland Transport and Main Roads – Fauna passage furniture



**Elevated pathway (Qld)**



**Non-use of flowering plants**



**Roosting (Qld)**



**Elevated logs (lizard runs, 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 have both wet and dry features.

### 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.

### 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

- Elevated horizontal logs or log rails should be approximately 300 mm in diameter (width), set 1500 mm above the ground, and with a minimum 500 mm clearance from the ceiling.
- Access ramps should be no steeper than 1V:5H.
- Flat planks are preferred to round logs.

## Traffic calming



Traffic calming on a rural road (Qld)



Traffic calming on a back road (Qld)



Traffic calming speed bump (Qld)



Warning sign (Qld)

### Introduction

- The risks to wildlife crossing roadways are influenced by a number of factors, including:
  - traffic volume
  - number of trafficable lanes
  - speed of the vehicles
  - 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

- 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.
- Designers should refer to relevant guidelines in each state and territory, or to AustRoads publications.

### 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.

## Risk of predation



Queensland Transport, 2024

### A concern raised by the author!

The Main Roads' document *Fauna Sensitive Transport Infrastructure Delivery – Chapter 6*: makes the following claim:

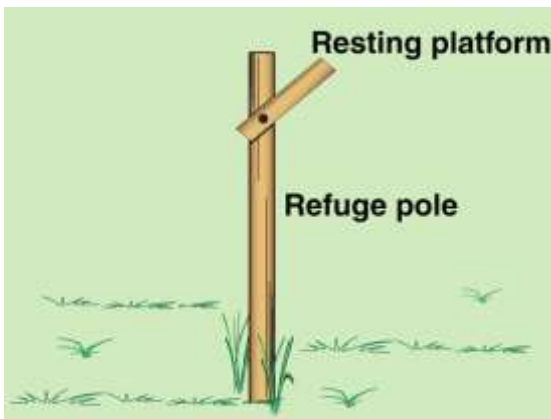
- 'There is a misconception that crossing structures are prey-traps for fauna because predators learn to preferentially hunt at those locations. Despite this assertion, there is no evidence that predators systematically use crossing structures in this way'.
- **The author of this field guide questions the above statement!**



White-faced heron waiting for dinner

### My observations

- Over the past 25 years the author has travelled the country and photographed many fauna tunnels.
- The author has observed:
  - 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; however, such a concern does not exist for fauna tunnels located outside floodplains.



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



## Predators



**Kookaburra (Qld)**

## Potential predators

- **Question:** How do you spot a fish barrier?
- **Answer:** Look for a bird that is looking at the water.



**Azure Kingfisher (NSW)**



**Azure Kingfisher (NSW)**



**White-faced heron (Qld)**



**White-faced heron (Qld)**



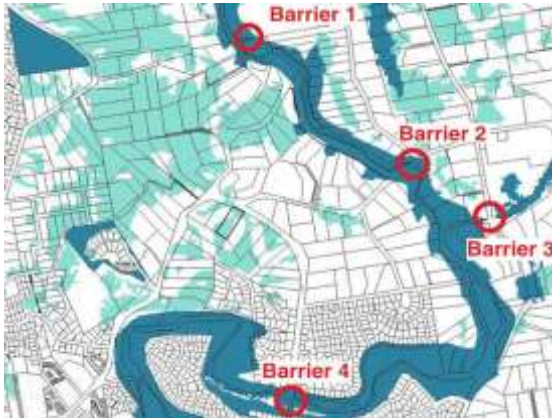
**White-faced heron (Qld)**



**Domestic cat (Qld)**

# **Appendix K: Culvert Upgrades**

## Introduction

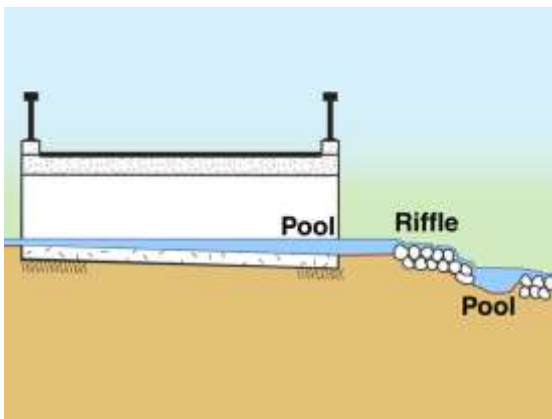


Mapping fish passage barriers

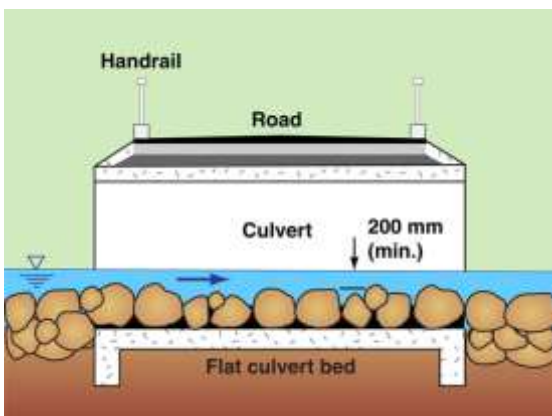


Photo supplied by Catchments & Creeks Pty Ltd

Culvert upgrade as part of road works



Downstream pool-riffle system



Improved bed roughness

## Introduction

- If circumstances allow the removal of fish passage barriers from a waterway, including the upgrading of culverts, then priority should be given to those projects that provide the greatest return for the money invested.
- Mapping exercises can assist in identifying which barriers are top priority.

## Reasons for a culvert upgrade

- A culvert upgrade may be commissioned for the following reasons:
  - the systematic removal of fish passage barriers
  - repairs to a culvert damaged during a flood event
  - expansion of the culvert as part of a road upgrade (an improvement to the fish passage conditions may be mandatory under local Fisheries legislation).

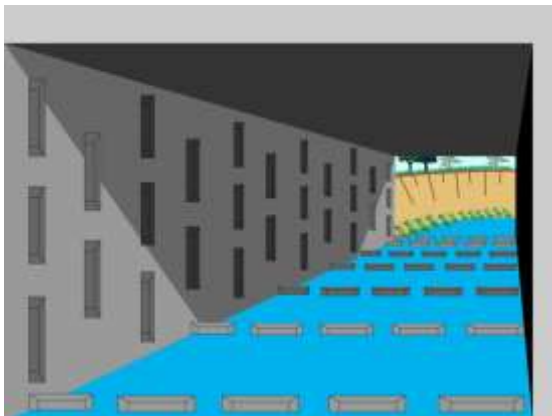
## Drowning of the culvert floor

- One of the most beneficial upgrade options for an existing culvert is the raising of downstream water levels such that the culvert floor becomes submerged during normal dry-weather flows.
- Raising the downstream water level can be achieved by constructing:
  - a pool-riffle system
  - a rock ramp (rock chute)
  - a ridge rock ramp
  - a formal fishway.

## Improved bed roughness

- The next step could be to introduce bed roughness to the culvert floor.
- Bed roughness can be achieved by:
  - introducing loose rock to the bed
  - grouting rocks to the culvert floor
  - allowing the natural deposition of bed material onto the culvert floor
  - installing floor baffles to encourage the natural deposition of bed material.

## Culvert upgrades



Floor and sidewall baffles



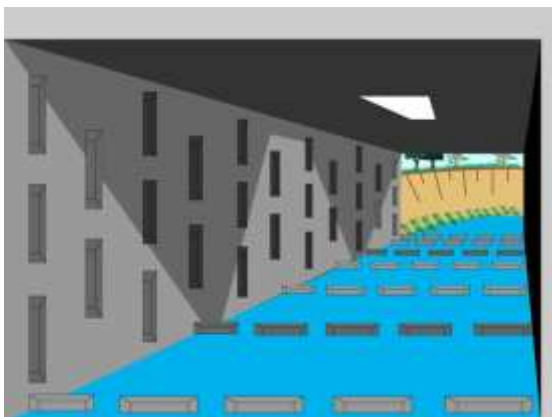
Photo supplied by Catchments & Creeks Pty Ltd

Introduced sidewall baffles (Qld)



Photo supplied by Catchments & Creeks Pty Ltd

Existing drop-inlet (fish barrier)



Skylight introduced to a culvert

### Artificial bed roughness

- Floor baffles can be formed from:
  - cast in-situ concrete baffles
  - pre-cast concrete blocks anchored with starter bar reinforcing
  - pre-cast 'parking stops' bolted to the culvert floor.
- Grouting isolated rocks to the culvert floor is not recommended due to the high risk of these rocks eventually being displacement.

### Sidewall roughness

- Sidewall baffles can be introduced to the sidewalls located adjacent to the creek banks.
- The various types of sidewall baffles are discussed in [Appendix E](#) of Part 2 of this document.

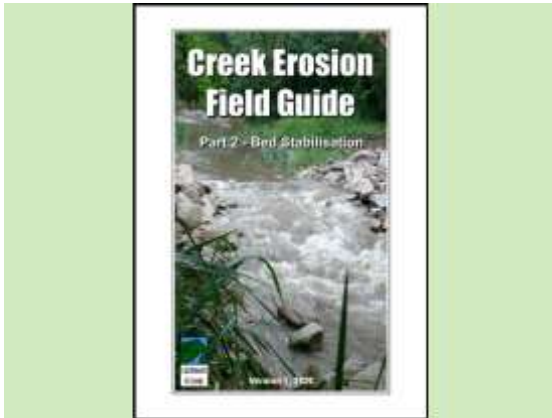
### Rehabilitation of an existing drop-inlet

- There is little point in making a culvert fish friendly if immediately upstream of the culvert there is an existing barrier to fish passage.
- Many older culverts have formal drop-inlets installed for the purpose of stabilising the upstream bed (i.e. avoiding the formation of head-cut erosion).
- These drop-inlets need to be replaced with a rock ramp or pool-riffle system.

### Improved lighting conditions

- If possible, skylights, in the form of grated stormwater inlets, can be introduced to:
  - a median island
  - the road verge (between the footpath and road kerb).

## Culvert upgrades – Raising the downstream channel bed



Creek Erosion Field Guide, 2022

### Reference document:

*Creek Erosion Field Guide Part 2 – Bed Stabilisation*, Catchments & Creeks Pty Ltd, 2022, Bargara Queensland.

Version 2, February 2022

Part 2 discusses the planning of creek erosion treatments, fish-friendly bed treatment, common properties of rock, the hydraulics of grade control structures, fish-friendly and non fish-friendly bed stabilisation techniques.



Photo supplied by Catchments & Creeks Pty Ltd

Constructed pool-riffle system (Qld)

### Pool-riffle systems

- The size of the rock is generally governed by the following hydraulic factors:
  - the maximum flow velocity during which the rock is required to be stable
  - the degree of exposure of the rock to high-velocity water flow (i.e. does the rock sit flush with adjacent rocks, or above adjacent rocks)
  - the degree of turbulence within the water flow—this usually varies with water depth and flow velocity.



Photo supplied by Catchments & Creeks Pty Ltd

Constructed rock ramp (Qld)

### Constructed rock ramps

- Critical design components of a rock ramp and rock chute are:
  - flow entry into the chute
  - the maximum allowable flow velocity down the face of the chute
  - energy dissipation at base of chute.
- Most rock ramps can fail as a result of rock displacement; therefore, it is critical to size the rocks using rock properties that are representative of the actual rocks that will be used in the structure.



Ridge rock ramp

### Ridge rock ramps

- General design specifications are:
  - spacing of rock ridges = 2 m
  - fall across a rock ridge = 100 mm
  - overall gradient = 1 in 20
  - maximum total fall = 1000 mm.
- Each ridge is formed from rocks with a length of around 600–1000 mm, standing vertically, and recessed into a bed of tightly packed smaller rocks such that just 200–300 mm of the ridge rock is exposed.

# K1 Pool-Riffle Systems



**Constructed riffle (NSW)**

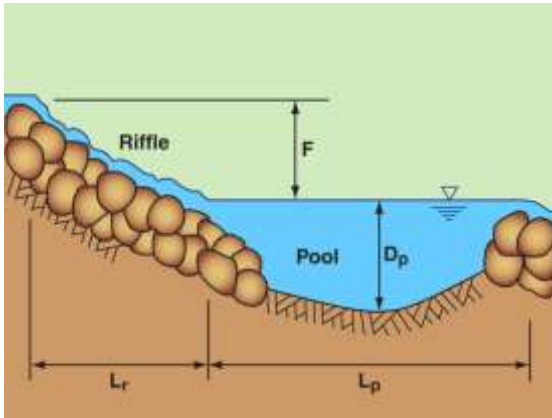
## Constructed riffles vs natural riffles

- Unlike natural riffles, most constructed riffles, rock chutes, rock ramps, ridge rock fishways and rock weirs, are required to be stable during a wide range of flow conditions.
- Constructed riffles usually contain rocks that are substantially larger than those found in natural riffles.
- This means their performance, especially with regards to fish passage, can vary significantly from natural riffles.

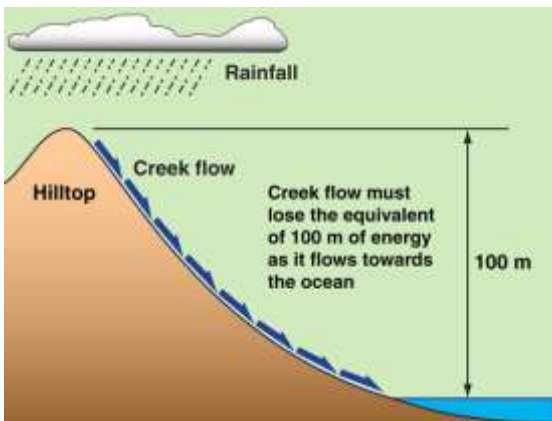


**Constructed riffle (Qld)**

## Constructed riffles – Hydraulics of the downstream pool



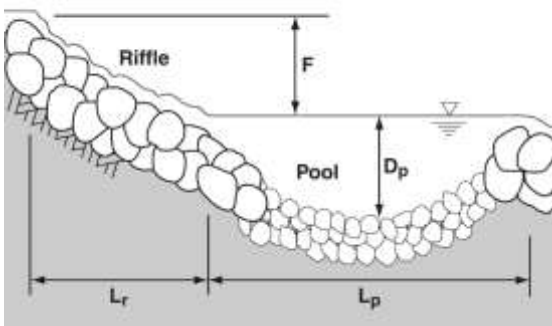
Profile of a pool-riffle system



Energy loss



A pool-riffle type water slide (NSW)



Profile of a pool-riffle system

### Introduction

- The existence of both pools and riffles increases the habitat diversity and resulting biodiversity of the waterway.
- There is also an important hydraulic relationship that develops between a riffle and the downstream pool.
- This hydraulic relationship means that there are some attributes (dimensions) of a pool that can be linked back to the riffle.

### Energy dissipation along creeks

- If a creek starts on a hilltop 100 m above sea level, then as the water travels the full length of the creek, it must lose the equivalent of 100 m of energy by the time the water enters the sea.
- Similarly, if the water descends a riffle that falls 500 mm, then the equivalent of 500 mm of energy must be consumed while the water passes down the riffle and into the downstream pool.

### Types of energy dissipation

- In pool-riffle systems, energy loss can occur in two ways:
  - friction (down the chute)
  - turbulence (within the pool)
- As the flow enters the downstream pool, the jetting effects of the inflow cause turbulence within the pool, which contributes to energy loss.
- These same hydraulic principles exist in water slides.

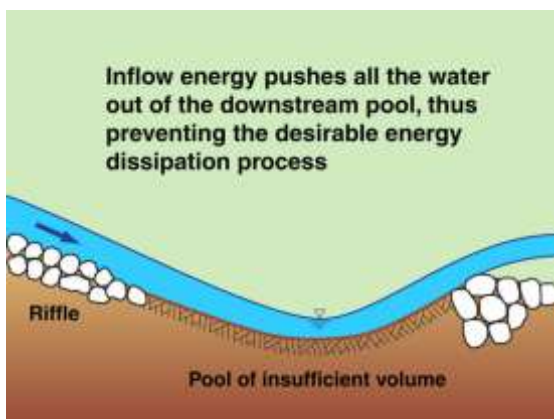
### Factors affecting the depth of a pool ( $D_P$ )

- A study of natural pool-riffle systems in South-East Queensland revealed that the depth of the downstream pool ( $D_P$ ) was usually equal to, or greater than, the fall ( $F$ ) of the upstream riffle.

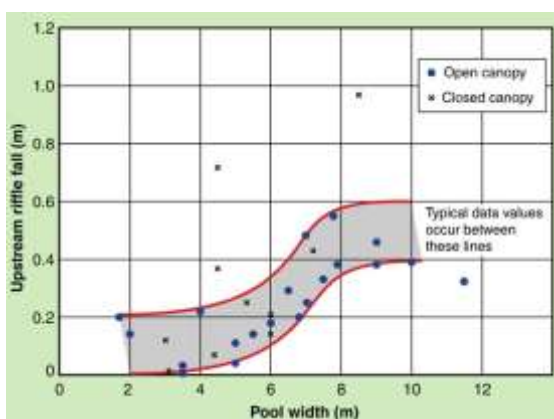
$$D_P(\text{min}) = F \text{ (typical)} \quad (K1)$$

- Waterfalls are different, however, the depth of the pool below a waterfall also increases with the height of the waterfall, but only to the point where the falling water reaches terminal velocity.

## Constructed riffles – Pool dimension in narrow channels



### Outcome of insufficient pool volume



### Relationship between 'fall' & 'pool width'



Pool downstream of a rock ramp (NSW)



Pool-riffle in a narrow channel (Qld)

### Factors affecting the **volume** of a pool

- The volume of water contained within the downstream pool is important in order to maintain the correct operation of the pool.
- If the downstream pool has insufficient volume, then as the flow rate increases, the water energy passing down the riffle will eventually be able to push the water out of the downstream pool causing the pool to act as a 'ski jump'.
- The volume of a pool is governed by its depth, width and length.

### Factors affecting the **width** of a pool ( $W_P$ )

- Hydraulic factors mean that:
  - pool depth is linked to riffle fall, and
  - the minimum pool volume is linked to the riffle's fall ('F' assume =  $D_P$ ) and width ( $W_R$ ).
- For relatively narrow channels (i.e. creeks) the pool width ( $W_P$ ) should be taken as the greater of:

$$W_P (\text{min}) = 1.3 + 4.5 D_P \quad (\text{K2})$$

$$W_P (\text{min}) = W_R + 4.5 D_P \quad (\text{K3})$$

### Factors affecting the **length** of a pool ( $L_P$ )

- The minimum length of a pool is in part governed by the minimum required volume of a pool in order to achieve efficient energy dissipation.
- A survey of pool-riffle systems in SE Qld creeks showed that the minimum pool length is around twice the pool width.

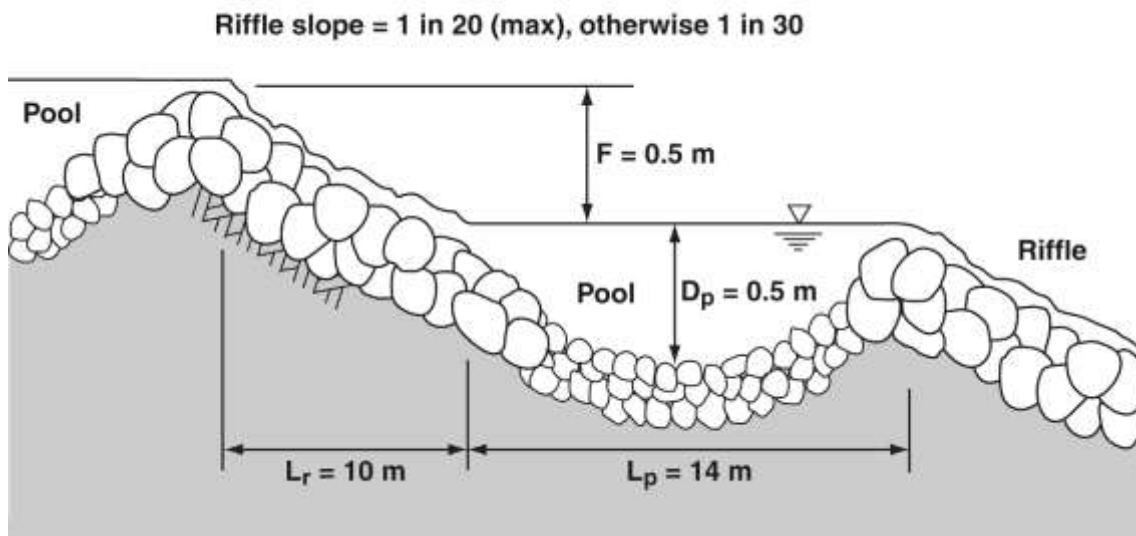
$$L_P (\text{min}) = 2 \text{ to } 4 \text{ times } W_P \quad (\text{K4})$$

- However, the actual length of the pool is usually governed by the gradient of the creek, and the spacing of the riffles.

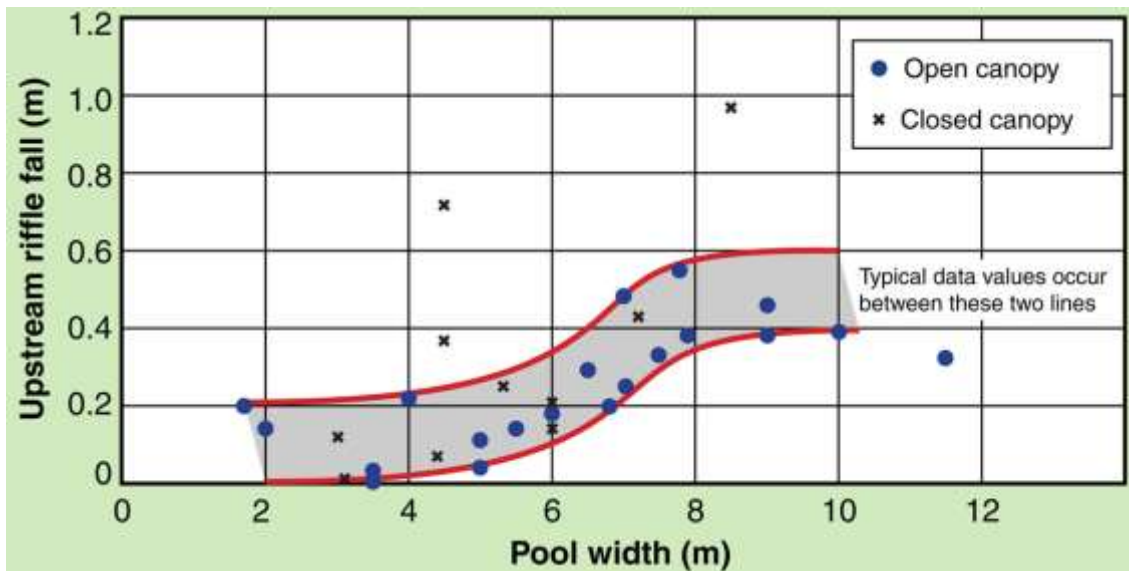
### Use of rock to stabilise narrow pools

- In constructed channels, limits on the overall width of the channel may not allow the construction of the ideal pool width.
- In such cases, a narrower (but longer) pool can be constructed, but the sides of the pool will need to be stabilised with rock and hardy plants (e.g. Lomandra) in order to control potential bank erosion.
- The length of the pool should exceed the minimum length determined for the pond width (equations K2 or K3).

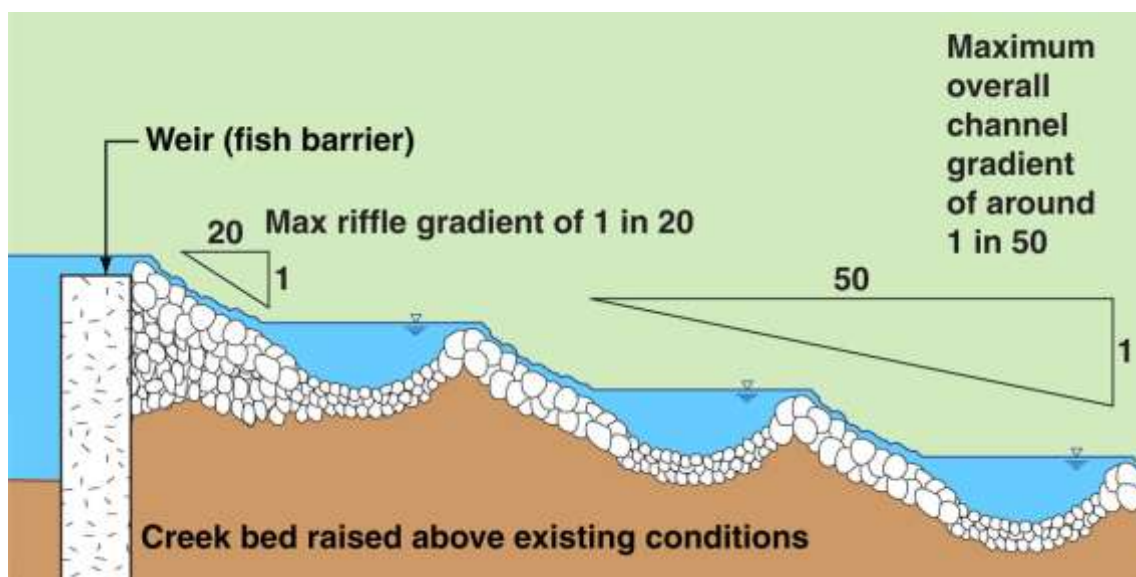
## Constructed riffles – Pool dimensions in narrow channels



Dimensions of maximum possible pool-riffle gradient



Relationship between the riffle fall ( $F$ ) and the pool width ( $W_p$ ) from creeks in SE Qld



Use of a pool-riffle system to raise the creek bed downstream of an existing weir

## Constructed riffles – Sizing rock for low-flow conditions



Photo supplied by Catchments & Creeks Pty Ltd

**Low-flow condition (Qld)**



Photo supplied by Catchments & Creeks Pty Ltd

### Sizing rock for low-flow conditions

- In most cases, the required rock size will **not** be governed by the low-flow conditions.
- The low-flow hydraulic check requires the determination of the maximum flow velocity that occurs on the riffle prior to the riffle being drowned-out by backwater.
- This analysis usually involves numerical modelling of the stream for a range of flow conditions.

### Rock sizing equation for low-flow condition

$$d_{50} = \frac{SF \cdot K_1 \cdot K_2 \cdot V^2}{(A - B \cdot \ln(S_o)) \cdot (s_r - 1)} \quad (K5)$$

For SF = 1.2: A = 3.95, B = 4.97 (default)

For SF = 1.5: A = 2.44, B = 4.60

(Note: 'ln' means natural logarithm to base-e)

### Flow approaching drowned conditions

A & B = equation constants; typically adopt A = 3.95 and B = 4.97 based on SF = 1.2

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

$K_1$  = correction factor for rock shape

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

$K_2$  = correction factor for rock grading

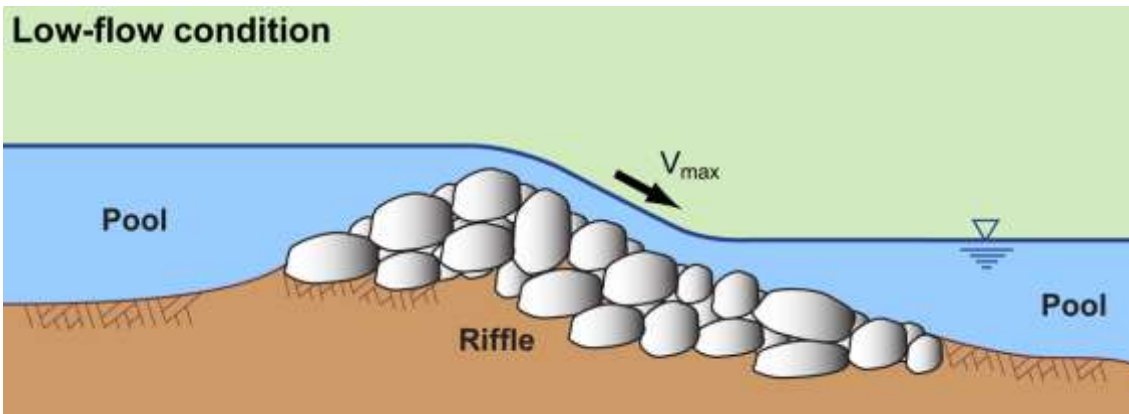
= 0.95 for poorly graded rock ( $C_u = d_{60}/d_{10} < 1.5$ ), 1.05 for well graded rock ( $C_u > 2.5$ ), otherwise  $K_2 = 1.0$  ( $1.5 < C_u < 2.5$ )

SF = factor of safety = 1.2 (recommended)

$S_o$  = gradient of the riffle face [m/m]

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

V = maximum depth-average flow velocity over the rocks during low flow [m/s]



**Shallow water, low-flow design conditions**

# K2 Rock Chutes and Rock Ramps



Photo supplied by Catchments & Creeks Pty Ltd

**Rock chute stabilising gully erosion (Qld)**

## Rock chutes and rock ramps

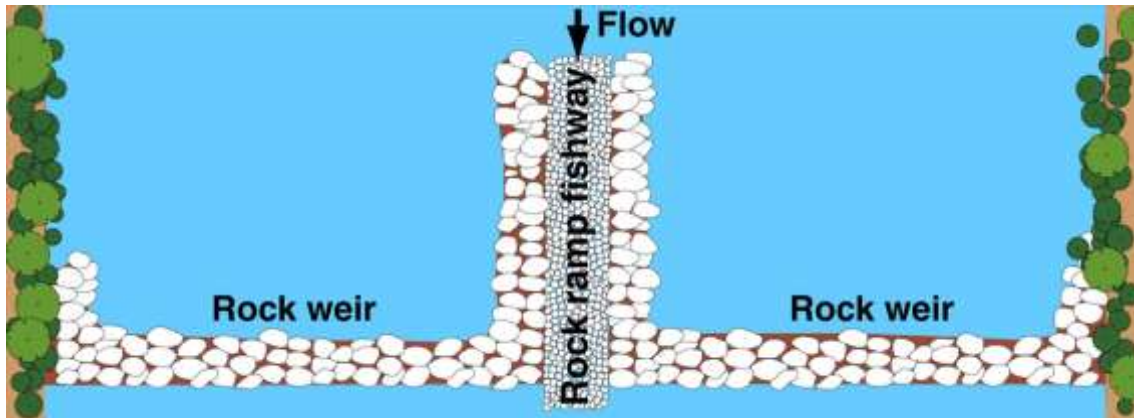
- The term 'chute' is normally associated with something descending a slope, such as water flowing down a rock chute.
- The term 'ramp' is normally associated with something ascending a slope, such as fish migrating up a rock ramp.
- However, the terms 'rock chute' and 'rock ramp' are just different names for the same type of structure.
- Unlike 'riffles', chutes and ramps can exist in all types of creeks, but may be unstable if placed in a sand-based waterway.



Photo supplied by Catchments & Creeks Pty Ltd

**Constructed rock ramp (fishway) in Tamworth, NSW**

## Rock chutes and rock ramps – Rock ramp fishway, Tamworth, NSW



Layout of the rock ramp fishway



Rock ramp fishway viewed from the right bank (Tamworth, NSW)



Rock ramp fishway looking upstream from the base of the fishway (Tamworth, NSW)



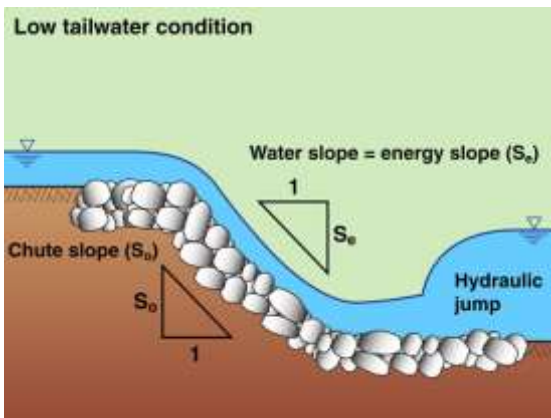
Rock ramp fishway looking downstream from the top of the fishway (Tamworth, NSW)

## Rock chutes and rock ramps – Design flow conditions

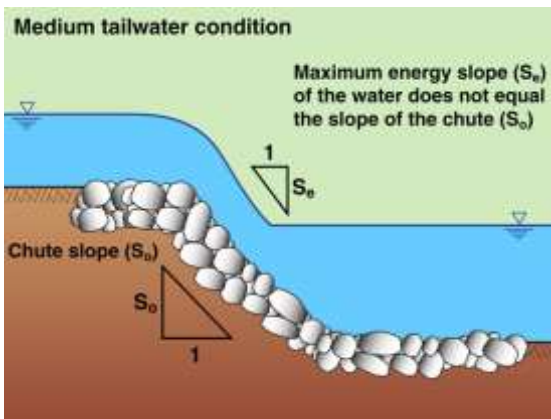


Photo supplied by Catchments & Creeks Pty Ltd

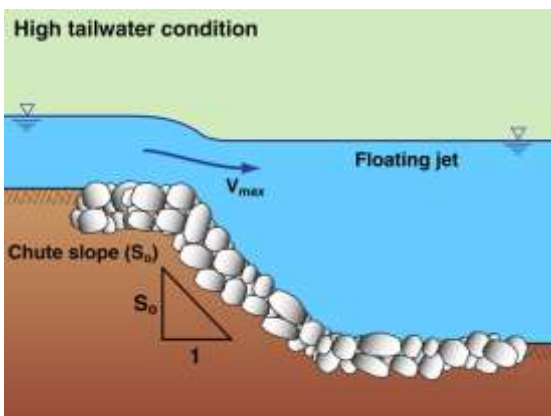
Partially drowned chute (Qld)



Low tailwater condition



Medium tailwater condition



High tailwater condition

### Introduction

- The hydraulic forces on the chute rock vary with:
  - flow velocity
  - the degree of turbulence.
- As the channel flow (Q) increases, it is normal for the tailwater level to also increase, which means the rock chute slowly becomes submerged.
- The rock size specified for the rock chute must be checked for three flow conditions: low, medium and high tailwater.

### Low tailwater condition

- In this condition, tailwater levels are so low that uniform flow conditions are developed on the chute (i.e. the water slope equals the energy slope equals the chute slope).
- Mean rock size should be checked against the following equation (K6, below).

$$d_{50} = \frac{1.27 \cdot SF \cdot K_1 \cdot K_2 \cdot S_o^{0.5} \cdot q^{0.5} \cdot y^{0.25}}{(s_r - 1)}$$

### Medium tailwater condition

- In this condition, tailwater levels begin to drown out the chute, and the maximum energy gradient does not equal the slope of the chute.
- Mean rock size should be checked against the following equation (K7, below).

$$d_{50} = \frac{1.27 \cdot SF \cdot K_1 \cdot K_2 \cdot S_o^{0.5} \cdot V_o^{2.5} \cdot y^{0.75}}{V_o^{2.0} (s_r - 1)}$$

### High tailwater condition

- In this condition, tailwater levels are so high that the rock chute is fully or partially drowned out.
- The falling 'jet' is likely to separate from the rock chute and begin to float.
- Mean rock size for the crest rock should be checked to ensure that it exceeds the general rock sizing equation for normal stream flow, i.e. Equation K8.

$$d_{50} = 0.04 V^2 \quad (K8)$$

# K3 Ridge Rock Ramps



Photo supplied by Catchments & Creeks Pty Ltd

**Ridge rock ramp (Qld)**

## Description

- Ridge rock ramps consist of a series of rock weirs, each having a maximum water level fall of around 100 mm.
- Typically used on ephemeral waterways where low-flow depths are around 100 to 300 mm.
- Ridge rock ramps differ from traditional rock chutes and rock ramps in regards to how the rocks are arranged on the creek bed.



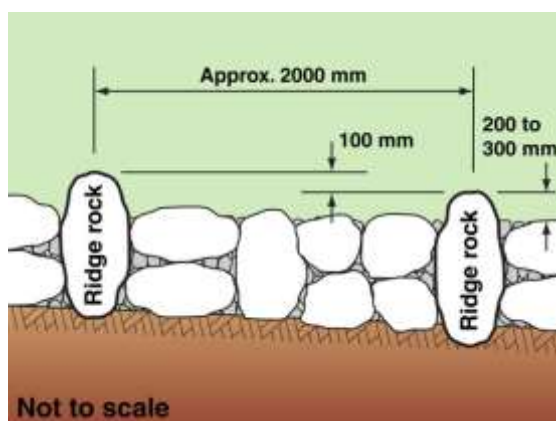
Photo supplied by Catchments & Creeks Pty Ltd

**Rock fishway (NSW)**

## Ridge rock ramps



Photo supplied by Catchments & Creeks Pty Ltd  
**Ridge rock ramp (Qld)**



**Typical dimensions**



Photo supplied by Catchments & Creeks Pty Ltd  
**Potential site for a ridge rock ramp (Qld)**



Photo supplied by Catchments & Creeks Pty Ltd  
**Highly unstable gravel bed (Qld)**

### Introduction

- In general I do not support the use of ridge rock ramps because I do not believe these structures are durable.
- The durability of these structures depends on the stability of the 'foundations' of the structure, which in most cases depends on the stability of the waterway bed, which in most cases is unstable (because waterways are dynamic landforms).
- To be effective, they need to be designed by the right people, and built with very close supervision.

### General design parameters

- General design specifications are:
  - spacing of rock ridges = 2 m
  - fall across a rock ridge = 100 mm
  - overall gradient = 1 in 20
  - maximum total fall = 1000 mm.
- Each ridge is formed from rocks with a length of around 600–1000 mm, standing vertically, and recessed into a bed of tightly packed smaller rocks such that just 200–300 mm of the ridge rock is exposed.

### Placement in fixed-bed creeks

- Both rock-based and clay-based creeks can be termed fixed-bed creeks, because in a catchment with stable hydrology, these creeks should be relatively stable.
- Rock-based creeks can provide a stable foundation, but may rely on grout to anchor the rocks to the bedrock.
- In clay-based creeks it is important to provide a stable downstream anchor (bookend) that can prevent any undermining of the structure (foundations mimic that of the old Roman road style).

### Placement in alluvial creeks

- Alluvial waterways include sand-based and gravel-based creeks.
- Ridge rock ramps should not be constructed in deep sand-based creeks.
- The stability of a ridge rock ramp in a gravel-based creek depends on the frequency of major bed movement, which can totally destroy the structure.
- Natural bed gravels will eventually migrate over the ridge rock ramp, which can either enhance or diminish the ramp's fish passage attributes.

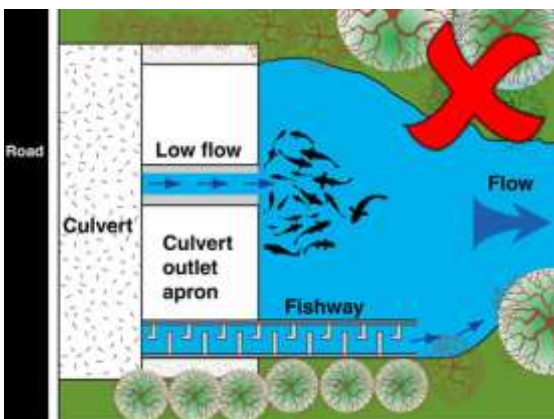
# K4 Fishways



Fishway (USA)



Fishway (Scotland)



Poor fishway design

## Introduction

- The term 'fishway' can refer to a variety of structures used by fish.
- In this case the term refers to constructed ramps (hydraulic chutes) that fish can use to access an elevated culvert.
- Fishways can be constructed from natural materials, such as rock, but are usually constructed from pre-cast units that have been tested for their fish passage efficiency.

## Critical design features

- Critical design features include:
  - capable of carrying all the base flow, thus attracting fish to the entrance of the fishway
  - suitable gradient
  - resting 'ponds' are included if the fishway is too long
  - if possible, shelter from excess sunlight and predators.

## Attracting flows

- It is essential for fish to be able to easily find the entrance to the fishway.
- 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 into the fishway entrance.
- Fish should not be able to swim past the entrance to the fishway as they swim towards the culvert.

## Baffled fishways – The Walaman system



Pre-cast concrete fishway (Qld)



Downstream end of fishway (Qld)



Debris blockage of fishway (Qld)



Upstream end of fishway (Qld)

### Introduction

- Pre-cast concrete units can be used as an alternative to ridge rock ramps.
- These fishways have been used to provide fish passage through roadway culverts that have become 'elevated' as a result of downstream bed erosion.

### Directing fish to the fishway

- It is important that the design of the fishway allows fish to readily find the downstream entrance to the fishway.
- Ideally, flow conditions should not allow fish to swim past the entrance to the fishway as they migrate up the creek towards the fish barrier.
- Note; birds collecting at the entrance to a fishway (as shown here) indicates that fish are actually using the fishway.

### Problems of organic and bed rock debris

- In natural riffles, the roundness of the riffle rock encourages flood debris to wash off the rocks.
- In pre-cast baffle fishways, the baffles can (depending on their design) temporarily collect both organic debris as well as bed gravel.
- Subsequent stream flows can displace this debris, but in a long structure it only takes one blockage to stop all fish passage.

### Directing low flows into the fishway

- It is important that the fishway directs low flows towards the upstream entrance of the fishway.
- If 100% of the low flows can be directed to the fishway, then this can improve the ability of fish to find the downstream entrance to the fishway.

## Bypass fishways



Reverse image of the Penrith weir fishway



Current weir in flood



Alternative fishway design



Alternative fishway in flood

### Introduction

- Presented on this page is a bypass fishway installed on a weir.
- Though rare, a similar design concept can be applied to culverts that cannot be otherwise modified.
- In this example (left), the current fishway is considered effective **if** the aim was to aid fish passage **only during normal dry-weather flows**.

### Use as a grade control structure

- However, a potential problem with the current 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.

The 'inlet' of the fishway being defined by the location where fish enter the fishway, not where flows enter the fishway.

### Potential impact of fish passage

- One solution to this problem is to design the fishway so that the initial channel 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.

### Impact of natural sediment migration

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

# **Appendix L: Culvert Upgrade Case Studies**

## Bennett Road, Enoggera Creek, Brisbane, Queensland



Location map



Floor baffles in the fishway (Qld)



Fishway ramp (Qld)



Inlet of the fishway (outlet of water flow)

**Note:** The comments provided on these case studies are just the author's personal opinion.

### Enoggera Ck, Bennett Rd, The Gap, Qld

- In its original condition, the Bennett Road culvert represented a significant barrier to fish passage.
- The culvert has a significant drop at its outlet, which results in downstream water levels being significantly lower than the culvert floor during dry-weather conditions.
- It would not have been practical to have elevate the downstream channel bed through the addition of a rock chute, or more pools and riffles, because of the downstream golf course.
- The adopted solution was to construct a narrow low-flow fishway through one cell of the culvert.
- The fishway passing through the culvert cell consisted of a pre-cast floor baffle system produced by **Walaman**.

### Fishway ramp

- Downstream of the culvert, a fishway ramp was constructed, which relied on fish jumping a series of 100 mm steps.

### Operation of the fishway

- Operation of the fishway has been monitored by **Walaman**.
- Visual evidence of the fishway's use by fish can be seen in the persistent presence of white-faced herons standing at the fishway entrance waiting for fish to swim by.

**Bennett Road, Enoggera Creek, Brisbane, Qld**



Photo supplied by Catchments & Creeks Pty Ltd

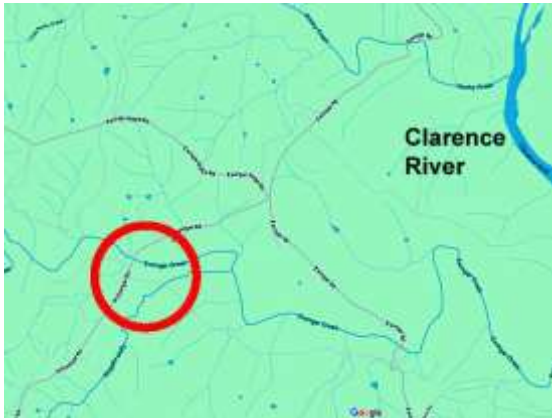
**Bennett Rd culvert prior to installation (a Photoshop-generated image)**



Photo supplied by Catchments & Creeks Pty Ltd

**Walaman Fishway installed at the Bennett Road culvert (a 'real' image, 2010)**

## Ewingar Creek, Northern Rivers Region of NSW



Location map

### Ewingar Ck, North Ewingar Rd, Ewingar

- In the year 2000, NSW Fisheries obtained a federal grant to trial some culvert upgrade options in the northern rivers region of New South Wales.
- Four culverts were identified as trial sites from a list of proposed culvert upgrades submitted to NSW Fisheries from local governments.



Photo supplied by Catchments & Creeks Pty Ltd

Constructed riffle upstream of the culvert

### Proposed upgrade at Ewingar Creek

- The proposed upgrade involved:
  - maintaining the current upstream and downstream dry-weather flow water levels
  - recessing the floor of a new three-cell box culvert below the downstream water level
  - constructing a rock riffle (rock ramp) upstream of the culvert to stabilise the existing fall in water level across the culvert.



Photo supplied by Catchments & Creeks Pty Ltd

Baffled cell (NSW)

### Sidewall baffles

- Given that this site was to be used as a test site, and fish passage monitoring was to be performed before and after construction of the new culvert, it was decided to fit sidewall baffles to only one cell.
- This allowed for fish passage through both baffled and non-baffled cells to be monitored.
- Monitoring showed fish passage improved from 0% to 44%.



Photo supplied by Catchments & Creeks Pty Ltd

Rusted sidewall baffles (NSW)

### Corrosion of the sidewall baffles

- Over a period of ten years, the galvanised steel baffles experienced significant corrosion.
- This corrosion is caused by flood abrasion of the zinc coating by sand particles suspended in floodwater.
- Conclusion: It is difficult to imagine small rural councils being able to justify the expense of (i) monitoring the fishway, and (ii) replacing damaged baffles on a regular basis.

**Ewingar Creek, Northern Rivers Region of NSW**



**Old Ewingar Creek culvert, Ewingar, NSW (2000)**



**Replacement culvert, Ewingar, NSW (2001)**

## Laura Creek, Guyra, New South Wales



Location map

### Laura Ck, Hudsons Rd, Guyra, NSW

- This site was very useful because, even though the culvert was on a public road, it was similar to the type of culvert often found within private properties.



Photo supplied by Catchments & Creeks Pty Ltd

Looking downstream (NSW)

### Existing site conditions

- The existing site conditions consisted of a concrete causeway with two very small low-flow pipes (see image over page).



Photo supplied by Catchments & Creeks Pty Ltd

Outlet of the new culvert (NSW)

### Proposed upgrade at Guyra

- The proposed upgrade consisted of:
  - maintaining the existing upstream and downstream channel conditions
  - constructing a new three-cell pipe culvert that had a total flow area equal to the natural flow area of an upstream riffle cross-section (determined for the equivalent water level that would have overtopped the new culvert, i.e. a high flow design)
  - the pipes were recessed 20% of their diameter into the bed.

### Outcome

- The cost of the upgrade was comparable to the cost of a typical causeway to culvert upgrade.
- Monitoring showed fish passage improved from 20% to 69%.
- Conclusion: Fish-friendly culverts are not necessarily more complex, nor more expensive than traditional culverts.



Photo supplied by Catchments & Creeks Pty Ltd

New culvert crossing (NSW)

**Laura Creek, Guyra, New South Wales**



Photo supplied by Catchments & Creeks Pty Ltd

**Old Laura Creek culvert, Guyra, NSW (2000)**



Photo supplied by Catchments & Creeks Pty Ltd

**Replacement Laura Creek culvert, Guyra, NSW (2001)**

## Washpool Creek Road, Tenterfield, NSW



Location map

### Washpool Creek Road, Tenterfield, NSW

- This site was another causeway to culvert upgrade, which is common in rural areas.
- The existing causeway had approximately a 1 m drop in water level across the structure.
- A critical outcome for this site was the need to maintain the current upstream water level, which the author believes is used as a local fishing pond.



New culvert during construction (NSW)

### Proposed upgrade

- The proposed upgrade consisted of:
  - maintaining existing upstream and downstream channel conditions
  - constructing a new three-cell box culvert, with the central cell being formed by use of bridging slabs
  - a rock ramp (fishway) was constructed inside the central cell in order to achieve the 1 m fall in water level.



Central fishway during a low-flow period

### Central fishway

- All three cells were designated as 'wet' cells, but effectively, dry-weather flows only pass through the central cell.
- The central fishway (rock ramp) allows fish to ascend the fishway using burst speed without formal resting areas because of the narrow culvert width.



Rock mattress bed roughness

### Outcomes

- At the time of the design, the displacement and wire-damage problems associated with the use of rock mattresses in alluvial waterways was not known.
- The outer cells that were fitted with the rock mattresses as bed roughness, but these cells became prone to debris blockage.
- Monitoring showed fish passage improved from 0% to 14%.

**Washpool Creek Road, Tenterfield, NSW**



Photo supplied by Catchments & Creeks Pty Ltd

**Old Washpool Creek causeway, Tenterfield, NSW (2000)**

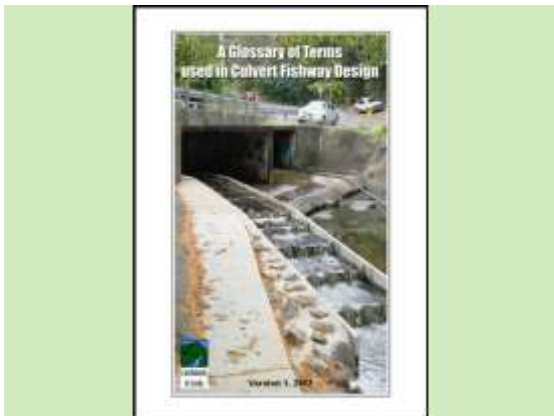


Photo supplied by Catchments & Creeks Pty Ltd

**Replacement Washpool Creek culvert, Tenterfield, NSW (2002)**

# **Appendix M: Terminology**

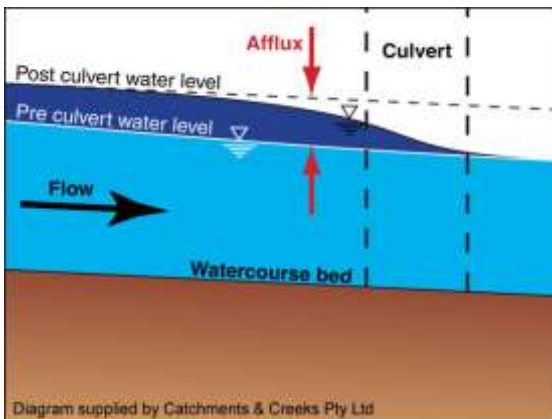
## AEP to Apron



Catchments & Creeks Pty Ltd, 2017

Annual exceedance probability (AEP)	Average recurrence interval (ARI)
0.01 (1 %)	1 in 100 years
0.02 (2 %)	1 in 50 years
0.05 (5 %)	1 in 20 years
0.10 (10 %)	1 in 10 years
0.18 (18 %)	1 in 5 years
0.39 (39 %)	1 in 2 years
0.63 (63 %)	1 in 1 year

### Relationship between AEP and ARI



Diagrammatic representation of afflux



Concrete apron at culvert inlet

### Introduction

- There are a variety of professions that work in and around waterways, including:
  - engineers (civil, structural, environ.)
  - scientists (biologists, ecological)
  - bush rehabilitation specialists.
- Each of these professions can have their own understanding of what is, or is not, a culvert.
- This chapter provides guidance on the terminology that has been adopted within this design guide.

### AEP and ARI

- AEP means 'annual exceedance probability'.
- ARI means 'average recurrence interval'.
- AEP is the probability that a particular storm or flood event will be equalled or exceeded in any year.
- AEP is not necessarily the complement of the *return period* or the average recurrence interval.

### Afflux

- The rise in water level on the upstream side of a constriction in a stream or channel relative to the water level on the downstream side. [AS1348-2002]
- A measure of the increase in water elevation at a given location caused by a given structure, relative to the water elevation that would have occurred at that location if the structure did not exist.

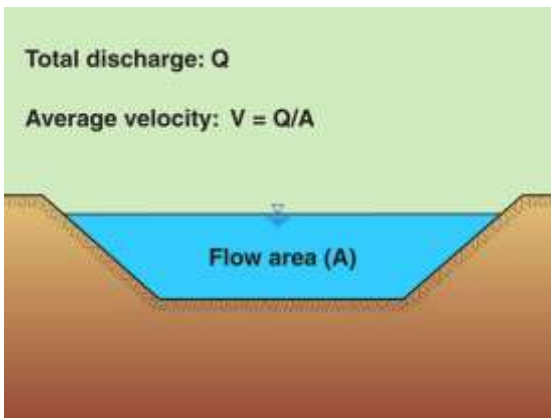
### Apron

- A layer of concrete, stone, timber or other durable material placed at the entrance or outlet of a hydraulic structure (such as a culvert) in the bed of a channel or watercourse, to protect the structure against scour. [AS1348-2002]

## Arch bridge to Base



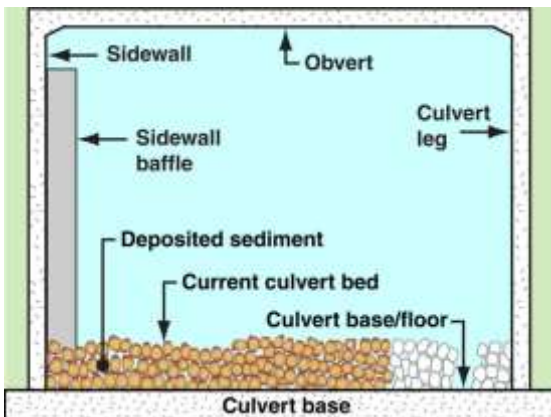
Arch bridge



Cross-sectional flow parameters



Backwater passing through a culvert



Culvert base

### Arch bridge

- A bridge, the deck of which is supported by a curved structural member in compression which transfers the loads to the abutments or piers. [AS 1348-2002]
- An arched structure resting on supports at both extremities (footings or abutments) without intermittent supports or piers.
- These structures are often **mistakenly** termed 'arch culverts', but they are not culverts because the conduit is not fully enclosed by structural surfaces.

### Average flow velocity

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

$$V = Q/A \text{ [m/s]}$$

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

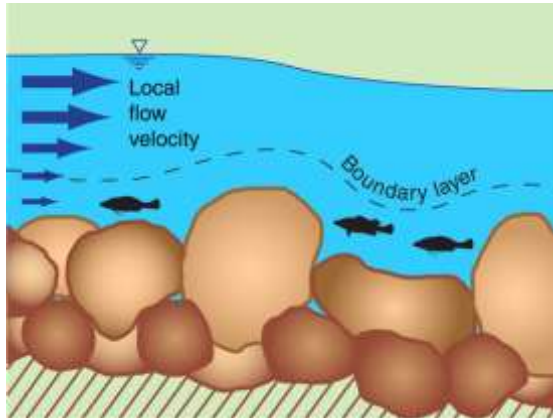
### Backwater

- That part of a stream, the water level of which is kept above normal due to some controlling influence downstream. [AS 1348-2002]
- A hydraulic condition where water levels at a given location are primarily controlled by the effects of a downstream structure (natural or artificial) or water body, rather than channel roughness.

### Base / floor

- The solid bed or floor of a culvert.
- Typically refers to the structural base of the culvert that may be buried under sediment or natural bedding material which forms the effective 'floor' or 'bed' of the culvert.

## Boundary layer to Cell



Boundary layer formed over a rocky bed

### Boundary layer

- A **boundary layer** is a region of lower than average flow velocities that exists immediately adjacent to any fixed surface such as the bed and sidewalls of a culvert.
- In general, the rougher and more irregular the fixed surface is, the thicker and the more effective the boundary layer is for fish passage.



Multi-cell box culvert

### Box culvert

- A culvert of rectangular cross-section. [AS 1348-2002]



Causeway

### Causeway

- A raised carriageway constructed across a watercourse or tidal waterway.
- 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 flows.



Single cell (barrel) of a pipe culvert

### Cell (culvert)

- The individual flow conduit of a culvert between the end walls.
- Also known as a 'barrel'.

## Circular culvert to Cover



**Single cell pipe culvert**

### Circular culvert (pipe culvert)

- A single or multi-celled culvert formed from circular (pipe) sections.



**Clay-based waterway (Townsville, Qld)**

### Clay-based waterways

- Clay-based waterways are often referred to as fixed-bed waterways because, in their natural state, they may not experience significant migration of bed material.
- However, in urban areas, these waterways can experience high sediment flows due to the sediment runoff from urban development.



**Countersunk box culvert**

### Countersunk (recessed) culverts

- A culvert with the structural base of the cells (or the nominated 'wet' cells) recessed into the channel bed such that a pool forms in the culvert during periods of zero flow.



**Small pipe culvert on a gravel road**

### Cover

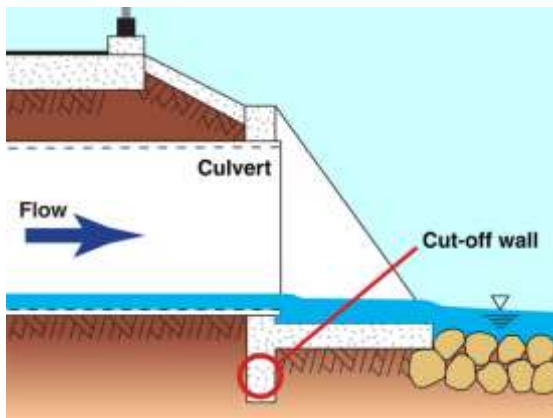
- The vertical difference between the road pavement and the upper surface (the crown) of a conduit (pipe or box culvert).
- The fill material (often road base and/or concrete) placed between the road pavement and the upper surface of a conduit.

## Culvert to Drop-inlet

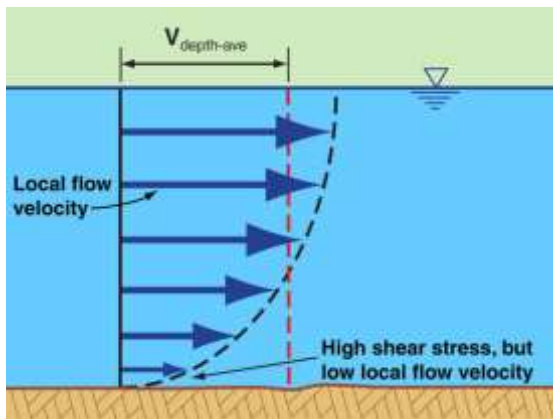


Photo supplied by Catchments & Creeks Pty Ltd

Rural culvert with stock underpass



Culvert cut-off wall



Depth-average flow velocity



Photo supplied by Catchments & Creeks Pty Ltd

Culvert with a drop-inlet

### Culverts

- One or more adjacent pipes or enclosed channels for conveying a watercourse or stream below formation level. [AS 1348-2002]
- Most commonly refers to those causeways where the conduit that passes under the causeway represents a significant part of the overall causeway.
- Culverts fully enclose the waterway; however, some culverts may be recessed into the waterway bed allowing natural bedding material to exist within the cells.

### Cut-off walls

- A watertight wall for preventing seepage or movement of water under or past a structure, or for preventing scour from undermining a structure. [AS 1348-2002]
- An impervious barrier of material or concrete designed to intercept seepage flows through or beneath a structure, and to prevent downstream bed erosion from undermining the structure.
- Commonly used at culvert head walls and on the energy-dissipation apron of drop structures.

### Depth-average flow velocity

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

### Drop-inlets

- An inlet to a hydraulic structure comprising of a sudden or rapid lowering of the bed elevation.
- Drop-inlets are commonly associated with no-slope culverts typically used on steep waterways.
- Fish passage through a culvert with a drop-inlet is normally limited to those periods when the culvert is operating under 'outlet controlled' conditions (i.e. a backwater exists through the culvert which drowns-out the drop-inlet).

## Drop-outlet to Fish ladder



Culvert with drop-outlet

### Drop-outlets

- An outlet of a hydraulic structure comprising a sudden or rapid lowering of the bed elevation.
- Typically associated with perched or elevated culverts.
- A fish barrier often exists during periods of low flow; however, fish passage may occur during high flows if the culvert operates under 'outlet controlled' conditions.



A culvert containing both wet and dry cells

### Dry cells

- A conduit within a multi-cell culvert that is expected to remain dry during base flow conditions.
- Dry cells are introduced into culverts to promote the under-road passage of native terrestrial fauna, which prefer a dry pathway.



Culvert with elevated apron

### Elevated apron

- An outlet apron that is elevated above the immediate downstream channel bed.
- Elevated aprons typically represent fish barriers during periods of low flow.



Fish ladder adjacent to a weir (Qld)

### Fish ladder

- 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.

## Fish migration to Floodplain culvert



**Fish migration in shallow water (SA)**



**Fish passage (SA)**



**Baffled fishway**



**Floodplain culvert**

### Fish migration

- Fish migration is the seasonal movement of fish and other aquatic organisms up or down a watercourse as part of their life cycle.
- It is one form of fish passage.
- It does not include the random day-to-day movement of fishes in search of food and habitat.

### Fish passage

- Fish passage is the movement of fish and other aquatic organisms up and down a watercourse.
- Movement can be for a variety of reasons including:
  - migration
  - reproduction
  - access new habitats
  - feeding
  - avoid predators
  - shelter from floodwaters.

### Fishway

- A fishway is a structure designed to enable fish to move past a physical barrier (e.g. dam or weir) in a waterway.

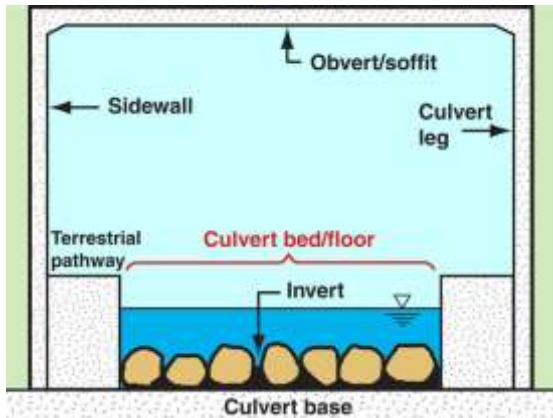
### Fishway entrance

- The 'fishway entrance' is defined as the location where fish will enter a fishway while swimming upstream (which is the location where flows exit the fishway).

### Floodplain culverts

- A culvert located in the land area adjoining rivers, streams, artificial channels, lakes, dams, bays, or oceans, that is inundated during flood events due to overbank stream flows or abnormal high tides resulting from severe storms.
- Typically these culverts are located within earth embankments adjoining a waterway bridging structure.

## Floor to Head differential



Culvert floor



Photo supplied by Catchments & Creeks Pty Ltd

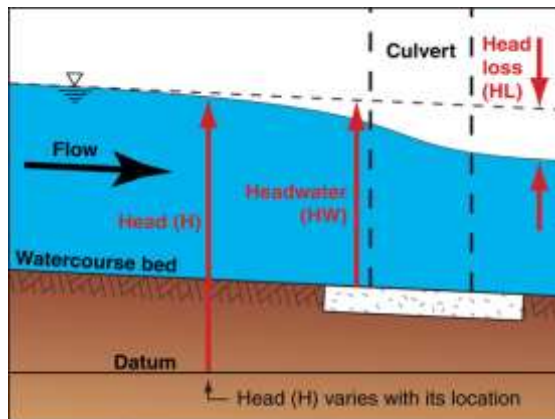
Gravel-based waterway (Eungella, Qld)

### Floor (base) of a culvert

- The exposed surface of the bed of the culvert cell.
- That part of the culvert cell that is not considered part of the roof or sidewalls.
- Typically does not include any part of an elevated terrestrial pathway that sits on the floor of the culvert.

### Gravel-based waterways

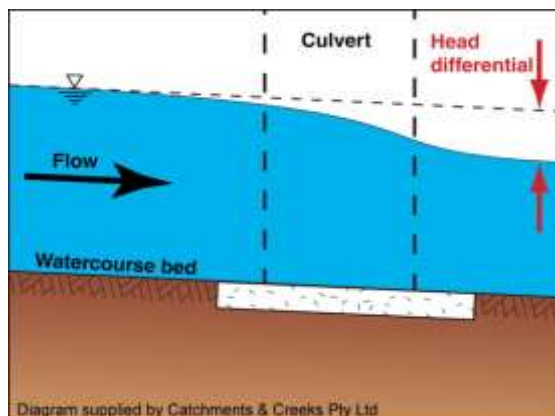
- Gravel-based waterways can experience significant movement of the rocky bed material during major and extreme flood events.
- During minor floods there may not be significant bed movement.
- Once this bed material smothers any floor baffles, they can only be removed by physical extraction, one-by-one.



Head, head loss & headwater

### Head (H)

- The height (above a standard datum) of the surface of the column of water that can be supported by the static water pressure **at a given point**.
- The term is often confused with the term 'head loss', which is the difference in the water 'head' between two locations.
- The term 'headwater' (HW) differs from 'head' because it refers to the head well-upstream of a culvert measured relative to the culvert invert at the culvert's inlet.



Head differential caused by culvert

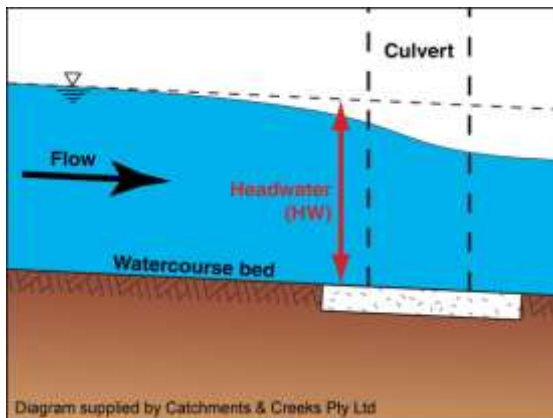
### Head differential or head loss (HL)

- The difference in static water pressure head upstream and downstream of a structure or component of a structure, e.g. the operating head of a hydraulic structure.
- Also known as 'head loss'.

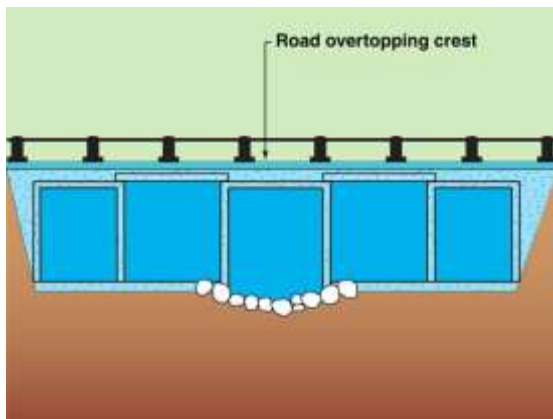
## Headwall to Invert



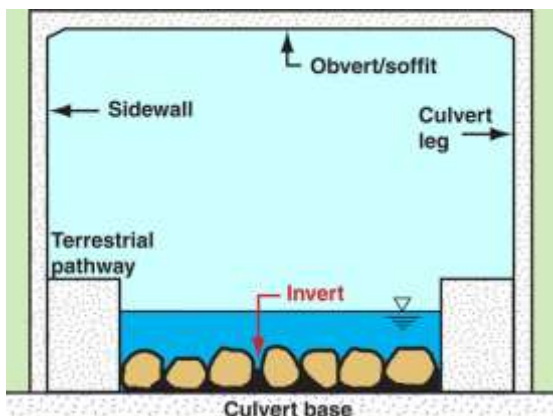
Culvert headwall without wingwalls



Culvert headwater



Example High Flow Design culvert



Invert of box culvert with 'natural' bed

## Headwall

- A structural retaining wall at the ends of a culvert, or at the end of a drainage conduit, used primary to control seepage from behind the wall and to prevent undermining of the structure.
- Also known as an 'end wall'.

## Headwater (HW)

- The height of water above the invert of a culvert measured at the inlet of a culvert. [Australian Standard, AS1348-2002]
- The parameter 'headwater' is relevant only to the design of 'inlet control' culverts, which are not common in current day waterway engineering.
- Also, the term 'Headwaters' refers to the small streams on the higher ground of a catchment that flow into a major watercourse.

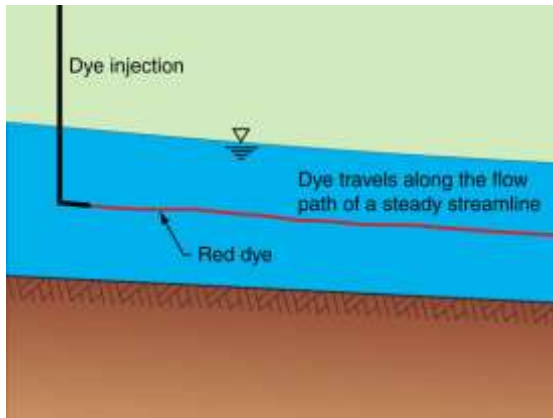
## High Flow designs

- A **High Flow Design** requires a minimum culvert flow area equal to the **stream's natural flow area** below the crossing's overtopping weir elevation.
- The depth of a culvert's deck (i.e. culvert obvert to the overtopping crest) is typically around 1 m; however, design options may be available to reduce this depth.
- If the crest of the culvert is higher than one of the approach roads, then the approach road crest should be taken as the crossing's overtopping elevation (below).

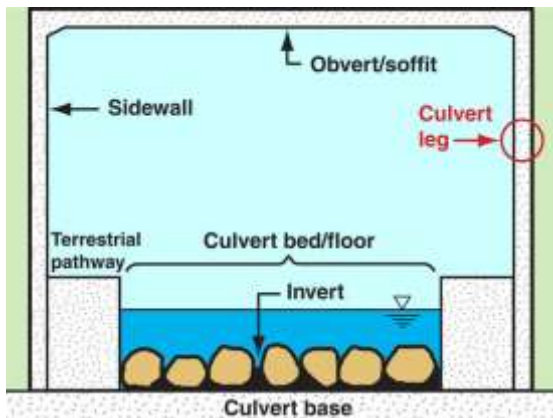
## Invert

- The lowest portion of the internal surface of a culvert or channel at a given location or cross-section.

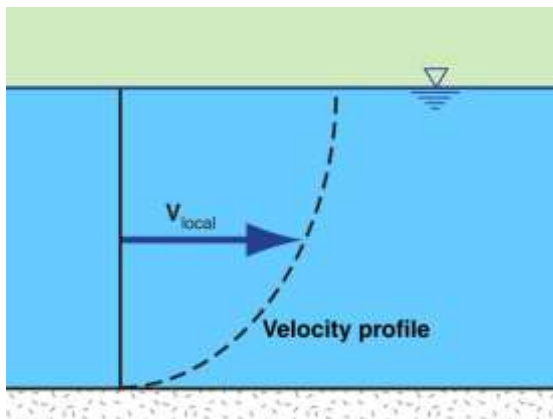
## Laminar flow to Low-flow design



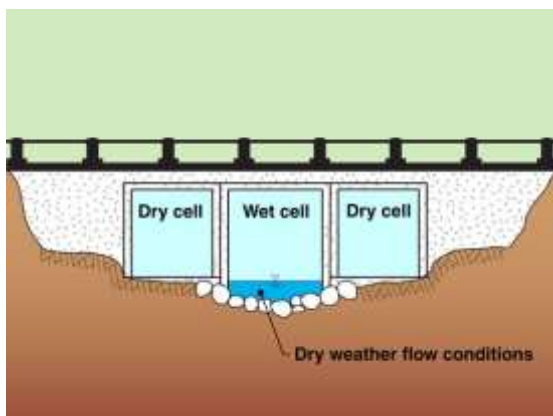
Laminar flow conditions



Vertical leg of a box culvert



Local flow velocity



Example Low-Flow Design culvert

### Laminar flow

- **Laminar flow** is a flow condition characterised by fluid particles moving along smooth paths in layers, with one layer gliding over an adjacent layer.
- The viscous properties of the fluid suppress any random (turbulent) motion of the fluid particles, thus preventing mixing between adjacent layers.
- Fisheries officers and engineers often use this term to refer to any flow that has low turbulence, but this is not 'technically' correct.

### Leg (culvert)

- The vertical member of a box culvert unit.

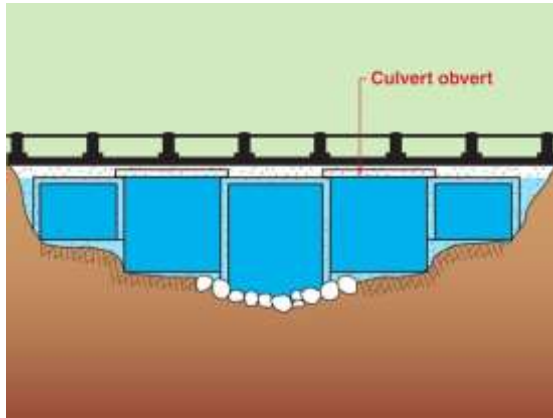
### Local flow velocity

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

### Low Flow designs

- In circumstances where a desirable minimum flow area cannot be achieved, designers should at least aim to satisfy a specified low-flow condition.
- Typical **Low-Flow Design** conditions:
  - minimum flow depth of 200 to 500 mm depending on species
  - maximum average flow velocity within fish passage cells of 0.3 m/s.
- This design standard targets the day-to-day movement of fish, not fish migration.

## Medium flow design to Obvert

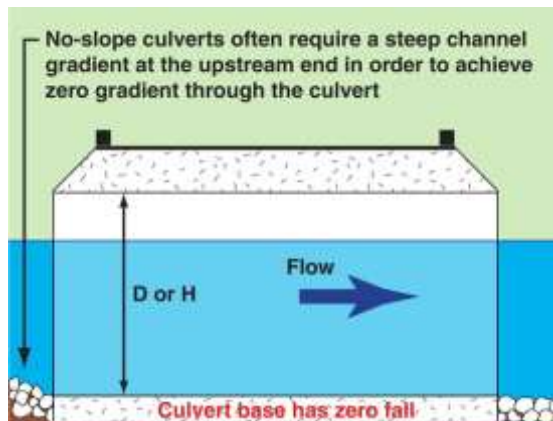


Example Medium Flow Design culvert

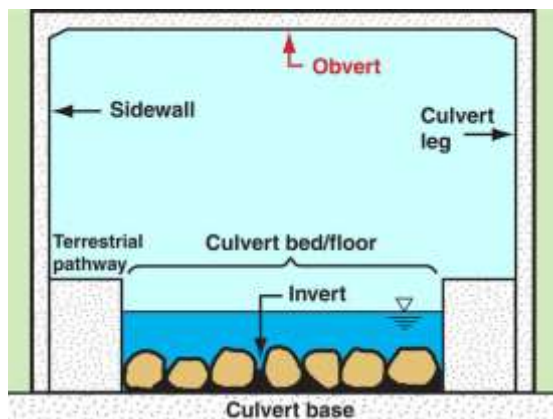


Photo supplied by Catchments & Creeks Pty Ltd

Multi-cell box culvert



No-slope culvert long-section



Culvert obvert

## Medium Flow designs

- The **Medium Flow Design** is based on providing suitable fish passage when:
  - flows are below the culvert roof, and
  - flows are overtopping the crossing,
  - but not necessarily when flows are level with the culvert deck.
- A **Medium Flow Design** requires a minimum culvert flow area equal to the **stream's natural flow area** below the elevation of the culvert's obvert (roof).

## Multi-cell culverts

- A causeway or culvert that contains more than one conduit.

## No-slope culvert designs

- A culvert design philosophy that involves the placement of culverts along a waterway where the base of the culvert has zero gradient (i.e. zero fall in the bed invert along the culvert's length).
- Sediment or natural bed gravel may be allowed to deposit along the base of the culvert to form a more fish-friendly channel bed.

## Obvert

- The highest portion of the internal surface of a culvert or arch at a given cross-section.
- Also known as the 'soffit'.

## Pipe culvert to Rock-based waterway



Pipe culvert

### Pipe culverts

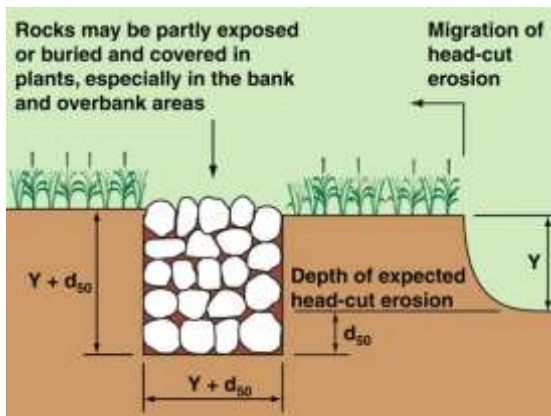
- A culvert containing circular (pipe) conduits.



Recessed box culvert

### Recessed culverts

- A culvert with the base of all or some of the cells recessed below the normal elevation of the channel bed.
- If only some of the cells are recessed, then those that are recessed are also termed, 'wet cells'.



Check dam used to control gully erosion

### Recessed rock check dams

- Unlike other structures, the purpose of a [recessed rock check dam](#) is to address bed erosion that is expected to occur some time in the future.
- The term 'check' is used in relation to its meaning: 'to stop or arrest the motion'.
- Each check dam consists of a deep trench filled with rock and soil (i.e. no voids).
- The check dam can be used to prevent the downstream creek bed falling (eroding) below the culvert floor.



Rock-based waterway (Spicers Creek, Qld)

### Rock-based waterways

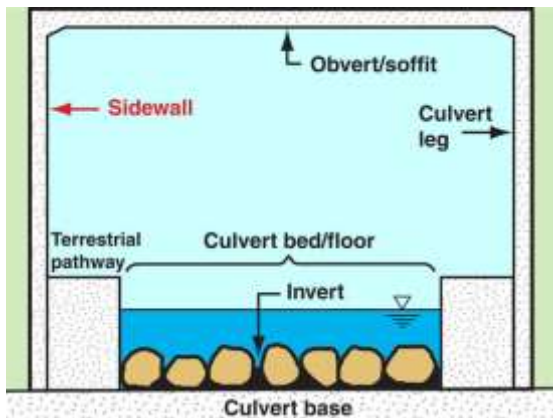
- Rock-based waterways can experience significant movement of bed material if the rocky reaches of the waterway are separated by sand-based or gravel-based reaches.

## Sand-based waterways to Smooth-turbulent flow



Photo supplied by Catchments & Creeks Pty Ltd

**Sand-based waterway (Bundaberg, Qld)**



**Culvert sidewall**



Photo supplied by Catchments & Creeks Pty Ltd

**Central skylight in a box culvert**



Photo supplied by Catchments & Creeks Pty Ltd

**Smooth-turbulent flow over a road (NSW)**

### Sand-based waterways

- Sand-based waterways can experience significant movement of the sandy bed material during both wet years and dry years.
- The sand can easily smother floor baffles.
- The sand can be flushed out by high-velocity flows, but most flood events end with a period of low-velocity flows that can simply replace the earlier displaced sediment.

### Sidewall (culvert)

- The exposed vertical surface of the culvert leg (box culverts) or the mid-elevation region of the inner surface of a circular (pipe) culvert.

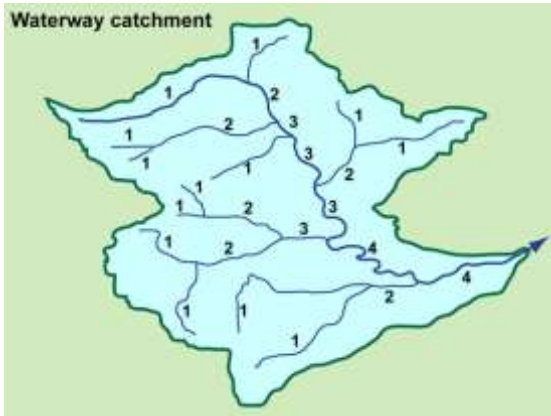
### Skylight (fishway)

- A device used to increase the protrusion of natural light through the roof of a culvert or bridge deck to aid fish and/or terrestrial passage during periods of daylight.

### Smooth-turbulent flow

- **Smooth-turbulent flow** is a condition where turbulence is limited, and large eddies generally do not exist, but full mixing does occur.
- Smooth-turbulent flow conditions normally exist only in low-gradient channels that have a uniform cross-section, and few surface irregularities.
- Smooth-turbulent flow is the flow condition that would be considered the normal environment for fish, except in large ponds where near-still water exists.

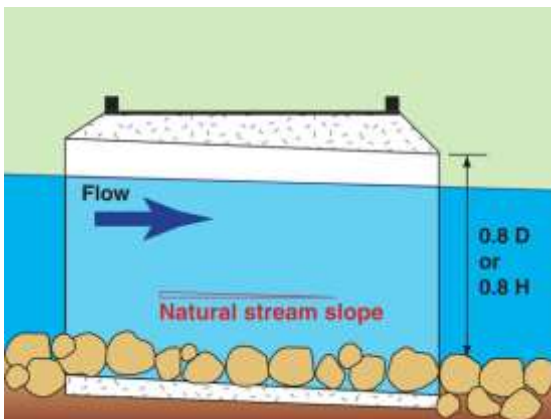
## Stream order to Terrestrial pathway



Horton's stream order system



Example of stream simulation



Stream-slope culvert long-section



Terrestrial pathways (including lizard run)

### Stream order

- Some states base the importance of fish passage on the [stream order](#).
- [Horton's stream order](#) ranks the 'reach' of a stream based on the number and ranking of its contributing branches.
- A [first-order stream](#) has no contributing branches based on a specified mapping scale—the choice of map scale is critical.
- A [second-order stream](#) has at least two contributing first-order branches.
- Similar for third and fourth-order streams.

### Stream simulation culvert designs

- A fish-friendly culvert design philosophy based on the reproduction of locally relevant 'natural' channel conditions within a culvert.

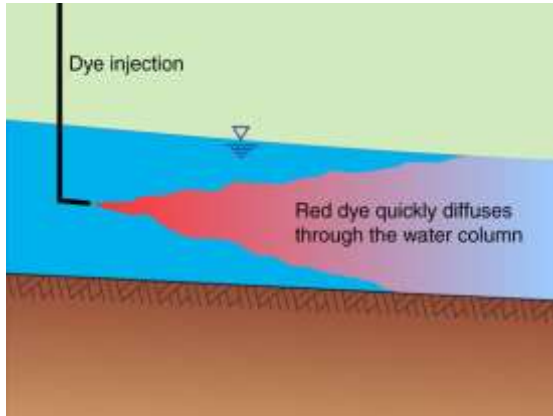
### Stream-slope culvert designs

- A culvert design philosophy that involves the placement of culverts along a waterway where the base of the culvert has the same gradient as the waterway.
- Sediment or gravels may be allowed to deposit along the base of the culvert to form a more natural channel floor.

### Terrestrial pathways

- A movement pathway specifically installed for the benefit of terrestrial fauna passage.
- Terrestrial pathways are most commonly 'dry' during periods of low flow.
- A 'lizard run' is an elevated terrestrial pathway specifically formed for fauna that would not normally move along open (exposed) low-level pathways.

## Turbulent flow to Wingwall



**Turbulent flow conditions**



Photo supplied by Catchments & Creeks Pty Ltd

**Waterway (watercourse/creek/stream)**



Photo supplied by Catchments & Creeks Pty Ltd

**A culvert containing both wet and dry cells**



**Culvert with wingwalls under construction**

### Turbulent flow

- **Turbulent flow** is a flow condition characterised by fluid particles moving along irregular flow paths.
- The viscous properties of the fluid are insufficient to suppress any turbulent motion of individual fluid particles, thus causing an exchange of momentum and mixing between adjacent layers.
- There are various classes of turbulent flow, including smooth turbulent, turbulent, and wholly rough flow.

### Waterway

- The term '**waterway**' typically includes a river, creek, stream, **watercourse**, drainage feature, and inlet of the sea.
- Readers should refer to the relevant legislation of each state and territory.

### Wet cells

- A conduit within a multi-cell culvert that is expected to pass water during base flow conditions.
- Wet and dry cells are introduced into culverts to promote the passage of both terrestrial and aquatic fauna.
- Normal design philosophy is to limit the total bed width of the wet cells to the average bed width of the watercourse.

### Wingwalls

- The extension of an abutment wall as in a bridge, or of an end wall in a culvert, used for retaining the side slopes of the earth filling. [Australian Standard, AS1348-2002]

