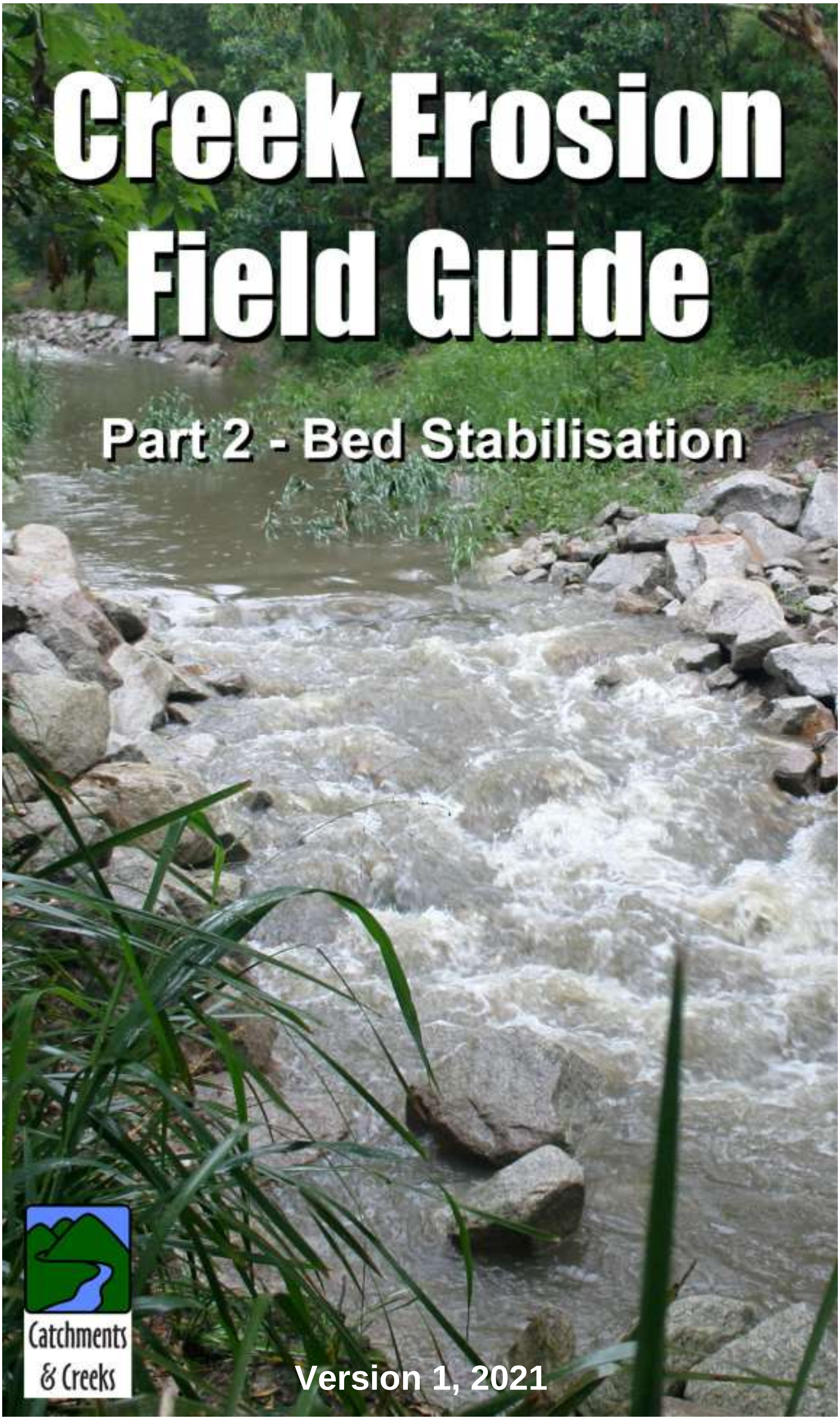
Creek Erosion Field Guide

Part 2 - Bed Stabilisation



Catchments & Creeks

Version 1, 2021

Creek Erosion Field Guide

Part 2 – Bed Stabilisation

April 2021

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Diagrams by: Catchments & Creeks Pty Ltd

Photos by: Catchments & Creeks Pty Ltd, Brisbane City Council, NSW Fisheries, and Scott Paten Consulting

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

Cover image: Minnippi Creek, Brisbane, Queensland, 2010

Disclaimer

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

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

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

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

(i) compliance with any statutory obligations

(ii) permanent control of erosion issues

(iii) avoidance of environmental harm or nuisance.

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Useful reference documents

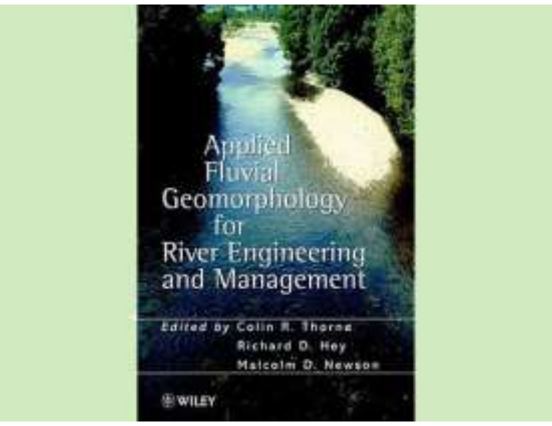
Victoria DSE (2007)

Technical Guidelines for Waterway Management

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

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

ISBN 978 1 74152 794 0



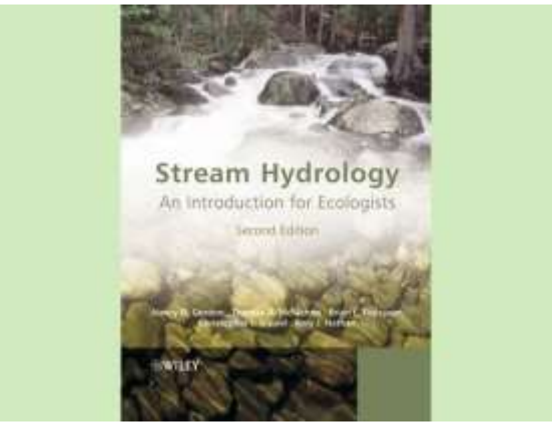
Thorne, Hey & Newson (2003)

Applied Fluvial Geomorphology for River Engineering and Management

Colin Thorne, Richard Hey and Malcolm Newson

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

ISBN 0 471 96968 0 (paperback)



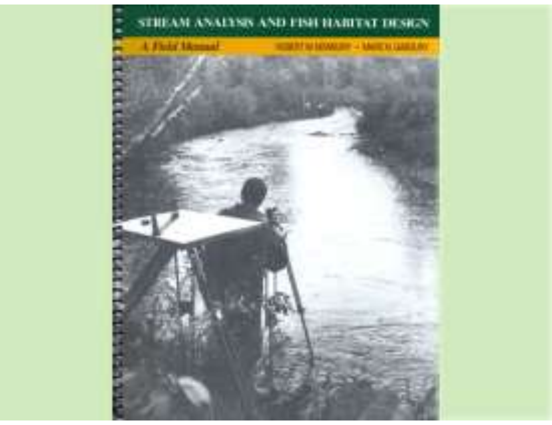
Gordon, McMahon, Finlayson, et al. (2004)

Stream Hydrology – An Introduction for Ecologists

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

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

ISBN 9780 4708 43581



Newbury & Gaboury (1993)

Stream Analysis and Fish Habitat Design

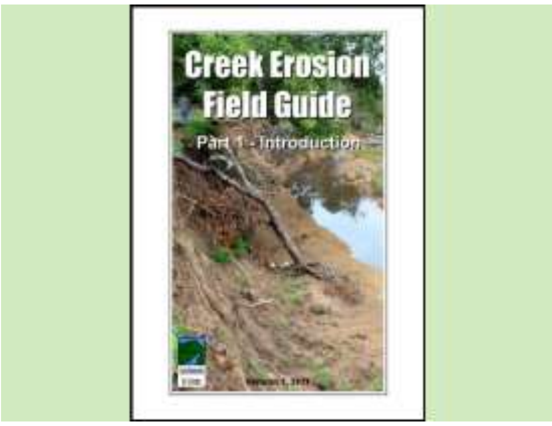
Robert Newbury and Marc Gaboury

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

ISBN 0 969 6891 0 1

Contents

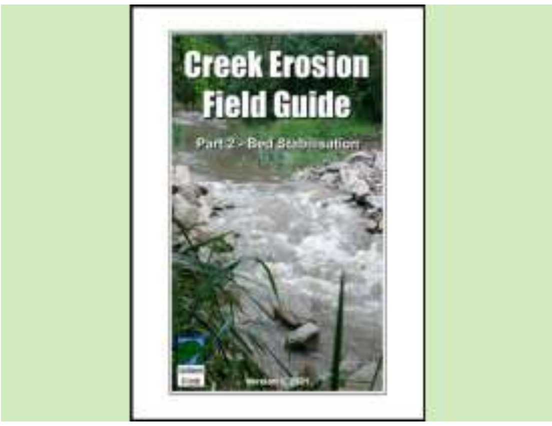
Layout of this four-part field guide



Creek Erosion Field Guide – Part 1

Part 1 – Types of waterways and causes of waterway erosion

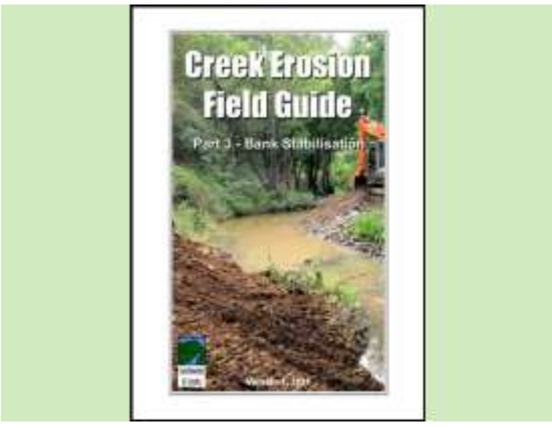
- Designing the appropriate treatment measures for creek erosion depends on knowing:
  - the type of watercourse
  - the type of erosion, and
  - the likely causes of the erosion.
- Part 1 discusses each of these issues, as well as presenting an introduction to creek engineering and fluid mechanics.



Creek Erosion Field Guide – Part 2

Part 2 – Bed stabilisation

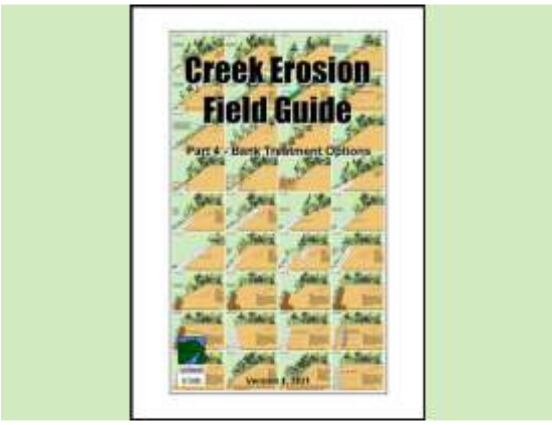
- Prior to presenting detailed information on bed stabilisation techniques, discussion is presented on the following topics:
  - fish-friendly waterways
  - common properties of rock
  - hydraulics of bed structures.
- Information on the treatment of <u>bed</u> erosion is then grouped into two chapters: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



Creek Erosion Field Guide – Part 3

Part 3 – Bank stabilisation

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



Creek Erosion Field Guide – Part 4

Part 4 – Bank stabilisation

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

Purpose of field guide

This field guide has been prepared for the purpose of:

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

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

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

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

About the author

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

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

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

Introduction

Many people view creek erosion as an indication that something is wrong with the creek or the catchment, and that it is something that needs to be fixed. But creek erosion is a natural process that can be made 'better' or 'worse' through the course of our actions. We shouldn't be fixing creek erosion just because it is occurring. We should only interfere with the natural processes of a creek if the erosion is occurring in an unnatural manner, or that the erosion is placing important assets at risk.

When we treat creek erosion there is a tendency for us to focus on what is best for the protection of the asset, and on what we would like to see as the long-term outcome; however, we should never forget the 'needs' of the creek.

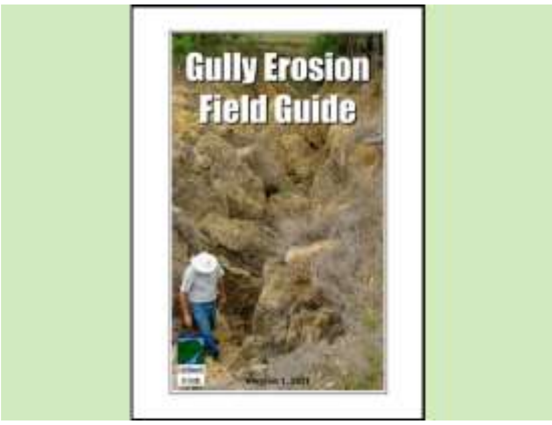
Drainage is an important function of a creek, but what makes a creek different from a 'drain' is the many fauna and flora-related attributes of the creek. A creek is a living community that has many components, each of which has specific needs. As waterway managers, we all need to become 'creek whisperers' that listen to our creeks. We should not just focus on what is best for us, but also on what is best for the creek.

Gully erosion (not discussed in this field guide)

Initial stage of gully erosion (Qld)

Branching of gully erosion (SA)

Treatment of gully erosion (SA)



Gully erosion field guide due in 2021

Introduction

- Gullies are recently formed channels, as opposed to creeks and rivers, which have existed for centuries.
- Gully erosion is a collective term that refers to the various types of channel erosion that can occur within a gully.
- The treatment of gully erosion is not specifically addressed within this document; however, there are many overlaps with the treatment of creek erosion.

Formation of a gully

- Gullies expand through the process of head-cut and lateral bank erosion.
- The growth of a gully often results in the creation of several branches, which can mimic the tributaries of a waterway.
- These expanding branches typically spread in all directions, radiating out across the floodplain or valley.
- The rate of erosion of the gully head is usually much faster than the erosion of the gully's banks.

Treatment of gully erosion

- There are typically three critical stages to the stabilisation of a gully:
  - stabilisation of the gully bed
  - stabilisation of the gully head
  - stabilisation of the gully banks
- Stabilisation of a gully normally needs to begin with the establishment of stable bed conditions.
- Only after the bed is stable is it normally feasible to stabilise the gully banks.

Gully erosion field guide

- A separate field guide is being prepared on the treatment of gully erosion (due for release in 2021).
- The main differences between the treatment of creek erosion, and the treatment gully erosion, include:
  - there is usually no need to incorporate fish-friendly features into gullies
  - the need to stabilise several different stormwater inflow points along a gully compared to fewer inflow points into a creek.

8. Planning Your Response to Creek Erosion

Introduction

Project meeting

A tree's response to severe bank erosion

16 steps to planning and design

Step 1 – Action or no action

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

Step 2 – Ownership

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

Step 3 – Interested parties

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

Step 4 – Data collection

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

Step 5 – Type and cause of erosion

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

Step 6 – Channel stability

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

Step 7 – Setting priorities

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

Step 8 – Assess material options

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

Step 9 – Assess equipment options

- Assess equipment availability and access to the site.

Step 10 – Develop treatment options

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

Step 11 – Impacts on fauna and flora

- Think about the needs of the creek.

Step 12 – Choose the best treatment option

- Look for the best overall outcome.

Step 13 – Detailed design of the preferred treatment option

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

Step 14 – Cost estimation

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

Step 15 – Recontact interested parties

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

Step 16 – Obtain approvals and permits

- Get all necessary approvals for your proposed works.

Steps 1 to 4

Natural creek erosion (Qld)

Fenced property (SA)

On-site community meeting (Qld)

Site inspection (Qld)

Step 1 – Action or no action

- The first step to planning your response to creek erosion should be to question whether or not you should be doing anything.
- Creek erosion can in some cases be a totally natural process that should be allowed to continue.
- We should only take steps to control creek erosion if:
  - the erosion is unnatural, and/or
  - the erosion threatens a valued asset.

Step 2 – Ownership

- The second step to planning your response to creek erosion should be to determine who owns the land over which the creek flows.
- Be very careful when reviewing electronic mapping services (e.g. Google maps) because the location of property boundaries may not always be correct.
- In some cases (but rare), the land boundary is identified as the centre of the creek, which means the property boundary actually moves if the creek moves.

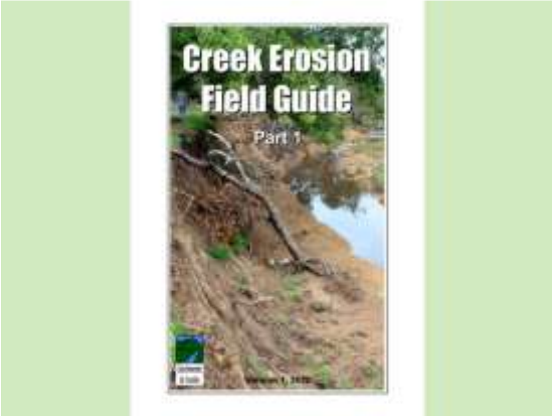
Step 3 – Interested parties

- The third step to planning your response to creek erosion should be to identify and contact all possible interested parties.
- Interested parties could include:
  - neighbours
  - traditional land owners
  - local government
  - state government.
- However, don't be surprised if you are the only interested party willing to inject time and money into the project.

Step 4 – Data collection

- Some data can be collected electronically from government files, but most of the data will need to be collected from the site.
- Data collection includes:
  - catchment hydrology
  - soil types
  - fauna and flora surveys
  - location for site access
  - availability of materials, such as rock.

Steps 5 to 8



Creek Erosion Field Guide – Part 1

Step 5 – Type and cause of erosion

- Assess the types of erosion that exist on the site, noting that there may be more than one form of erosion occurring at any given location.
- To the best of your ability, determine the likely cause, or causes, of the erosion.
- Determine if these causes can be controlled, or if the erosion is likely to be an ongoing problem.
- Guidance on these issues can be found in Part 1 of this field guide.

Unstable waterway channel (Qld)

Step 6 – Channel stability

- There is little point in spending money to fix an erosion problem if it is known that:
  - the cause of the erosion is still active
  - the channel is highly mobile and could move again in the near future
  - the creek bed is lowering in response to long-term changes to the catchment
  - urbanisation is expanding rapidly throughout the catchment.
- All of these are 'big picture' issues that need to be investigated.

Bed and bank scour (Qld)

Step 7 – Setting priorities

- If the site is experiencing both bed and bank erosion, then as a general rule, the first priority should be to stabilise the channel bed.
- However, it is possible to design bank stabilisation measures that can survive even if the channel bed is unstable.
- If there are several erosion problems along a given reach, then a scoring system can be used to rank the relative importance of each site.

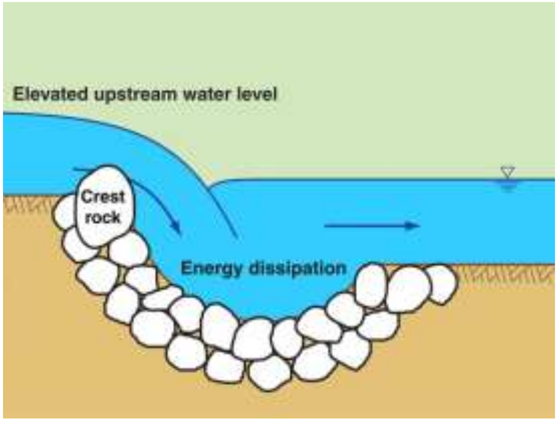
Local rock quarry (Qld)

Step 8 – Assess material options

- In most cases the treatment options will not be limited by the availability of materials.
- However, when dealing with creek erosion on farm land it may be advantageous to utilise only those materials readily available to the landowner.
- In some arid areas there may be a limited supply of suitable rock.
- Similarly, some equipment or plant species may not be readily available in all areas.

Steps 9 to 12

Access ramp cut down a creek bank (Qld)



Rock-lined plunge pool

Questionable environmental outcome


Creek Rehabilitation Projects

1 = Low 3 = Medium 6 = High

Waterway Location	Class	Risk	Community	Fauna	Flora	Score	Rank
Jesling St, Albany Creek	B1	6	6	3	6	21	1
118 Mt Gravatt Capalaba Rd	B1	6	6	6	1	19	2
92 Eugenia St, Inala	B2	6	6	6	1	19	3
21 Ringrose St, Stafford Heights	B2	6	6	6	1	19	4
Brisbane Corso, Yeronga	B1	6	1	6	3	16	5
882 Logan Rd, Holland Park West	B1	6	6	3	1	16	6
884 Logan Rd, Holland Park West	B2	6	6	3	1	16	7
115 Carvey Rd, Upper Kedron	B2	3	6	6	1	16	8
114 Dunellan St, Greenslopes	B2	6	6	1	3	16	9
13 Arcadia Pl, Eight Mile Plains	D	6	6	3	1	16	10
152 Mt Coot-tha Rd, Mt Coot-tha	B2	6	6	1	1	14	11
19 Delafield St, Sunnybank	B2	6	6	1	1	14	12
7 Arpege Cres, Eight Mile Plains	B2	6	6	1	1	14	13
605 Wynnum Rd, Cannon Hill	A2	3	6	3	1	13	14
23 Mingoola St, [illegible]	B1	6	3	3	1	13	15
491 Ellison Rd, Aspley	B2	3	6	3	1	13	16
487 Ellison Rd, Aspley	B2	3	6	3	1	13	17
318 Milton Rd, Milton	D	3	6	1	3	13	18
154 Handford Rd, Zillmere	D	3	6	3	1	13	19
67 Kenilworth Place, Carindale	D	3	6	3	1	13	20

Ranking proposed creek projects

Step 9 – Assess equipment options

- The choice of treatment options may depend on:
  - what equipment is available, and
  - whether suitable access exists at the site for large or heavy machinery.
- On a farm it may be preferable to utilise only general farm equipment.
- Long-reach excavators, or telescopic equipment, may be needed to reach over, or through, riparian vegetation.

Step 10 – Develop treatment options

- In some cases it can be useful to develop at least three options for the treatment of the creek erosion:
  - a low cost option that could be built with local equipment (such options usually have a higher risk of failure if unfavourable weather conditions occur)
  - a medium cost, medium-risk option
  - a high cost option that has enhanced fauna and flora features, and/or increased long-term channel stability.

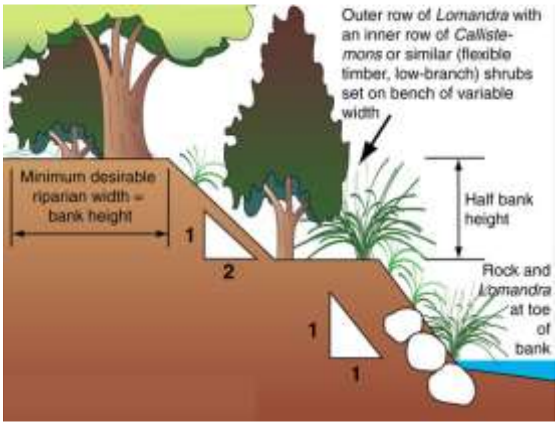
Step 11 – Impacts on fauna and flora

- Each treatment option should be assessed with respect to its potential environmental impacts, including:
  - impacts on fauna habitats
  - impacts on fauna movement corridors
  - potential damage to, or removal of, habitat trees
  - the risk of causing excessive instream sedimentation during construction
  - impacts on the waterway aesthetics.

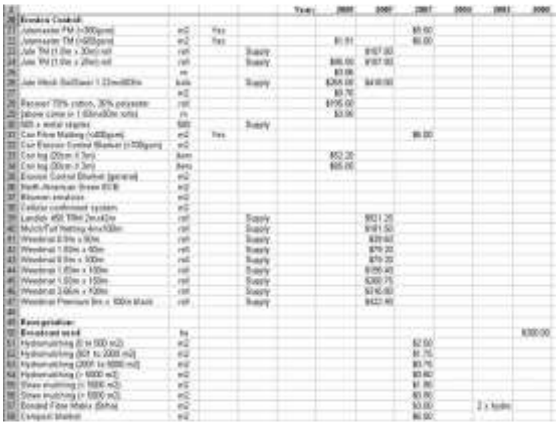
Step 12 – Choose the best treatment option

- In some cases it will be the client or landowner that chooses their preferred treatment option.
- However, in most cases there will be a need to rank the options, then provide the client with the preferred treatment option.
- Critical issues can include:
  - cost (initial estimate)
  - risk of short-term failure, usually as a result of a subsequent flood
  - what works best for the waterway.

Steps 13 to 16



Bank stabilisation proposal



Unit cost spreadsheet (example only)

On-site meeting of interested parties

Queensland Water Act, 2000

Step 13 – Detailed design of the preferred treatment option

- To save money, a detailed design is normally only completed on the chosen treatment option.
- This means the cost estimates prepared in Step 12 (the ranking of options), are based on preliminary designs only.
- Formal engineering drawings are usually required if:
  - construction needs to go to tender, or
  - government approval is required.

Step 14 – Cost estimation

- During my career I have found that most people believe that engineers should be able to calculate the cost of any project to the nearest dollar—that is <u>not</u> so!
- Cost estimation is a very specialised task, and rarely is it more accurate that +/- 20%.
- The cost of supplying materials and constructing earthworks can also vary significantly between urban and rural areas.

Step 15 – Recontact interested parties

- Finally, all interested parties should again be consulted—this time notifying them of the final proposal.
- On rural properties it is likely that the only interested parties are those that sit around your kitchen table on a daily basis.

Step 16 – Obtain approvals and permits

- State government approval may be required in order to:
  - conduct any works within a creek
  - disturb native vegetation.
- Note: freshwater creeks and saltwater estuaries may be managed by different government departments.
- The fisheries office may be required to issue a permit for any instream disturbance, or for the installation of a temporary waterway barrier.

Consideration of the *'Do nothing'* approach (Step 1)

Bird nests in an eroded creek bank (Qld)

Introduction

- Incidents of creek erosion should not be repaired simply because they occur; there needs to be justifiable reasons before we interfere with the natural processes of a waterway.
- Some forms of creek erosion can be very useful to the long-term functioning of a creek.
- Some forms of creek erosion can provide habitat diversity, which can be essential for certain types of fauna.

Meandering channel (Qld)

Natural channel meandering

- Most waterways twist and turn as they meander down a valley or pass through a floodplain.
- Over time these meander patterns can change, and these changes generally occur through a process of natural erosion and accretion (sedimentation).
- Wherever possible, creeks should be allowed to freely develop their natural meander patterns.

Burnt catchment (Qld)

A natural response to changes in catchment hydrology

- Bed and bank erosion is a creek's way of responding to long-term changes in the catchment hydrology.
- Long-term changes in catchment hydrology can result from:
  - urbanisation
  - climate change
  - the cycle of long-term changes in tree density as a result of severe bushfires and/or fire management.

Tree growing on an ephemeral creek bed

A natural process of plant selection

- In nature, plants don't always grow in their ideal location; sometimes a tree can start to grow on the bed of an ephemeral creek, or on the side of an unstable bank.
- Natural selection not only occurs in the animal world, it also occurs in the growth of plants.
- If a plant starts to grow in the 'wrong' location within a creek, then it is likely that the plant will be undermined by erosion during flood events—this is the creek's way of dealing with plant selection.

Data collection (Step 4)

The data collection phase is very important, but if poorly managed, it can become an enormous waste of money.

Try to remember how things were back in your school days; when you were given an assignment or an examination question, you would have been given all the data that you needed in order to complete the task. But in the real world things are not so simple. When dealing with a creek erosion problem it will be up to you to decide what data is needed in order to assess the problem and design any treatment.

If you ask the landowner what data they want you to collect, their first response is likely to be the more the better. But data collection costs time and money, and your client may not be willing to pay the full cost of data collection, or be willing to wait the extra time needed in order to collect all the available site data.

The data collection phase of a project should focus on collecting only the data that is considered necessary to complete the design, and to make sure the design is compatible with the dynamics and characteristics of the waterway.

In creek engineering, the three most important design 'tools' are your eyes, your training, and your experience. In many cases there will be very little need to collect vast amounts of numerical data. Your eyes will collect most of the information you will need simply by visiting the site.

Catchment hydrology:

Do you really need to set-up a complex hydrologic model of the drainage catchment?

Do you really need to know the 10 year, 50 year, or the 100 year flow rate for the waterway, or do you just need to know the bankfull flow rate?

Maybe you don't need to know any flow rates. Maybe you just need an estimate of the average flow velocity in the waterway during those conditions that are likely to cause the erosion.

Channel hydraulics:

Do you need a complex hydraulic model of the channel in order to estimate the flow velocity, or can you estimate the flow velocity by using a simple Manning's calculation based on an approximation of the bankfull discharge?

In many cases you can estimate the bankfull discharge (m^3/s) by multiplying the bankfull flow area (m^2) by your best guess of the flow velocity (m/s). You can then use Manning's equation to check if your first guess of the flow velocity was close enough. If your first guess isn't good enough, then repeat the process until you are satisfied with the result.

River morphology:

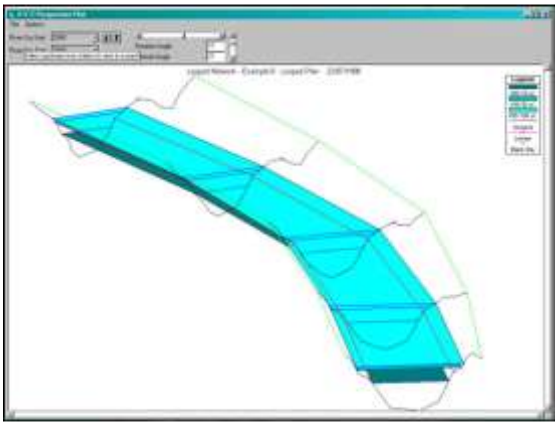
Do you really need to calculate the 'stream power', or the 'shear stress'? If you are dealing with a dynamic river system, and you don't know the answers to these questions, then you may need the assistance of an experienced river morphologist.

Extensive data collection:

Extensive data collection is likely to be required in the following circumstances:

- if it is suspected that the waterway is highly unstable, and that any bed or bank stabilisation measures will likely fail during the next flood event
- designing the rehabilitation of an instream extractive industry site
- designing a major road or railway crossing of a highly mobile waterway
- ranking the importance of several proposed waterway rehabilitation projects.

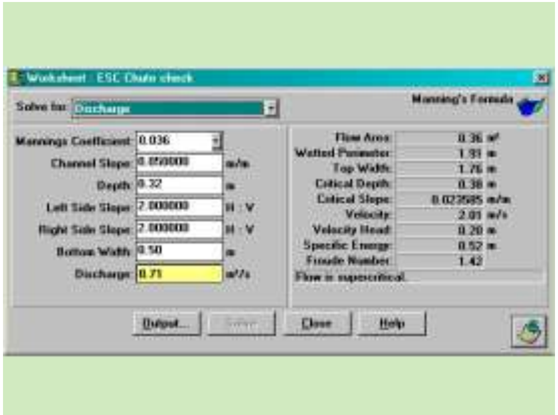
Estimating flow velocity (Step 4)



Numerical analysis (HecRas)

Numerical models

- On important projects it will be necessary to determine flow velocities through an appropriate hydraulic analysis.
- There are various forms of numerical models that can be used to determine the average flow velocity within a channel.
- For very simple channels that have a near-uniform cross-section, a spreadsheet or Manning's analysis can be used.



Spreadsheet model (Flow Master)

Manning's equation

The average flow velocity may be estimated using Manning's equation:

$$V = (1/n)\, R^{2/3} \cdot S^{½} \qquad (8.1)$$

where:

V = average flow velocity (m/s)

n = Manning's roughness coefficient

R = hydraulic radius (m) = A/P

A = cross-sectional flow area (m^2)

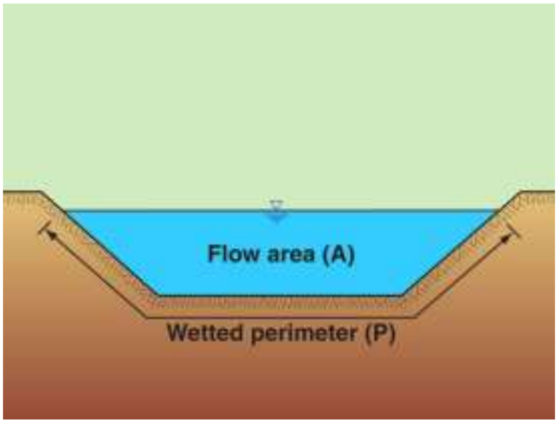
P = wetted perimeter of flow (m)

S = channel slope (m/m)

Rainwater tank in a flooded river (Qld)

On-site flow monitoring

- If the waterway is flowing during your site visit, then an approximate flow velocity can be obtained by timing the movement of floating debris over a travel distance measured out along the edge of the channel.
- This is a very crude method for estimating flow velocity, and it is important to remember that flow velocity usually increases with increasing flow depth.



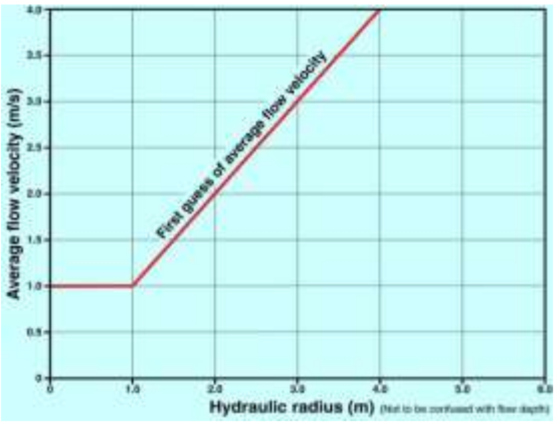
Channel cross-section

Estimating flow velocity based on the channel's hydraulic radius

- On low-risk projects it may be acceptable to determine just an estimate of the flow velocity.
- The charts presented on the following page can be used to determine a 'first guess' of the flow velocity based on the bankfull hydraulic radius (R) of the channel.

$$R = A/P \qquad (8.2)$$

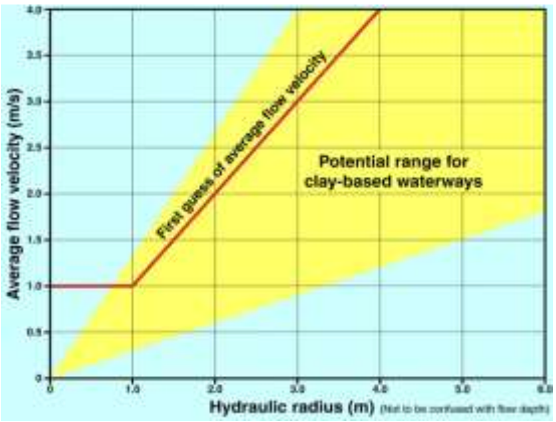
Estimating flow velocity (Step 4)



'First guess' flow velocity

Estimating the average flow velocity

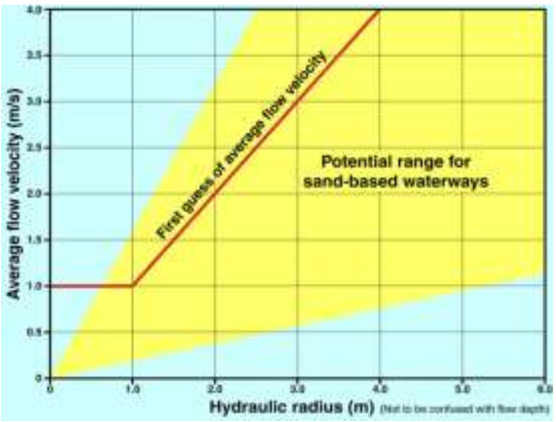
- If it is not feasible to use hydraulic analysis to determine a flow velocity, then as a first guess:
  - assume the average velocity (m/s) is equal to the hydraulic radius (m), but
  - do not choose a velocity < 1 m/s.
- For design purposes, the flow velocity is typically based on bankfull flow conditions, but in some cases a lower water level is chosen, for example, in a deep gully.



Clay-based waterways

Clay-based waterways

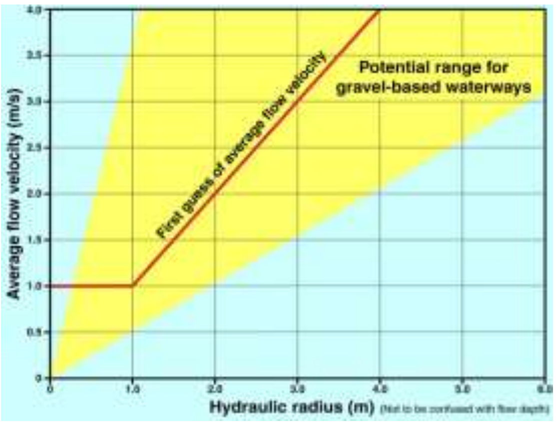
- The same 'first guess' line can be used for all types of creeks.
- This means the first guess line is:
  - conservative for both clay-based and sand-based creeks; but is
  - representative of 'mean' values for gravel-based creeks.
- The 'yellow' highlight (left) shows the typical range of values for clay-based creeks as determined from the author's analysis of New Zealand waterways.



Sand-based waterways

Sand-based waterways

- The 'yellow' highlight shows the typical range of values for sand-based creeks as determined from an analysis of New Zealand waterways.
- In many cases, loose sand can be more mobile than a cohesive clay soil, so the average flow velocity in a sand-based creek can potentially be lower than in a clay-based creek (but not always).



Gravel-based waterways

Gravel-based waterways

- Flow velocities in gravel-based creeks can be significantly higher than in sand or clay-based creeks.
- For experienced professionals, an estimate of the flow velocity can be determined by calculating the flow velocity that would move the largest bed rock.
- This means determining the threshold (critical) flow velocity:

$$V_{max} = (1/n).(d/1000/g)^{1/2}.y^{1/6} \quad (8.3)$$

where: 'd' = largest rounded bed rock (mm)

Assessing channel stability (Step 6)

Meandering waterway (Qld)

Introduction

- You would not spend money renovating a house that was about to collapse into an eroding waterway, and similarly you shouldn't spend money stabilising the bank of a waterway that was likely to relocate in the near future.
- The lateral movement of some waterway channels can be very slow, but on other waterways the channel can be highly mobile, especially when passing through a wide, silty floodplain.

Identification of old channel flow path

Observations of old channel markings

- Aerial photographs can be used to identify historical channel locations.
- These old channel markings can provide some indication of past channel movement.
- Using a stereoscope to study aerial photographs can help to make the location of old channels more obvious to the eye.

Historical aerial photograph (Qld)

Historical aerial photography

- State governments often have a library of historical aerial photographs that can be used to identify likely channel mobility.
- These images are slowly being uploaded onto government websites.

Mature trees on a river bank (Qld)

Study the age of trees

- A study of tree species and their age can sometimes be used to identify stable and unstable waterways and channel banks.
- Obviously, a bank would need to be relatively stable in order for a large tree to reach maturity.
- Much of the information that you need to know about a creek is just sitting there in plain sight.

Working in urbanised catchments (Step 6)

Urban creek (Qld)

Bank erosion undermining a car park

Revegetating an urban creek (Qld)

Old concrete-lined urban creek (Qld)

Introduction

- Creeks typically respond to urbanisation by expanding their cross-section.
- Urban creeks achieve this expansion through the process of bed and bank erosion.
- In some cases, trying to arrest this erosion is simply an act of fighting against what the creek naturally wants to do.
- The best course of action is to help the creek to find a new form of channel stability.

Stabilising creeks in recently urbanised catchments

- If the urbanisation within a catchment is relatively new (less than say 20 years), or is still actively expanding, then erosion control measures along the creek should focus on stabilising:
  - bed erosion
  - bank erosion that may undermine public or private assets
  - bank erosion that is resulting in the formation of a heavily-shaded northern bank (refer to Part 1).

Returning riparian vegetation and canopy cover to urban creeks

- Many inner-urban creeks become so modified that they completely lose their riparian vegetation and canopy cover.
- Returning a canopy cover to these urban creeks can be an admirable objective; however, introducing shade will usually cause the creek to expand.
- This is because the shade will reduce the strength and density of ground cover vegetation, which will allow increased bed and bank erosion.

Rehabilitating old stormwater drains

- One-by-one old stormwater drains are being rehabilitated back into creeks.
- *Natural Channel Design* is the name given to the design principles used to rehabilitate these channels.
- It is recommended that practitioners always investigate 'why' the old creek was concrete lined in the first place—in many cases it was for reasons of flood control, but in some cases was because the underlying soil is highly erodible, which means it probably still is.

Setting priorities – Bank erosion and bed erosion (Step 7)

Extreme effects of a lowering gully bed

Advancing 'head-cut' (Qld)

Exposure of a dispersive soil (NSW)

Loss of riparian vegetation (Qld)

Introduction

- Bank erosion problems are often the primary interest of landholders because they can present an immediate threat to the landholder's assets.
- However, if bed erosion is active along the waterway, then this can ultimately present a greater risk to the landholder.
- If the channel bed continues to lower, then it can undermine any bank stabilisation measures, and cause a significant widening of the channel.

Head-cut bed erosion (1st priority)

- There are basically two forms of bed erosion:
  - uniform bed scour
  - head-cut erosion.
- Potentially the most damaging form of bed erosion is a rapidly advancing head-cut.
- Stabilising such erosion should, in most cases, become the first priority.
- In creeks it is usually necessary to make all bed stabilisation measures fish friendly.

Dispersive soils (2nd priority)

- If the creek erosion has exposed some dispersive, sodic, or slaking soils, either along the bed or along the banks, then the stabilisation of such soils should become the second highest priority.
- Many forms of creek erosion can, over time, stabilise themselves; however, when an active form of creek erosion exposes a dispersive soil, it often becomes very difficult for the creek to find a stable outcome.

Undermining of important assets

- A ranking system can be used to determine a priority list for the repair of erosion sites along a waterway.
- The ranking system can allocate points to each site based on the value of the assets that are under risk of damage by the erosion (also see Step 12).
- Assets can include:
  - structures (buildings, roads, bridges)
  - critical habitat trees
  - farm land.

Typical erosion control materials (Step 8)

Jute or coir blanket (organic)

Jute or coir mesh (organic)

Filter cloth (100% synthetic)

Erosion control mat (composite material)

Gravel (which includes fines)

Aggregate (near-uniform in size)

Gabions (during construction)

Rockfall netting (anchored to rock)

Equipment options (Step 9)

Mini loader

Skid steer (skid-steer loader, *Bobcat*)

Backhoe loader

Rock grab

Excavator

Longreach excavator

Feller buncher

Telehandler (telescopic handler)

Revegetation equipment (Step 9)

Seeder

Scarifier

Straw mulcher

Straw mulcher with bitumen spray

Hydromulcher (hydromulch)

Hydromulcher (Bonded Fibre Matrix)

Deep ripper (for ripping hard soil)

Skid-steer topsoil leveller/spreader

Treatment options – Bank stabilisation options (Step 10)

Bank scour (Qld)

Bank scour

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

Bank slumping (Qld)

Bank slumping

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

Bank undercutting (Qld)

Bank undercutting

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

Gully erosion within a dispersive soil (Qld)

Soil dispersion and fluting

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

Treatment options – <u>Bed</u> stabilisation options (Step 10)

Clay-based creek (Qld)

Clay-based creeks

- The types of bed stabilisation structures commonly used in clay-based creeks are:
  - constructed pool-riffle systems
  - rock chutes and rock ramps
  - ridge rock ramps
  - recessed rock check dams
  - rock weirs and log weirs.
- Clay-based creeks have the advantage of a relatively stable bed condition (relative to sand and gravel-based creeks).

Sand-based creek (Qld)

Sand-based creeks

- The types of bed stabilisation structures commonly used in sand-based creeks are:
  - rock chutes and rock ramps
  - recessed rock check dams
  - pile fields.
- Constructing a rock riffle on the bed of a sand-based creek can be problematic.
- If the depth of the sand exceeds the depth of the rock structure, then the rocks could simply sink into the sand during a flood.

Gravel-based creek (Qld)

Gravel-based creeks

- The types of bed stabilisation structures commonly used in gravel-based creeks includes:
  - natural pool-riffle systems
  - constructed pool-riffle systems
  - rock chutes and rock ramps
  - ridge rock ramps.
- Any structure built across the base of a gravel-based creek must be compatible with the natural migration of bed gravel during flood events.

Rock-based creek (Qld)

Rock-based creeks

- In general, bed stabilisation structures are rare in rock-based creeks because the extent of any bed erosion is generally controlled by the exposed sections of rock.
- If bed stabilisation structures are used, then they are more likely to be associated with the sections of clay, sand or gravel-based channels found between the outcrops of bedrock.
- Constructed rock ramps can be used to allow fish to migrate past recently exposed bedrock.

Assessing impacts on riparian vegetation (Step 11)

Restoration of a site access pathway

Open-void rock work can attract weeds

Retention of a mature habitat tree (Qld)

Multi-layer planting (Qld)

Introduction

- Erosion control projects can either:
  - enhance riparian areas as part of the project's overall aims, or
  - result in a net loss of riparian values as a result of providing access to the work site, or the battering of creek banks.
- Obviously the preferred outcome is an enhancement of riparian values, or at least the protection of existing values.
- Such outcomes require appropriate planning and funding.

Impacts on weed control

- The process of repairing creek erosion problems can provide opportunities for weed control in the local area.
- Ideally, new vegetation will be introduced as part of the channel stabilisation works.
- Significantly fewer weeds are generated if the area is appropriately planted, instead of relying on natural regeneration.
- Ideally, rock-stabilised banks should be planted immediately after rock placement.

Protection of endangered species

- Endangered plant species and critical habitat trees should be identified and adequately protected from damage.
- If significant vegetation clearing is required in order to provide access for earthmoving equipment, then adjacent vegetation should be protected wherever possible.
- If the creek erosion is endangering the stability of mature trees, then the advice of an arborist may be required.

Blending lower, middle and upper storey vegetation

- Most people readily accept that there is an important link between animal species and plant communities.
- It is also noted that there are many links between the different types of plant communities, from ground covers to middle storey to upper storey plants.
- Creek rehabilitation should not just focus on the planting of trees.

Assessing impacts on aquatic fauna (Step 11)

Diverse aquatic habitat (Qld)

Loss of aquatic habitats

- Like all living creatures, aquatic life needs a place to live, food to eat, a place to shelter from predators and extreme weather conditions, and the ability to interact for the purpose of reproduction.
- The control of bed scour can sometimes result in a change in water levels and the size of permanent pools, which can directly impact upon the aquatic life that depends on these pools.

Open voids between submerged rocks

Impacts of food supply

- It can be difficult to recognise potential food sources for aquatic life.
- Critical factors are:
  - aquatic plants
  - total surface area of submerged surfaces, including plants and rocks
  - species diversity.
- There are a lot of little things that can be done in erosion control that can make a big difference to aquatic habitats.

Shading of the water's edge (Qld)

Impacts on shelter and water temperature

- Plants placed along the water's edge should partially cover and shade the water in order to:
  - control the water temperature
  - hide fish from terrestrial predators.
- The voids between submerged rocks are generally left open in order to:
  - allow fish to shelter during flood events
  - protect small fish from larger fish.

Inadequate bank vegetation

Impacts on fish passage

- Adverse impacts on fish passage can result from:
  - the creation of high steps in the channel bed (i.e. mini waterfalls)
  - non fish-friendly grade control structures (e.g. steep rock chutes)
  - changes in the vegetation and hydraulic roughness of channel banks that: (i) reduces the ability of fish to hide from high-velocity flows, and (ii) reduces the ability of fish to swim upstream during minor floods.

Assessing impacts on <u>terrestrial</u> fauna (Step 11)

Habitat diversity (Qld)

Impacts on terrestrial habitats

- For aquatic life, the three most important factors affecting their habitat are: food supply, water quality, and good company.
- For terrestrial life, the three most important factors are likely to be:
  - habitat diversity
  - plant diversity
  - habitat continuity (i.e. a continuous migration path between areas of bushland).

Natural food chain (Florida, USA)

Impacts on food supply

- For terrestrial wildlife, food supply is closely linked to the diversity of native plant species.
- Plants not only provide a source of food for some animals, they also attract a wide range of wildlife.
- The use of just rock and grasses to stabilise a creek bank can be a cheap and easy option, but such simplistic solutions can severely deplete the value of terrestrial habitats.

Terrestrial habitat (Qld)

Impacts on shelter and roosting areas

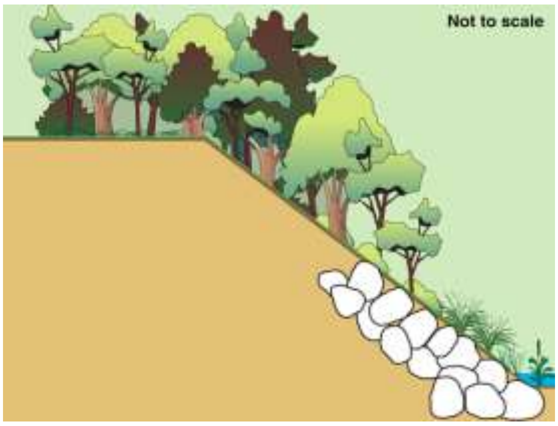
- Terrestrial wildlife typically needs access to:
  - sun and shade
  - a place to be seen, and a place to hide
  - places of low and high elevation.
- The aim is <u>not</u> to build a 'zoo', or an extension of someone's backyard.
- The aim is to appropriately integrate natural features into the site rehabilitation measures.

Terrestrial movement corridor (Qld)

Impacts on movement corridors

- Ideally, the bushland that follows an urban waterway should be linked to adjacent bushland reserves using suitable movement corridors.
- Corridor mapping (e.g. *Mountain to Mangroves*) can help governments and communities recognise and protect essential terrestrial movement corridors.

Selecting the preferred treatment option (Step 12)



Bank stabilisation design sketch

Introduction

- Ideally, more than one treatment option should be investigated for each erosion site.
- This means that eventually a preferred treatment option will need to be selected.
- Typically this selection process will occur before detailed designs are prepared.

Community meeting (Qld)

Assessing impacts on the community

- The task of selecting the preferred option involves considering the relative importance of the:
  - needs of the community
  - wants of the community
  - needs of the waterway
  - 'wants' of the waterway.
- In order to be effective, waterway managers need to be good communicators, and good people managers.

Well-maintained parkland (Qld)

The importance of aesthetics

- Most healthy creeks look 'messy', while most parks look well-maintained.
- A messy creek positioned in the middle of bushland can look natural and pleasing to the eye.
- A messy creek passing through a well-maintained council park can look neglected and unsightly.
- Waterway managers should avoid turning a creek into a 'decorative water feature' just to keep adjacent neighbours happy.

Creek Rehabilitation Projects

1 = Low 3 = Medium 6 = High

Waterway Location	Class	Risk	Community	Fauna	Flora	Score	Rank
Josling St, Albany Creek	B1	6	6	3	6	21	1
118 Mt Gravatt Capalaba Rd	B1	6	6	6	1	19	2
92 Eugenia St, Inala	B2	6	6	6	1	19	3
21 Ringrose St, Stafford Heights	B2	6	6	6	1	19	4
Brisbane Corso, Yeronga	B1	6	1	6	3	16	5
882 Logan Rd, Holland Park West	B1	6	6	3	1	16	6
884 Logan Rd, Holland Park West	B2	6	6	3	1	16	7
115 Carvey Rd, Upper Kedron	B2	3	6	6	1	16	8
114 Dunellan St, Greenslopes	B2	6	6	1	3	16	9
13 Arcadia Pl, Eight Mile Plains	D	6	6	3	1	16	10
152 Mt Cootha Rd, Mt Cootha	B2	6	6	1	1	14	11
19 Delafield St, Sunnybank	B2	6	6	1	1	14	12
7 Arpege Cres, Eight Mile Plains	B2	6	6	1	1	14	13
806 Wynnum Rd, Cannon Hill	A2	3	6	3	1	13	14
23 Mingoola St, [illegible]	B1	6	3	3	1	13	15
491 Ellison Rd, Aspley	B2	3	6	3	1	13	16
487 Ellison Rd, Aspley	B2	3	6	3	1	13	17
316 Milton Rd, Milton	D	3	6	1	3	13	18
154 Handford Rd, Zillmere	D	3	6	3	1	13	19
67 Kenilworth Place, Carindale	D	3	6	3	1	13	20

Example of project ranking

Ranking systems

- Ranking systems can be developed for a variety of purposes, including:
  - ranking the preferred treatment option at a given location
  - ranking the importance of various erosion sites along a waterway
  - ranking the priority of repairs after a flood event
  - ranking community-based rehabilitation projects prior to the allocation of government funding.

Example site ranking system (Step 12)

Ranking creek projects

Introduction

- Ranking systems need to be developed for the specific needs of the local community.
- Issues that appear within the ranking system will vary from region to region depending on local issues.
- Below is an example scoring system used in the ranking of community-based creek rehabilitation projects that were seeking local government funding.

Waterway attribute	Rating	Points	Score
Aesthetics	Low improvement Medium improvement High improvement	0 2 4	
Asset protection	No threat to assets Low improvement Medium improvement High improvement	0 3 6 10	
Construction cost	Low Medium High	0 3 6	
Channel stability	Low risk of bank failure Medium High risk of bank failure	0 3 6	
Community interest	Low Medium High	0 2 4	
Ecology	Low improvement Medium improvement High improvement	0 4 8	
Maintenance costs	Low Medium High	0 3 6	
Public safety	Low improvement Medium improvement High improvement	0 8 16	
Public usage	Low Medium High (highly visible)	0 2 4	
Riparian vegetation	Low improvement Medium improvement High improvement	0 2 4	
Water quality	Low improvement Medium improvement High improvement	0 2 4	
Use of natural materials	Low (hard engineering) Medium High (all natural)	0 2 4	
		Total score =	

Example site ranking system – Background notes (Step 12)

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Aesthetics

- Aesthetics can be an important attribute for the public, even though it may not be important to the ecology that lives in and around the watercourse.
- Waterway rehabilitation projects that can be seen and enjoyed by many people provide a greater value to the city than works that will be viewed by just a few.
- However, creeks are not supposed to look like gardens or parks, and not all creeks should look like babbling brooks.

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Construction cost

- Councils should always give priority to those projects that provide the greatest value for money, or benefit:cost ratio.
- Factors to consider include:
  - the cost per metre length of channel
  - the total cost of the project
  - the likely escalation in costs if the project were to be delayed another year or two (i.e. the ‘cost’ of not doing the work this year).

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Channel stability

- In this context, the term ‘channel stability’ refers to:
  - the overall stability of the channel within the floodplain with respect to active channel meandering
  - the likelihood of the long-term success of the proposed erosion control measures.
- Short-term success is often governed by weather conditions (i.e. the timing of the next flood), but long-term success is usually governed by how well our designs integrate with the long-term behaviour and characteristics of the waterway.

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Community interest

- Waterway rehabilitation is not always done purely for the benefit of the public.
- In some cases it is performed to prevent or minimise environmental harm.
- Community support and community participation is a very important aspect of any proposed council activity.
- Waterway rehabilitation projects can also have an educational component.
- Articles in local newspapers can help to make the wider community aware that they live within a waterway catchment, and that their council recognises the value of healthy waterways.

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Public safety

- Factors to consider include:
  - is the area accessible to the public
  - does the existence of a unstable bank increase the risk of a person falling into dangerous waters
  - is the safety risk new to the area
  - is public access new to the area
  - will children, especially unsupervised children, visit the area.

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Public usage

- Increased public access to waterways can be a key objective of a council; however, the public does not need direct access to every part of the waterway.
- Factors to consider include:
  - should a given area of the waterway be protected from the public
  - should public access be encouraged
  - should the creek works be used as a means of improving public access.

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Riparian vegetation

- Factors to consider include:
  - does the project minimise the loss of existing habitat trees
  - is the revegetation phase adequately funded
  - does the proposal incorporate weed control measures
  - does the project enhance overbank riparian values
  - does the project incorporate lower, middle and upper storey planting.

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Water quality

- Factors to consider include:
  - will the works improve ongoing water quality
  - will the project incorporate water quality improvement systems
  - will the works ultimately improve shading of the water’s edge
  - will the works reduce ongoing channel erosion
  - will the works stabilise a dispersive soil.

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Assessing likely maintenance costs (Step 12)

Channel maintenance (Qld)

Introduction

- From a local government perspective, one of the most important design considerations is to reduce the need for ongoing maintenance of waterways.
- High maintenance costs are a 'drain' on government funds, which ultimately is a drain on the finances of all rate payers and tax payers.

Weed control of rock mattresses (Qld)

Weed control

- The initial cost of repairing creek erosion can be reduced by not completing proposed site revegetation; however, this can result in increased maintenance costs.
- The failure to appropriately revegetate a site will enable weeds to invade the area.
- An increase in weeds often results in an increase in public complaints about the waterway, which can lead to ongoing weed control programs, and ongoing maintenance costs.

Selective tree removal (Qld)

Controlling vegetation in flood control areas

- Creek rehabilitation plans often specify a recommended tree spacing, which is based on an allowable channel roughness, which is based on flood modelling.
- However, trees don't know when to stop growing, and when to stop seeding.
- Intelligent waterway design can help to avoid the ongoing cost of removing plants—the key is knowing how to establish and use plant communities.

Local community group (Qld)

A watch and act approach

- Some councils, such as Brisbane City Council, operate very successful community-based bushcare groups that carry out voluntary maintenance of creeks, wetlands and bushland reserves.
- In effect, the council manages the community groups, that in-turn manage their own local waterways and bushland.
- Community groups are more likely to recognise and act upon problems before the cost of repairs becomes excessive.

Cost estimation (Step 14)

Paying the bills

Introduction

- Estimating the cost of a project is a difficult task that usually requires experience.
- Project costs can include:
  - investigation and design phases
  - the provision of site access
  - supply of materials
  - equipment (and operator) hire
  - temporary erosion and sediment control during the construction phase
  - site revegetation, including watering.

Site investigation (NSW)

Cost of investigation, design and construction management

- Project costs don't start at Step 14, they start at Step 1, from the first moment that someone is being paid to investigate the project.
- Reducing or removing the investigation phase can reduce costs, but it can put the whole project at risk.
- If the project team lacks experience, then consider employing a project manager to run the team.

Construction materials (Qld)

Cost of materials and equipment

- The cost of delivering rock to a project can vary **significantly** from city to rural areas, and from region to region.
- A significant part of the supply cost can be the cost of delivery.
- Some equipment can only be hired on a daily basis, and the hire costs may not include the supply of an operator.
- Special equipment may be required just to move materials through the riparian zone without causing damage to trees.

Site revegetation (Qld)

Cost of revegetation

- Project managers can be tempted to save costs at the end of a project by reducing the proposed site revegetation.
- It is obviously much cheaper to simply dump loose rock onto a creek bank than it is to integrate the rock into the final site revegetation.
- However, such cost savings can ultimately harm the creek.
- Project funding should also include the cost of short-term watering, and subsequent site inspections and weeding.

9. Fish-Friendly Waterway Design

Introduction

Aquatic habitat (Qld)

Freshwater turtle (Qld)

Recreational fishing (SA)

Small freshwater fish (Qld)

The importance of maintaining fish-friendly waterway conditions

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

Not just fish

- References to the terms: ‘fish-friendly’, ‘fish habitat’ and ‘fish passage’, do not just refer to fish.
- Fisheries legislation typically defines ‘fish’ as including:
  - prawns, crayfish, crabs & crustaceans
  - scallops, oysters and molluscs
  - sponges and annelid worms
  - eggs of fish
  - turtles and platypus (possible inclusion).

Not just for the benefit of the fish

- Australian bass and barramundi, both prized recreational fish species, migrate from freshwater into estuaries to spawn, with the juveniles then migrating back upstream.
- Sea mullet, a popular commercially caught fish, enters freshwater habitats as a juvenile, then migrates into estuary waters in preparation for annual spawning.

Not just for the benefit of large fish

- Protecting fish habitats is not just about protecting those fish that are large enough to be caught on a fishing line.
- Small fish exist in most of our waterways, and these fish are very important in providing biodiversity, as well as helping to control mosquito numbers along many of our urban waterways.

Fish-friendly waterways

Aquatic habitat and food supply (Qld)

Interconnected habitat ponds (Qld)

Turtle in need of shelter (Qld)

Introduced species (Qld)

Introduction

- 'Fish-friendly' is a term commonly used to describe a design process that promotes appropriate consideration of aquatic life within the design of waterway structures.
- To be fish friendly, a project needs to consider the following issues:
  - aquatic habitat and food supply
  - shelter requirements
  - diversity of aquatic life
  - protection of movement corridors.

Habitat and food supply

- Native fauna require a wide range of habitats to live in, feed and reproduce.
- Aquatic habitats usually require high-quality water during periods of low flow, and the shading of permanent water bodies to control water temperature.
- The provision of suitable habitats also requires the temporary or permanent connection of permanent water bodies in order to allow aquatic life to search for food on a day-to-day basis.

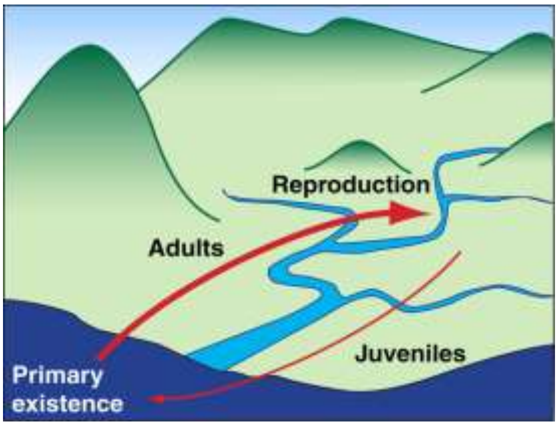
Shelter

- 'Shelter' is that part of a fauna habitat that allows wildlife to hide from predators (including humans), and to shelter from adverse weather and flow conditions.
- The provision of shelter integrates well with the ideals of providing hydraulic roughness and habitat diversity.
- Shelter may consist of cavities between submerged rocks, as well as areas of low-velocity water flow in and around reed beds, rocks and debris snags.

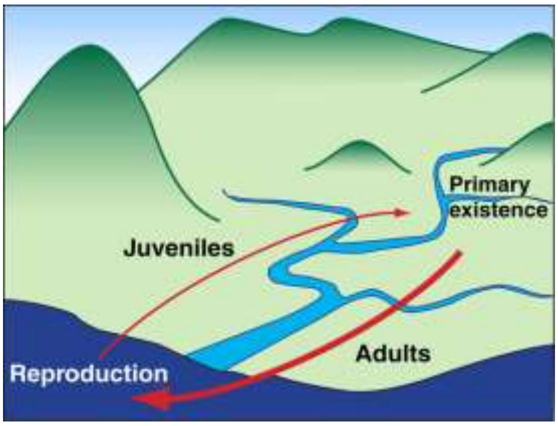
Biodiversity

- The biodiversity of species is important for the maintenance of sustainable ecosystems; however, this does **not** mean that biodiversity should be encouraged beyond that which is natural for the waterway.

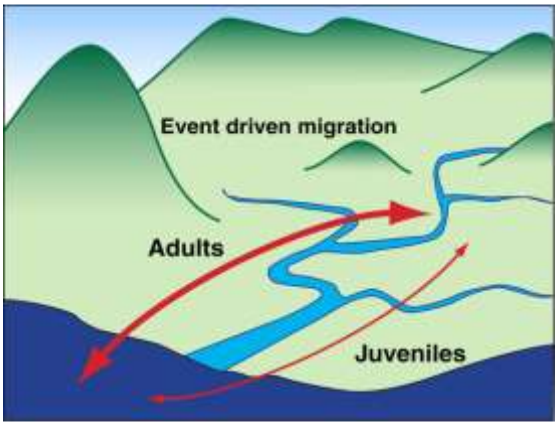
Fish passage and the protection of movement corridors



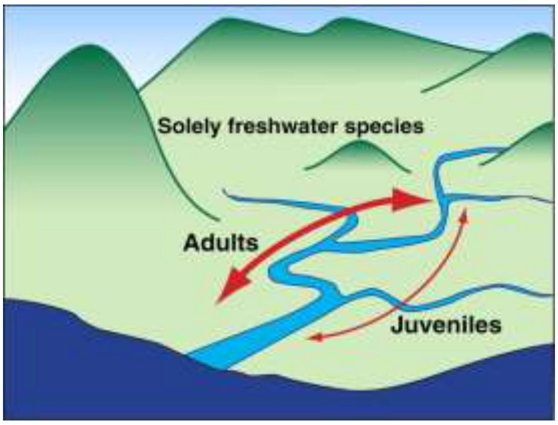
Anadromous fish movement



Catadromous fish movement



Diadromous fish movement



Potamodromous fish movement

The importance of fish passage

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

Types of fish movement

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

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

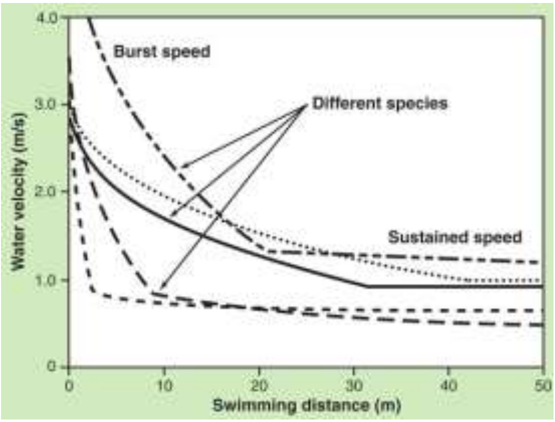
A natural response to flood flows

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

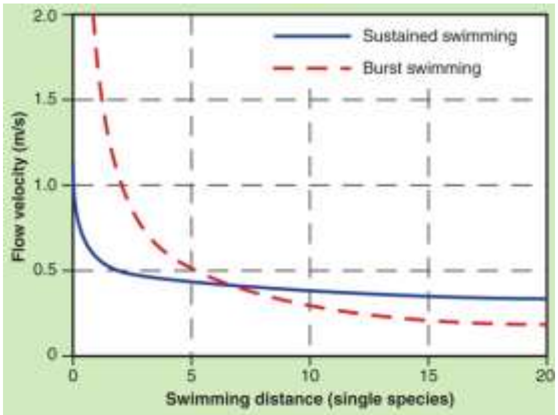
The swimming ability of fish

Pygmy perch (NSW Fisheries)

Large fish in shallow water (SA)



Examples of fish swimming ability



Example of speed over distance

Size and species

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

Swimming ability in shallow water

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

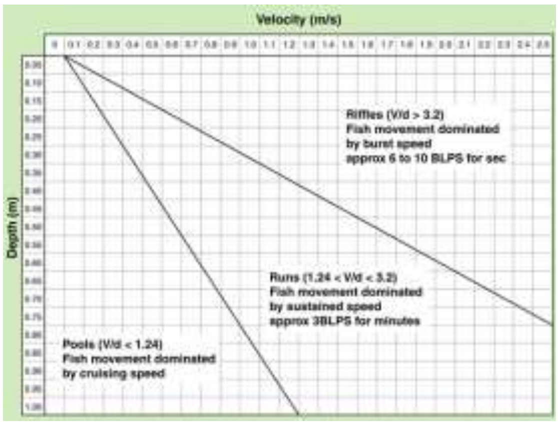
Approximate swimming speeds

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

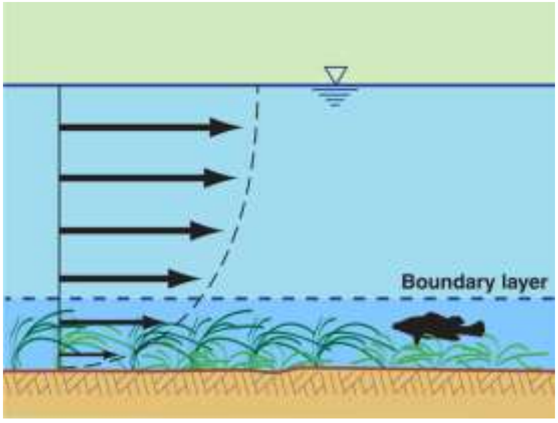
Swimming ability over long distances

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

Waterway hydraulics and its interaction with fish passage



Typical flow conditions



Boundary layer flow conditions

Whirlpool in a flooded rural creek (Qld)

Gravel-based creek with boulders (Qld)

Natural obstacles

- Creeks are rarely uniform in their cross-section and bed conditions.
- Fish passage can be obstructed by natural features, such as riffles, rapids, waterfalls, dry creek beds, and disconnected pools.
- To negotiate these obstacles, fish can use:
  - burst speed
  - jumping from the water
  - crawling over damp rocks (used by a very limited number of species).

Variation in flow velocities within a channel

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

The effects of turbulence

- Water turbulence can help to reduce flow velocities, but excessive turbulence can become a barrier to fish passage.
- Small-scale turbulence is most commonly associated with water flowing over rough or irregular surfaces.
- Large-scale turbulence (eddies and whirlpools) can be shed from large irregular objects, or from rapid changes in the direction of the waterway channel.

Small backwaters and shadow zones

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

Fish-friendly bed stabilisation measures

Gravel-based creek (Qld)

Constructed rock ramp/chute (NSW)

Constructed rock riffle (Qld)

Bed level falling downstream of culvert

Desirable creek bed features

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

Fish-friendly rock ramps

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

Fish-friendly hydraulic steps

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

Allowance for future changes in bed levels

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

Fish-friendly bed stabilisation measures

Habitats formed by placement of boulders

Random placement of boulders

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

Constructed pool-riffle system (Qld)

Use of pool-riffle systems

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

Constructed fishway (Qld)

Use of fishways

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

Fish ladder on a river weir (USA)

Use of fish ladders

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

10. Common Properties of Rock Sizing and Placement

Introduction

Bank stabilisation with rock (Qld)

Round river rock (NSW)

Sizing rock for use in straight channels

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

where:

d_{50} = mean rock size (mm)

V = average flow velocity (m/s)

Note: this equation gives d_{50} in millimetres

Large fractured rock (Qld)

Introduction

- Rock is one of the most common materials used in the repair of creek.
- Rock is successful because it works well with the dynamics of most waterways.
- The purpose of this chapter is to present much of the design information on rock selection and placement, thus avoiding having to repeat the same information each time rock is discussed in the following chapters.

Types of rock

- Common types of rock, including:
  - sandstone
  - granite
  - limestone
  - basalt
- The shape of the rock can either be:
  - 'round' typically originating from instream or floodplain extraction, or
  - 'angular' which is fractured quarry rock.

Specifying a required rock size

- The good thing about rock-sizing equations is that they can be programmed into design spreadsheets.
- The bad thing about rock-sizing equations is that they can present values to the nearest millimetre, which is simply unrealistic.
- There is little point in determining rock size to the nearest millimetre or centimetre given the natural variation in flow conditions.

Quarry face or selected rock sizing

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

Design parameters

Bank stabilisation (NSW)

Bank stabilisation (SA)

Fractured rock (Qld)

Individual placement of rocks (Qld)

Introduction

- The following pages present an overview of the various properties of rock, including:
  - equation safety factors
  - rock shape
  - method of placement
  - use of an underlying filter system
  - Manning's roughness
  - rock density
  - effective thickness of a rock layer.

Safety factor (SF)

- For low risk sites, a safety factor of 1.2 is recommended.
- Examples of low-risk structures include:
  - most bank stabilisation measures
  - riffles and chutes in low-gradient creeks
- For high risk sites, a safety factor of 1.5 is recommended, for example:
  - bed stabilisation in steep creeks
  - areas of very high turbulence.

Effects of rock shape (K_1)

- Fractured rock is generally more stable than rounded rock.
- Most rock sizing equations, including those presented within this document, are based on the use of fractured (angular) rock.
- A correction factor (K_1 = 1.36) must be applied if rounded rock is used.
- This means rounded rock needs to be 36% larger than angular rock.

Effects of rock placement on rock stability

- Rock-lined surfaces formed by the individual placement (stacking) of rocks are generally more stable than rock-lined surfaces produced by dumping the rock from a truck or bucket.
- Rocks dumped from a height, such as being dumped from a truck, will fall to a lower bank slope (angle of repose) than selectively placed rock.
- However, both methods of placement can fail if the foundations (toe) of the rock are disturbed.

Use of filter layers and filter cloth

Filter cloth (Qld)

Conditions where filter cloth should be used

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

Voids filled with soil prior to planting (Qld)

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

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

Rock filter layer (blue) under surface rock

The use of aggregate filters

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

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

where:

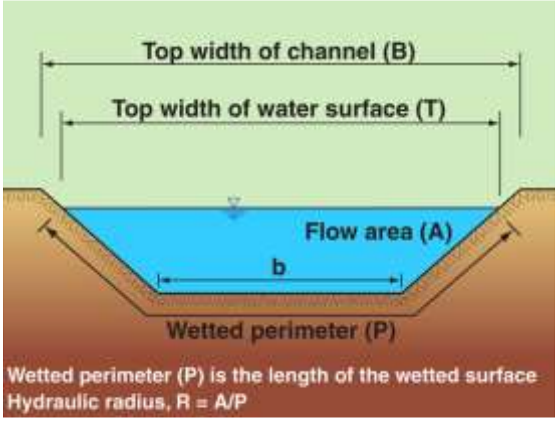
- ‘c’ and ‘f’ refer to the coarse layer and fine rock underlay respectively.

Erosion under rocks on a dispersive soil

Filter cloth cannot be placed directly on a dispersive soil

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

Manning's roughness of rock



Channel geometry and flow conditions

Gravel-based alluvial waterway (Tas)

Deep water flow conditions (Qld)

Shallow water flow conditions (Qld)

Manning's equation

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

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

where:

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

Factors affecting the hydraulic roughness of rock-lined surfaces

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

Manning's roughness in deep water

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

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

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

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

where:

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

Manning's roughness in shallow water

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

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

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

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

Manning’s roughness of rock

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

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

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

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

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

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

Table 10.2 provides the range of data values used in the development of Equation 10.4. This table also contains the data range for the selected variables for which the calculated Manning’s n value using Equation 3.4 fall within +/-10% of the observed Manning’s n.

Table 10.2 – Data range used in determination of Equation 10.4

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

Maximum bank gradient

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

Table 10.3 – Typical angle of repose for dumped rock

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

Typical properties of rock

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

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

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

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

Table 10.4 – Relative density (specific gravity) of rock

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

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

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

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

Effective thickness of a rock layer

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

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

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

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

Related documents

Background to Rock Roughness Equation

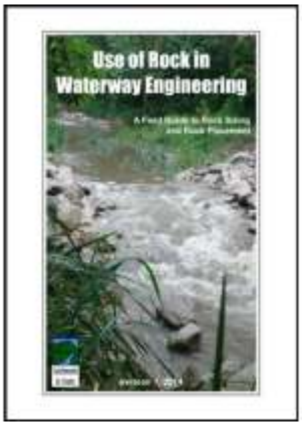
Background to Rock Roughness Equation

- A detailed discussion on the development of the Manning's roughness coefficient (n) for rock-lined surfaces (Equation 10.4) is presented in a separate publication available within the Fact Sheet section of the Catchments and Creeks website.
- https://www.catchmentsandcreeks.com.au/fact-sheets/esc_rock_sizing.html

Background to Rock Sizing Equations

Background to Rock Sizing Equations

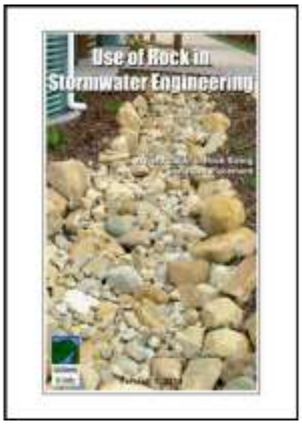
- A detailed discussion on the rock sizing equations developed for rock chutes (equations 12.10 to 12.13) is presented in a separate publication available within the Fact Sheet section of the Catchments and Creeks website.
- https://www.catchmentsandcreeks.com.au/fact-sheets/esc_rock_sizing.html



Use of Rock in Waterway Engineering

Use of Rock in Waterway Engineering

- A separate Field Guide was prepared in 2014 and revised in 2020 on the use of rock in waterway engineering.
- https://www.catchmentsandcreeks.com.au/waterways_field_guides.html



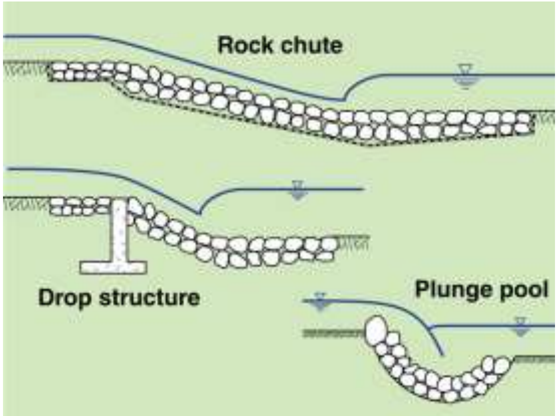
Use of Rock in Stormwater Engineering

Use of Rock in Stormwater Engineering

- A separate Field Guide was prepared in 2014 and revised in 2020 on the use of rock in stormwater engineering.
- https://www.catchmentsandcreeks.com.au/stormwater_field_guides.html

11. Hydraulics of Grade Control Structures

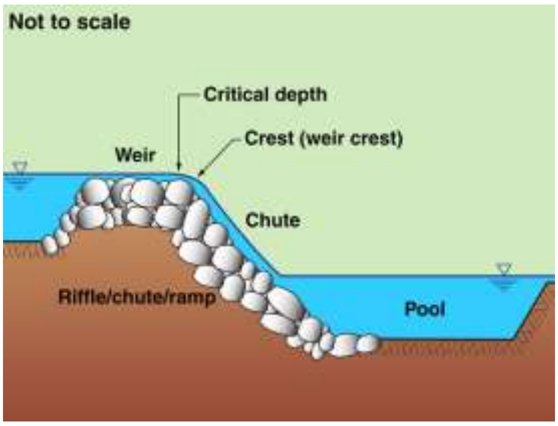
Introduction



Grade control structures

Grade control structures

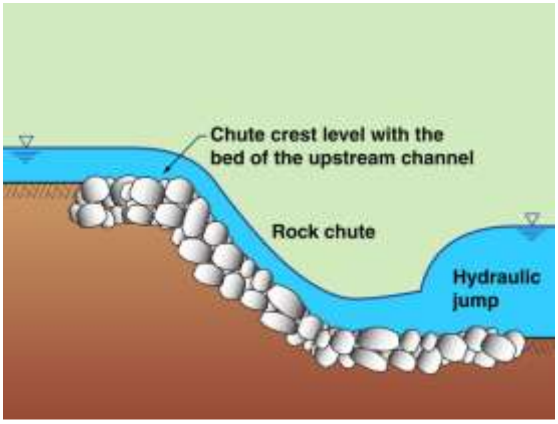
- Most forms of bed stabilisation can be classified under the general heading of 'grade control structures'.
- All of these structures incorporate a sudden change in bed level (a chute), which has a crest, often in the form of a raised weir, and a base that usually incorporates an energy dissipation pool.
- These common features mean that these structures share some common hydraulic principles.



Terminology

Terminology

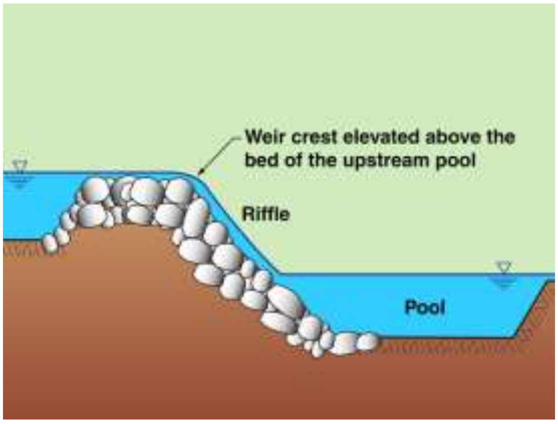
- Chute: the steeply inclined section (face) of the structure
- Critical depth: a flow condition between subcritical and supercritical flow
- Crest: the top of the chute
- Grade control structure: a generic term for any bed stabilisation structure, including riffles, chutes, ramps and weirs
- Pool: a water body with a recessed bed
- Weir: a raised crest
- Weir crest: the top of the weir



Bed-level crest

A bed-level (non-raised) crest

- Unlike most riffles, rock chutes can be designed with a bed-level crest that does not allow water to pool upstream of the crest during periods of low or zero flow.
- Hydraulically, this means:
  - the location of 'critical depth' may move upstream of the crest
  - upstream flow velocities are likely to be higher that for a raised crest
  - a person caught in the stream will more likely be swept over the crest.

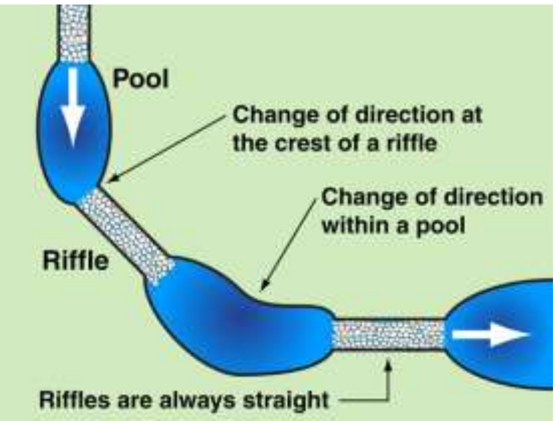


Raised weir-crest

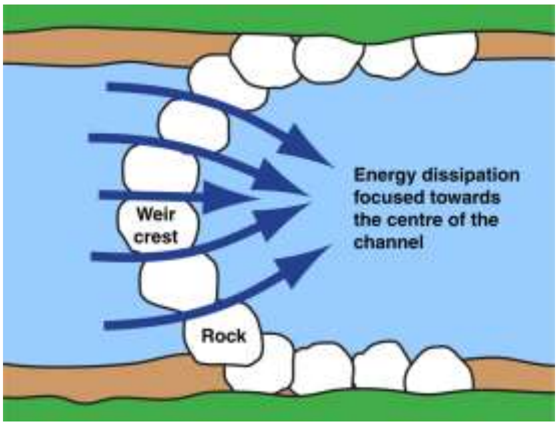
A raised weir-crest

- Natural and constructed riffles are likely to have a raised crest that allows a pool to exist upstream of the crest.
- Hydraulically, this means:
  - critical depth will be located at the crest (if the structure is not drowned out)
  - upstream flow velocities are likely to be lower than for a non-raised crest
  - these lower flow velocities can reduce the risk of erosion and vegetation damage upstream of the weir.

Geometry of the weir crest



Straight riffles and changes of direction



Concave rock weir

Trapezoidal dam spillway crest (Qld)

Canoe trail (Denver Colorado, USA)

Alignment of the weir crest

- As a general rule, the crest of the 'chute' (or riffle) should align at 90-degrees to:
  - the direction of the riffle, and
  - the initial direction of the downstream pool.
- If a change of direction is required along a series of pools and riffles, then such a change in direction shall occur only:
  - at the crest of a riffle
  - within the downstream section of a pool.

Use of a concave weir crest and chute

- The crest of a weir can be either straight or curved in the <u>horizontal</u> plane, and/or straight or curved in the <u>vertical</u> plane.
- A crest and chute that is curved in the horizontal plane will form a low-flow channel down the centre of the chute.
- Such a weir/chute geometry is desirable when it is important to focus the flow energy towards the centre of the down-stream pool, such as in narrow channels.

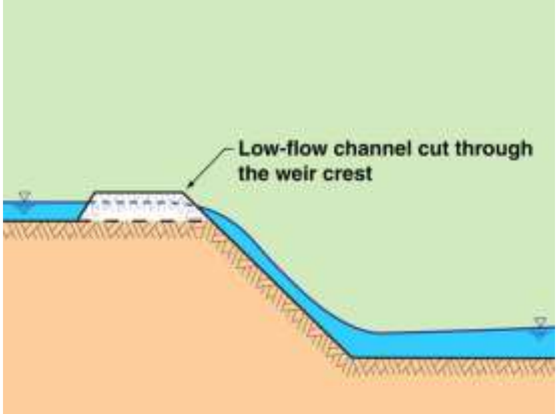
Use of a wide, flat, weir crest

- In wide channels (say > 5 m) it is usual for the weir crest to be both flat and straight in both the horizontal and vertical planes.
- At the outer edges of the weir crest the rock protection must extend up the channel banks, which ultimately results in the formation of a trapezoidal weir profile.
- On such structures, the 'chute' also has a slightly trapezoidal cross-section, usually <u>without</u> a low-flow channel.

Complex weir profiles

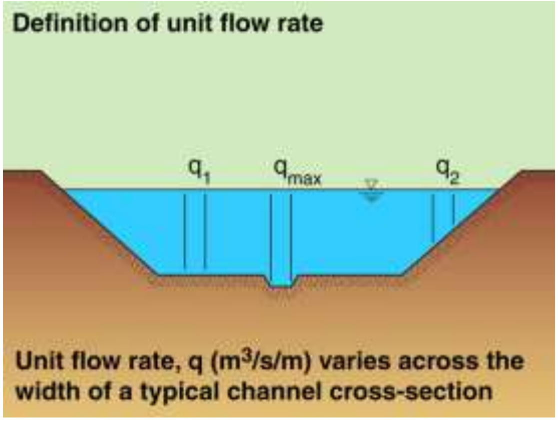
- In very wide channels (e.g. rivers) grade control structures may have a complex weir geometry that incorporates several water features, such as:
  - a partial-width rock ramp fishway
  - a canoe chute
  - a whitewater rafting rapid
  - a partial-width rock weir.
- Incorporating a partial-width weir can reduce the volume of required rock, and thus reduce construction costs.

Formation of a low-flow channel through a weir crest



Low-flow channel cut through weir crest

Low-flow channel cut through weir crest



Effects of a low-flow channel

Concrete-grouted low-flow channel (Qld)

Introduction

- Having a raised weir crest can provide several benefits to the design and operation of the upstream channel.
- However there can also be circumstances where it is desirable to allow the upstream channel to partially or fully drain during low flow conditions.
- Forming a low-flow channel through the raised weir will increase the complexity of the hydraulic analysis and (in my opinion) is generally not desirable.

Typical geometry

- A low-flow channel can be created by:
  - adopting a U-shaped weir crest
  - forming a narrow open slot through the weir crest (left and above images)
  - incorporating a fishway (rock ramp) in part of the grade control structure.
- If a low-flow fishway is incorporated into the weir, then it will usually be necessary for some type of permanent pool or channel to exist upstream of the fishway.

Hydraulic considerations of low-flow channels passing through a weir crest

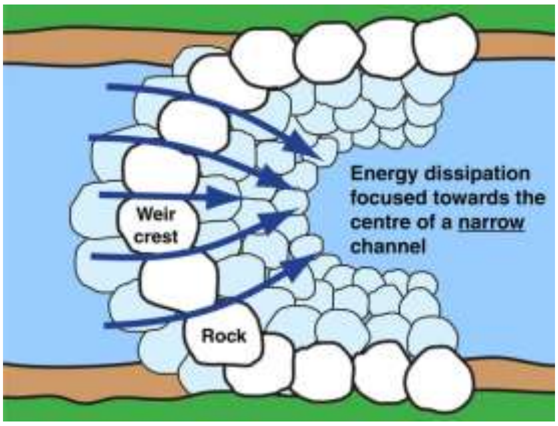
- If a low-flow channel is formed through the raised weir crest, then the hydraulic shear stresses passing through this low-flow channel:
  - will be greater than for the rest of the weir
  - will be proportional to the unit flow rate (q_{max}) passing through the low-flow channel, which is proportional to the local flow depth.

Practicalities of constructing low-flow channels in rock weirs

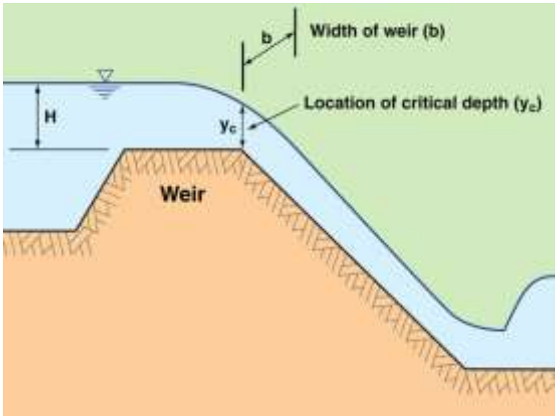
- In a design office it can be a simple task to 'draw' a low-flow channel through the centre of a weir crest; however, in reality:
  - it can be very difficult to form a low-flow channel through a weir that is constructed from large rock
  - it is unlikely that the low-flow channel will survive over time if the weir is formed from loose rock
  - the rock may need to be grouted in place to allow the channel to survive.

Weir equations

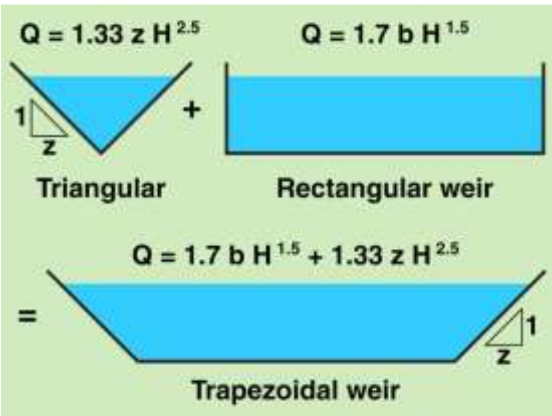
Concave weir crest (Qld)



Concave weir crest



Weir flow head (H) and width (b)



Components of a trapezoidal weir

Introduction

- Adopting a U-shaped or concave weir crest, or incorporating a low-flow channel into a raised weir crest will:
  - focus flow energy (and stress) towards the centre of the chute, and
  - increase the complexity of the hydraulic analysis.
- The use of computer models and hydraulic spreadsheet programs can make the hydraulic analysis much easier, but only if correctly programmed.

Curved weir crests

- Concave weir crests: (i.e. a weir crest curved in the horizontal plane), the weir equation remains largely unchanged from a simple rectangular weir, but rock size must be based on the maximum unit flow rate (q_{max}) in the centre of the weir
- U-shaped weir crests: (i.e. a weir crest curved in the vertical plane), the weir equation is complex and best analysed using numerical models, <u>and</u> rock sizing must be based on the maximum unit flow rate (q_{max}) in the centre of the weir.

Wide, flat, weir crests

- For wide channels, it can be acceptable to adopt a simple rectangular weir equation, such as:

$$Q = 1.7\ b\ H^{1.5} \qquad (11.1)$$

where:

- Q = total flow rate [m^3/s]
- b = width of the weir crest [m]
- H = upstream hydraulic head (water level) relative to the weir crest [m]

Trapezoidal weir crests

- For trapezoidal weirs either use a numerical model, or analyse using a combined rectangular weir equation (above) plus a triangular weir equation.
- Weir equation for a triangular weir:

$$Q = 1.33\ z\ H^{2.5} \qquad (11.2)$$

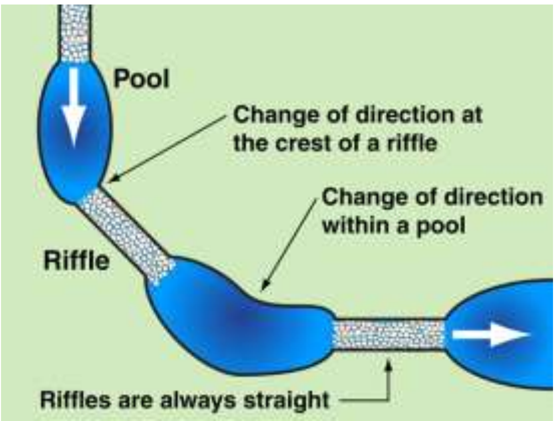
where: z = the side slope (1 in z) of the trapezoidal weir.

- Thus the combined weir equation is:

$$Q = 1.7\ b\ H^{1.5} + 1.33\ z\ H^{2.5} \qquad (11.3)$$

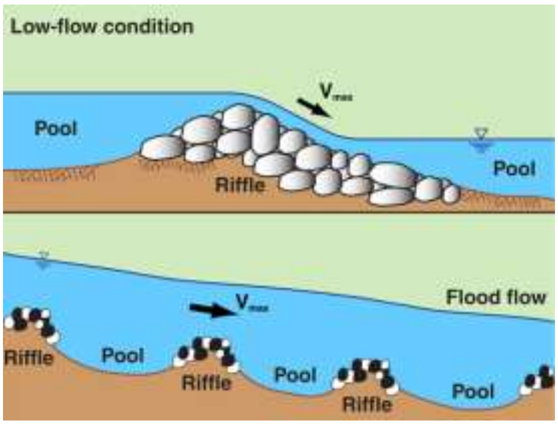
Hydraulics of the chute

Flow over a constructed riffle (Qld)



Straight riffles and changes of direction

Constructed riffle (Qld)



Flow conditions over riffles

Introduction

- The crest, chute and pool all play a different role in the functioning of a riffle, rock chute, or rock ramp.
- Highest flow velocities usually occur while the flow is passing down the face of the chute.
- However, the highest flow energy and turbulence usually exists within the downstream pool.

The term 'chute' can be used to describe the whole structure, or just the face of the drop.

The importance of a straight chute or riffle

- It is essential that the steeply inclined section of a riffle, chute, or rock ramp is 'straight', this is because the flow down the inclined chute is usually 'supercritical'.
- If the creek meanders through the valley, this does not mean that the alignment of the chute should also be curved.
- Any change of direction of the main channel, or low-flow channel, must occur within the 'pools', not down the face of the riffles.

Determination of surface roughness

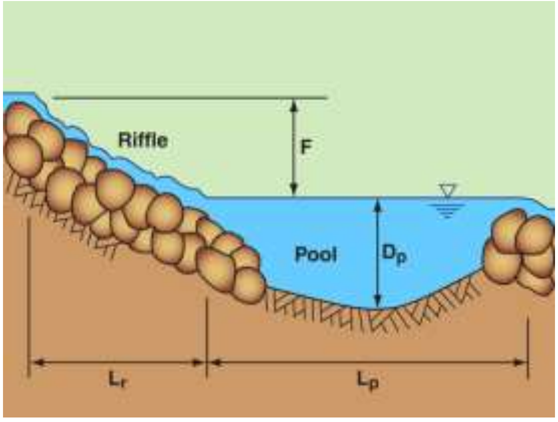
- The determination of the maximum flow velocity down the face of the chute is dependent upon:
  - the slope of the chute
  - the roughness of the chute
  - the impact of any backwater effects.
- Numerous equations have been developed to determine the roughness of rock; however, it is important to use an equation specifically developed for shallow water conditions (e.g. Equation 10.4).

Determination of maximum flow velocity

- The rock size usually needs to be checked for both low-flow (shallow flow) and high-flow (deep water) conditions.
- During low-flow conditions the flow velocity is usually governed by the slope of the chute.
- During high-flow conditions the flow velocity is likely to be governed by the overall channel slope, not the riffle slope (thus the pools and riffles become part of the overall bed roughness).

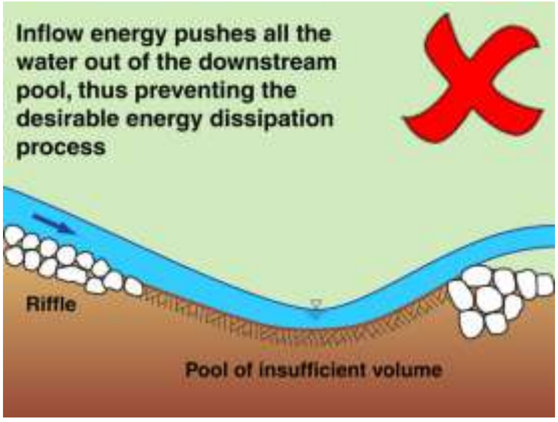
Hydraulics of the energy dissipation pool

Constructed pool-riffle sequence (Qld)



Profile of a pool-riffle system

Pool downstream of a rock chute (NSW)



Outcome of insufficient pool volume

Introduction

- A 'pool' is required at the base of a chute for three main reasons:
  - to allow fish to recover their energy levels before ascending the rock ramp
  - to dissipate flow energy at the base of the chute
  - to ensure that any bed scour that occurs at the base of the chute does not undermine the chute rock.
- Of course, all pools can provide habitat values for aquatic life.

Depth of the pool

- In general, the depth of the downstream pool (D_p) should be at least equal to the fall (F) of the upstream riffle or chute.

$$D_{p\ (min)} = F \quad \text{(typical)} \qquad (11.3)$$

- Similarly, the depth of the pool below a waterfall increases with the height of the waterfall, but only up to the point where the falling water reaches terminal velocity.

Length of the pool

- For gravel-based creeks, the length of the pool is governed by riffle spacing.
- For clay-based creeks the minimum pool length = 2 x pool width (or 9 x pool depth).
- Also, in order to achieve effective energy dissipation, the length of the pool should be at least six times the pool depth.
- The suggested minimum pool length is:

$$L_{p\ (min)} = 9\ D_p \qquad (11.4)$$

- But the actual pool length will frequently be greater than this minimum value.

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 push the water out of the downstream pool causing the pool to act more like a 'ski jump'.
- Wherever possible, use the geometry of existing pools to determine the minimum dimensions of constructed pools.

12. Fish-Friendly Bed Stabilisation Methods

Application of bed stabilisation measures

Constructed riffle (Qld)

Introduction

- Creek bed stabilisation may be required for the following reasons:
  - to arrest the migration of head-cut erosion
  - to control excessive bed scour
  - to raise a creek bed
  - to establish a habitat pool or wetland
  - to form a drop-inlet into a culvert
  - to stabilise the outlet of a culvert
  - as a grade control structure.

Head-cut erosion (Qld)

Head-cut erosion

- A 'head-cut' is a type of bed scour where bed erosion causes the formation of a near-vertical 'waterfall' that progressively migrates up the channel.
- A head-cut can occur naturally, but it is more commonly associated with unnatural erosion conditions with the waterway.
- A head-cut is one of the most destructive forms of creek erosion, and in most cases will eventually cause a significant increase in bank failures.

Creek bed scour (Qld)

Bed scour

- Bed scour occurs when flow velocities exceed the critical (threshold) scour velocity of the bed material.
- Minor structures, such as rock weirs and constructed riffles, can be used to stabilise the channel bed.
- Major structures, such as rock chutes (also known as rock ramps), can be used as 'grade control structures' for the purpose of slowing the flow velocity within sections of the creek.

A 'barrier' to fish passage (Qld)

Elevating the bed of a creek

- Small waterfalls can form in creeks from time to time, and these structures can become barriers to normal fish passage.
- Such waterfalls can form when:
  - a lowering creek bed exposes a section of bedrock
  - head-cut erosion approaches a culvert.
- Progressively raising the downstream creek bed can eventually smother these waterfalls and return suitable fish passage conditions to the creek.

Application of bed stabilisation measures

Constructed wetland (Qld)

Establishing a habitat pool, lake or wetland

- When a pool, lake or wetland is introduced to an existing creek, it causes a discontinuity to exist within the original gradient of the creek.
- Creeks generally have a reasonably constant slope (within a given reach), but the water surface of a pool, lake or wetland is 'flat'.
- This means a weir or grade control structure needs to exist at either the inlet and/or outlet of the body of water.

Stabilised drop-inlet at a road culvert

Stabilising a drop-inlet upstream of a waterway culvert

- Fish-friendly culverts are usually required to have a flat, or very low gradient, bed slope.
- When such culverts are located across a creek that has a medium to steep gradient, it can result in the need to establish a fish-friendly drop-inlet upstream of the culvert.

Stabilised outlet pool at a road culvert

Stabilising the outlet of a culvert

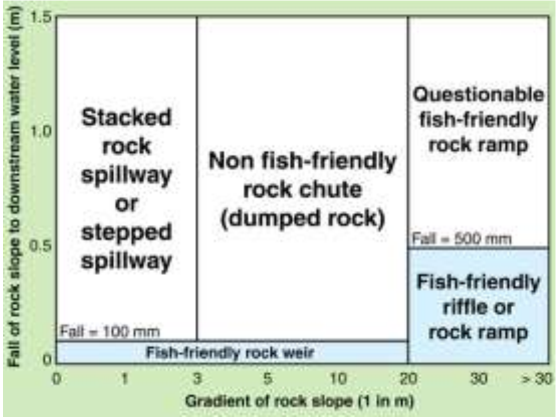
- A fish barrier can often be created when bed scour or head-cut erosion migrates up a creek and arrives at a culvert.
- To correct such problems, or to avoid such problems occurring in the future, rock chutes or recessed rock check dams can be constructed downstream of the culvert.

Constructed stormwater channel (Qld)

Grade control structures

- The term 'grade control structure' is a generic term that is often used to describe a wide range of fish-friendly and non fish-friendly bed stabilisation structures.
- The term is probably best used to describe any steep sections of channel, formed at regular intervals along a constructed drainage channel, that allows the intermediate sections of the channel to have a flatter hydraulic gradient, thus allowing these sections of channel to be stabilised only with vegetation.

Types of fish-friendly bed stabilisation



General classification of structures

Constructed riffle (Qld)

Ridge rock ramp (Qld)

Rock weir (Qld)

Introduction

- The fish-friendly bed treatments that will be discussed in this chapter include:
  - riffle systems
  - rock chutes and rock ramps
  - ridge rock ramps
  - recessed rock check dams
  - rock weirs and log weirs
  - pile fields.
- It is also noted that bypass fishways can be placed adjacent to non fish-friendly steep grade control structures.

Riffles, rock chutes and rock ramps

- Riffles, chutes and ramps can in many cases appear to be the same types of rock formation, and in most cases they are.
- Riffles are more commonly associated with gravel-based waterways, and often exist as a series of structures.
- The term 'rock chute' is more commonly used by water engineers, and these structures may or may not be fish friendly.
- The term 'rock ramp' is more commonly used by fisheries officers and biologists.

Ridge rock ramps

- A ridge rock ramp is a baffle-type fishway that is formed from well-anchored rock that has been placed in a specific pattern.
- Construction techniques vary with the type of waterway.
- In most cases the rock will be held in place with concrete or carefully positioned smaller rocks.
- Pre-cast concrete fishway baffles can be used as an alternative to ridge rock ramps.

Weirs

- Fish-friendly weirs can appear in many different forms, and can be made from a variety of materials.
- The most common construction materials are rock and logs.
- Log weirs, which are rare in Australia, are only used in locations where appropriate timber can be found.
- In order to be fish friendly, these weirs must be relatively small structures, otherwise they must be replaced with a rock riffle.

Bed stabilisation options for different creek types

Clay-based creek (Qld)

Clay-based creeks

- The types of bed stabilisation structures commonly used in clay-based creeks are:
  - constructed pool-riffle systems
  - rock chutes and rock ramps
  - ridge rock ramps
  - recessed rock check dams
  - rock weirs and log weirs.
- Clay-based creeks have the advantage of a relatively stable bed condition (relative to sand and gravel-based creeks).

Sand-based creek (Qld)

Sand-based creeks

- The types of bed stabilisation structures commonly used in sand-based creeks are:
  - rock chutes and rock ramps
  - recessed rock check dams
  - pile fields.
- Constructing a rock riffle on the bed of a sand-based creek can be problematic.
- If the depth of the sand exceeds the depth of the rock structure, then the rocks could simply sink into the sand during a flood.

Gravel-based creek (Qld)

Gravel-based creeks

- The types of bed stabilisation structures commonly used in gravel-based creeks includes:
  - natural pool-riffle systems
  - constructed pool-riffle systems
  - rock chutes and rock ramps
  - ridge rock ramps.
- Any structure built across the base of a gravel-based creek must accommodate the natural migration of bed gravel during flood events.

Rock-based creek (Qld)

Rock-based creeks

- In general, bed stabilisation structures are rare in rock-based creeks because the extent of any bed erosion is generally controlled by the exposed sections of rock.
- If bed stabilisation structures are used, then they are more likely to be associated with the sections of clay, sand or gravel-based channels found between the outcrops of bedrock.
- Constructed rock ramps can be used to allow fish to migrate past recently exposed bedrock.

12.1 Natural Riffles

Nive River, NSW

Description

- A riffle is an isolated section of channel bed where the steepness of the bed allows for a local acceleration of flows and the possible exposure of the bed rocks during periods of low flow.
- A natural riffle is formed from the natural bed material available within the creek.
- Riffles are commonly found in gravel-based waterways, but similar steep channel reaches can also be found in rock, sand and clay-based waterways.

Peel River, Tamworth, NSW

Natural riffles

Natural riffle (Qld)

Introduction

- Natural rocky riffles are found in gravel-based creeks and rivers.
- The rocks that make up the riffle have migrated down the waterway, and will continue to migrate down the waterway.
- This means natural riffles, by their very nature, are unstable structures.
- During a flood, it is likely that some rocks will be dislodged from the riffle, only to be replaced by new rocks migrating down the waterway.

Natural riffle (Qld)

Use of natural riffles

- A 'natural' riffle is likely to need to be <u>constructed</u> in the following circumstances:
  - rehabilitation of the natural riffles found in a gravel-based waterway following the construction of a culvert crossing
  - formation of a riffle downstream of a constructed instream lake or wetland
  - rehabilitation of the natural riffles found in a gravel-based waterway following the relocation of the channel.

Pool-riffle sequence (NSW)

Key features of natural riffles

- When reconstructing a series of natural riffles, the key design features are:
  - use of the natural bed gravels (rock) that is currently migrating down the waterway
  - simulation of the existing pool-riffle spacing
  - consideration of the consequences of the future lateral movement of the waterway channel.

Natural rounded river rock (NSW)

Type of rock used in natural riffles

- In most circumstances, the preferred rock is the natural rounded rock that currently migrates down the waterway.
- However, if an upstream structure has effectively stopped the natural migration of bed rock (gravels), such as a weir or dam, then consideration must be given to the long-term sustainability of the riffle.
- In such cases, larger diameter rock may be required such as recommended for 'constructed riffles' (over page).

12.2 Constructed Riffles

Constructed riffle (NSW)

Constructed riffles vs natural riffles

- Unlike natural riffles, most constructed riffles, rock chutes, fishway 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.

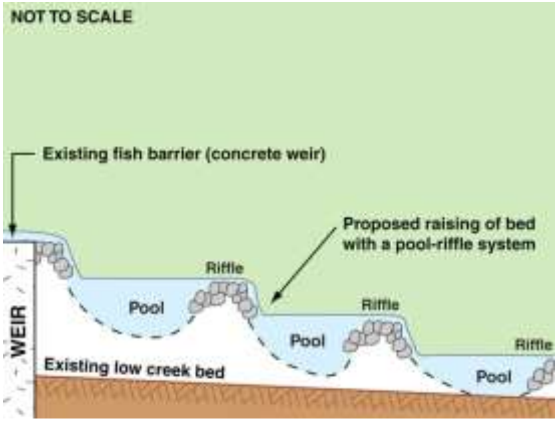
Constructed riffle (Qld)

Constructed riffles – Use of constructed riffles

Constructed pool-riffle sequence (Qld)

Introduction

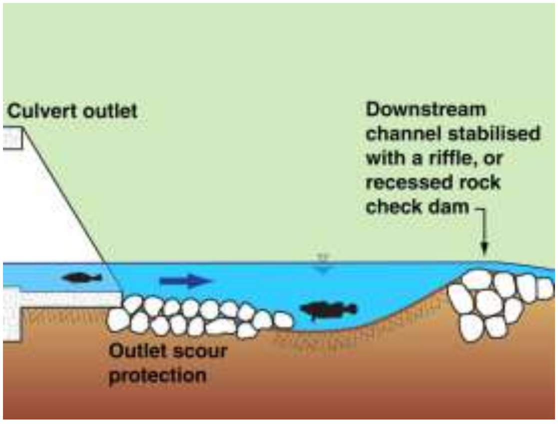
- Riffles, can exist in a wide variety of waterways.
- However, the waterway feature commonly known as 'pools and riffles' is most commonly found in gravel-based waterways.
- Waterway managers should not build a pool-riffle system in a clay or sand-based creek just because they think such a feature would look good within their waterway.



Bed raised using a pool-riffle system

Elevating a channel bed to drown out a fish barrier

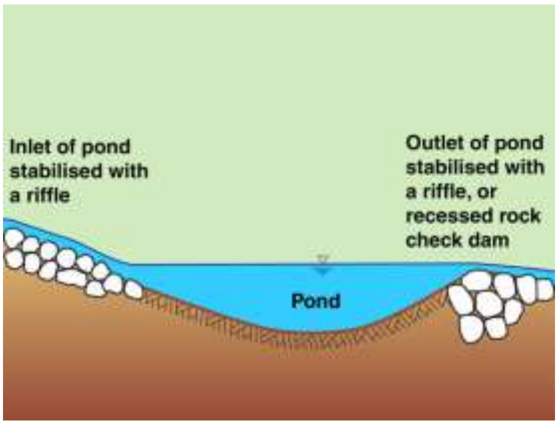
- A series of constructed pools and riffles can be used to elevate an existing creek bed in order to drown-out a recently formed barrier to fish passage, such as:
  - a small weir
  - a road causeway
  - a concrete-encased sewer pipe crossing.



Bed stabilised downstream of a culvert

Reconstructing a fish-friendly channel upstream or downstream of a culvert

- When a long culvert is installed on a steep creek, the flat gradient of the culvert bed usually means a steeper channel gradient is required at the upstream and/or downstream ends of the culvert.
- A series of pools and riffles can be used to make this steep channel gradient suitable for fish passage.



Stabilised inlet and outlet of a pond

Stabilising the channel bed upstream or downstream of an instream lake or wetland

- Creeks generally have a reasonably constant channel slope (within a given reach), but the water surface of a pool, lake or wetland is 'flat'.
- If a habitat pond, lake or wetland is constructed within a creek, there is usually a need to form a grade control structure at either the inlet or outlet of the water body.
- A constructed riffle can be used to form this grade control structure.

Constructed riffles – Use of riffles in different types of waterways

Constructed riffle in a clay-based creek

Clay-based waterways

- In an ideal world, pool-riffle systems would not be constructed within waterways where such features do not naturally exist.
- However, our waterways do not exist in an ideal world, and there are circumstances where a constructed pool-riffle sequence could benefit a clay-based waterway.
- In clay-based waterways there is no natural migration of bed rock; therefore, the rock used in a constructed riffle must be sized to be stable (i.e. not move).

Sand becomes 'unstable' after a flood

Sand-based waterways

- Constructing a rock riffle on the bed of a sand-based creek can be problematic.
- If the depth of the sand exceeds the foundation depth of the rock structure, then the rocks could simply 'sink' into the sand during a major flood.
- If the depth of the bed sand does <u>not</u> exceed the depth of the rock structure, then the structure could interfere with the natural migration of sand, or could simply become buried by the sand.

Unstable riffle in a gravel-based creek

Gravel-based waterways

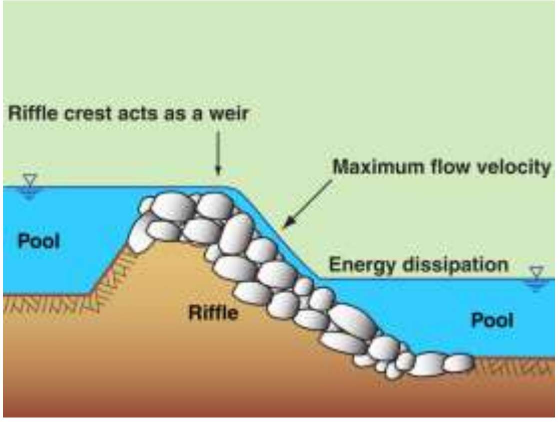
- If a new riffle needs to be constructed within a gravel-based waterway, then natural bed rock should be used in circumstances where the natural migration of bed rock and gravel can be maintained.
- However, if a riffle needs to be constructed downstream of a water feature that is likely to prevent the natural migration of bed rock (e.g. downstream of a constructed lake), then larger rock may be required (such as that recommended for constructed riffles).

Exposed bedrock (Qld)

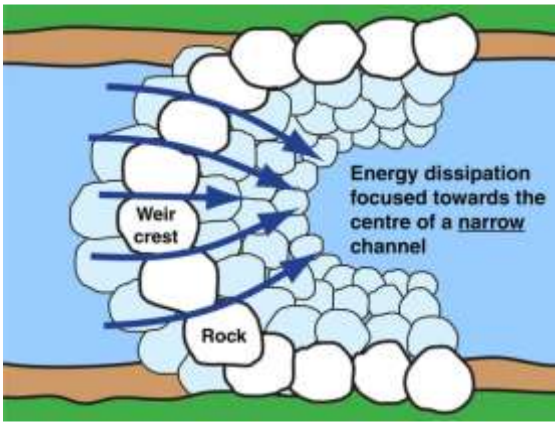
Rock-based waterways

- It would be rare for constructed riffles to be required near sections of exposed bedrock.
- If constructed riffles are needed, then they are more likely to be associated with the sections of clay, sand or gravel-based channels found between the sections of exposed bedrock.
- If bed erosion results in the formation of an unnatural waterfall, then a riffle may be used to raise the downstream bed in order to maintain natural fish passage.

Constructed riffles – Hydraulics of the riffle

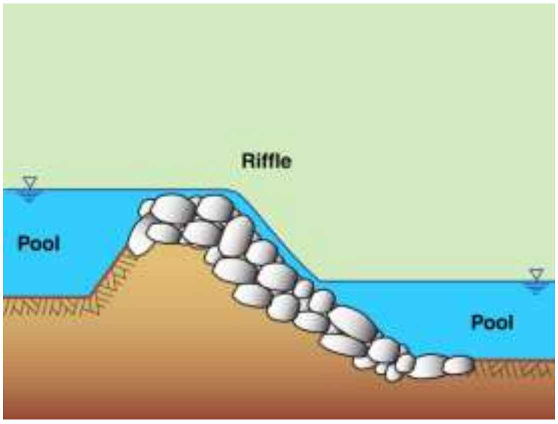


Riffle hydraulics



A curved riffle crest in a narrow channel

Constructed riffle (Qld)



Rock riffle profile

Riffle gradient

- There are three aspects to the hydraulics of a riffle:
  - crest hydraulics
  - chute hydraulics
  - downstream energy dissipation.
- A survey of natural riffles found in South-East Queensland creeks found that riffles had a typical gradient of 1 in 30.
- In order to be considered fish friendly, it is recommended that constructed riffles have a maximum gradient of 1 in 20.

Weir crest in narrow channels

- A 'pool' must exist downstream of a riffle in order to facilitate energy dissipation.
- In narrow channels, the width of this pool can be a critical factor in some designs.
- The existence of a curved (concave) riffle crest helps to focus the flow energy towards the centre of the pool, thus reducing the risk of bank erosion.
- Hydraulically, the significance of the weir crest profile reduces as the length of the riffle increases.

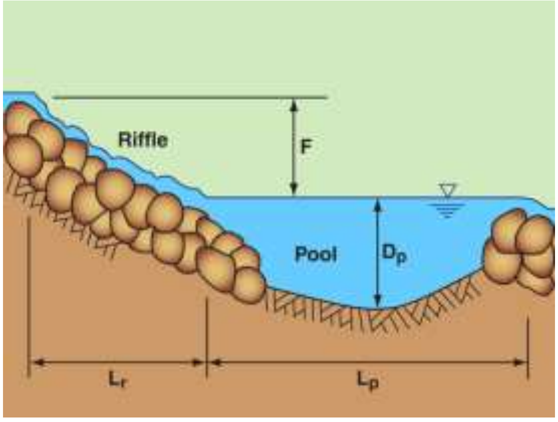
Weir crest in wide channels

- In wide channels it is normal for the crest of the riffle to be relatively straight and flat, and aligned at 90-degrees to the riffle chute.
- If the pool-riffle sequence meanders across the bed of a wide channel, then 'changes of direction' can either occur:
  - within a long pool, or
  - at the crest of a riffle, but
  - the riffle chute must remain straight.

Elevated weir crests

- Unlike some rock chutes, the crest of a riffle is normally elevated above the upstream channel in order to facilitate the existence of an upstream pool.
- Elevating the weir crest also helps to reduce flow velocities immediately upstream of the riffle, which helps to provide a rest area for migrating fish.

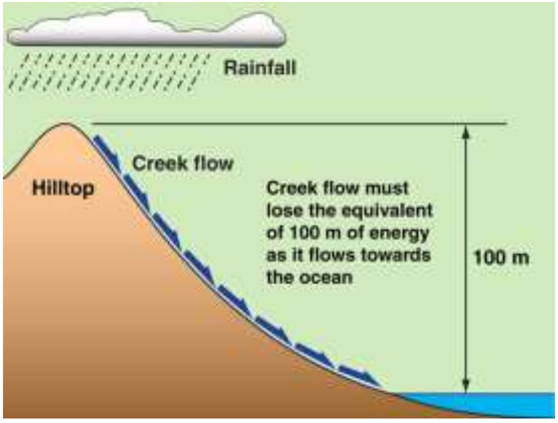
Constructed riffles – Hydraulics of the downstream pool



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 loss

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 equivalence 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 equivalence of 500 mm of energy must be consumed while the water passes down the riffle and into the downstream pool.

A pool-riffle type water slide (NSW)

Types of energy dissipation

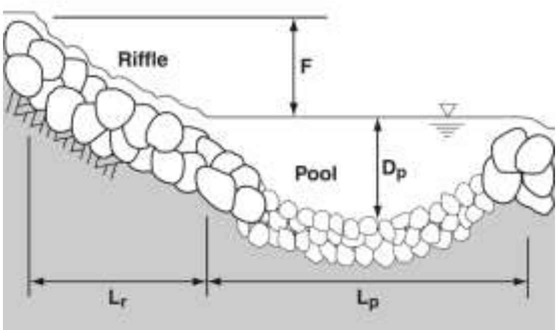
- In pool-riffle systems, energy loss can occur in two ways:
  - friction (down the chute)
  - turbulence (within the pool)
- As the flow enters the downstream pool, the jetting effects of the inflow cause turbulence within the pool, which contributes to energy loss.
- These same hydraulic principles exist within a wide range of hydraulic structures, including 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 then, the fall (F) of the upstream riffle.

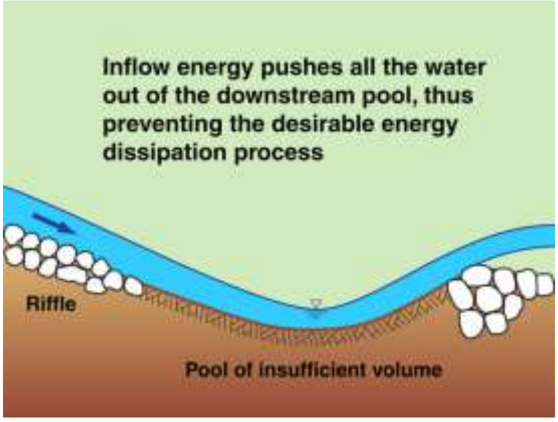
$$D_{p\,(min)} = F \quad \text{(typical)} \qquad (12.1)$$

- 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.

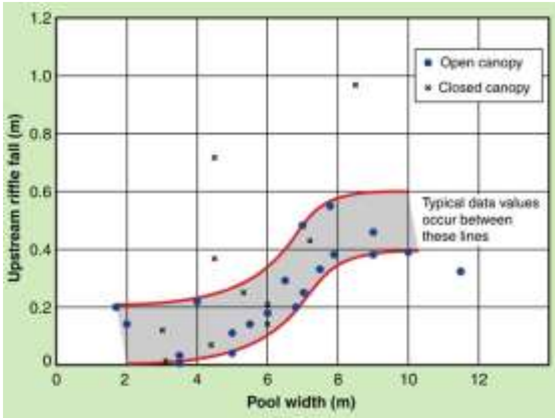


Profile of a pool-riffle system

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 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 and width.
- For relatively narrow channels (i.e. creeks) the pool width (W_p) should be taken as the greater of:

$$W_{p\,(min)} = 1.3 + 4.5\,D_p \qquad (12.2)$$

$$W_{p\,(min)} = W_r + 4.5\,D_p \qquad (12.3)$$

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.

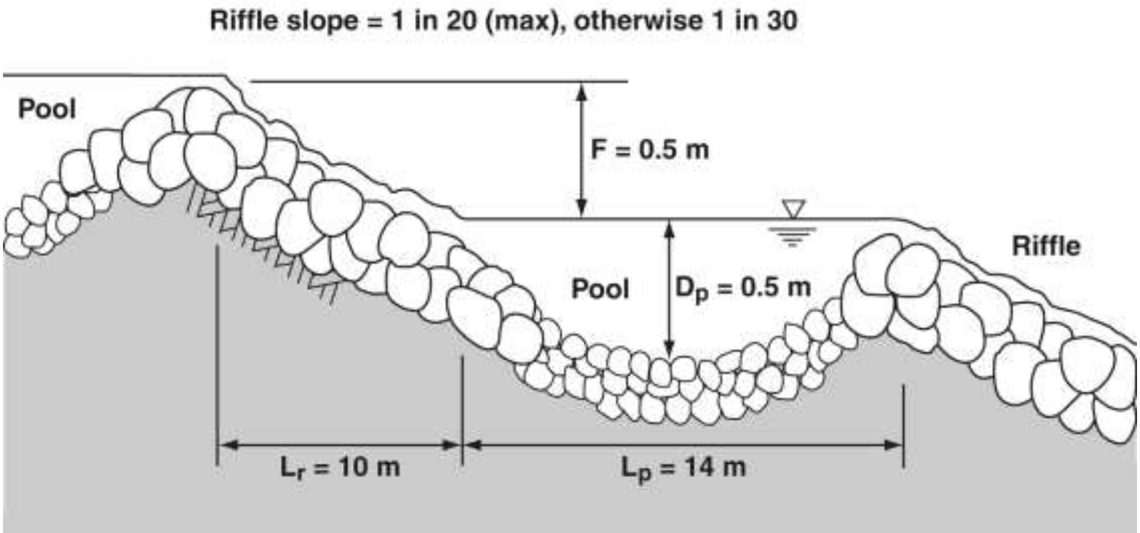
$$L_{p\,(min)} = 2 \text{ to } 4 \text{ times } W_p \qquad (12.4)$$

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

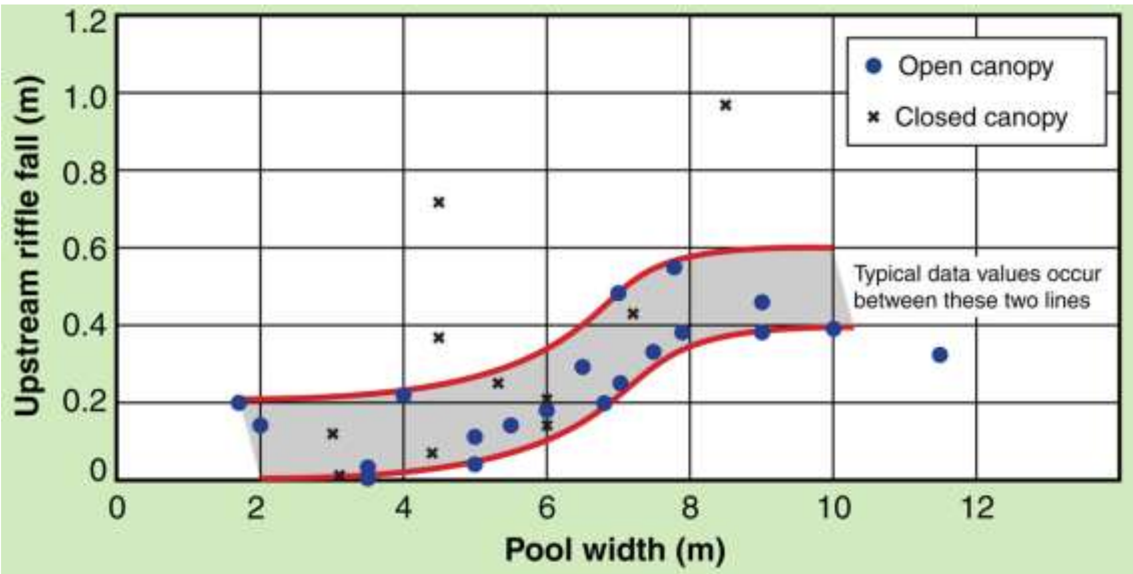
Use of rock to stabilise narrow pools

- 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 (determined from equations 12.2 or 12.3).

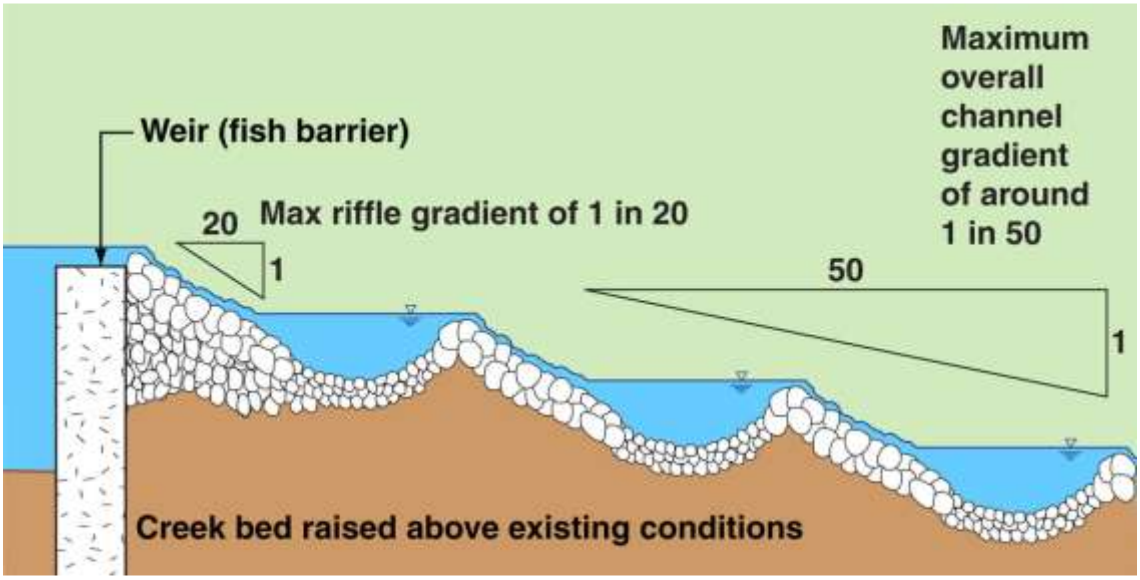
Constructed riffles – Pool dimensions in narrow channels



Dimensions of maximum possible pool-riffle gradient

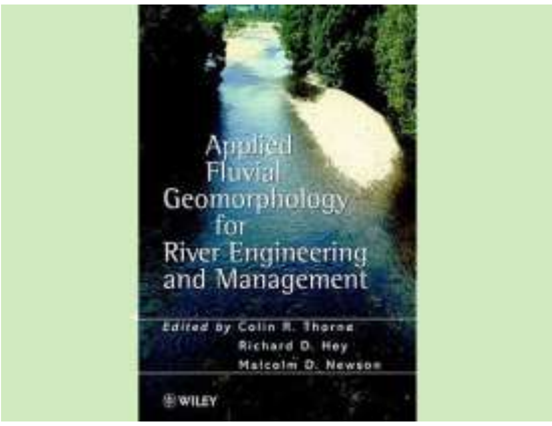


Relationship between the riffle fall (F) and the pool width (W_p) from creeks in SE Qld



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

Constructed riffles – Pool and riffle dimensions in wide channels



Thorne, Hey & Newson, 1997

Introduction

- The previous discussion referred to the sizing of pool-riffle systems in narrow creeks based on a survey of creeks in South-East Queensland.
- It is not the intent of this field guide to provide sufficient information to allow the reader to design pool-riffles systems for larger waterways (i.e. rivers).
- Designing works in rivers requires the guidance of experts (river morphologists) and survey data from local river systems.

Riffle on the Gwydir River, NSW

Width of riffles in wide channels

- In rivers, riffles are:
  - located at inflection points, midway between bends (but not always)
  - usually exposed across the full width of the channel bed, even though dry weather flows may only spill over a portion of the riffle.

$$W_r = 1.03\ b \qquad (12.5)$$

where:

- W_r = crest width of riffle (m)
- b = average width of channel bed (m)

Gwydir River, Moree, NSW

Depth and width of pools in wide channels

- In rivers, pools:
  - have a dry weather water surface width approximately equal to the channel width, and
  - typically extend from riffle to riffle, with the deepest part of the pool located at channel bends.
- The depth of pools at channel bends depends on the bed width (b) and the bend radius (refer to text books for typical relationships).

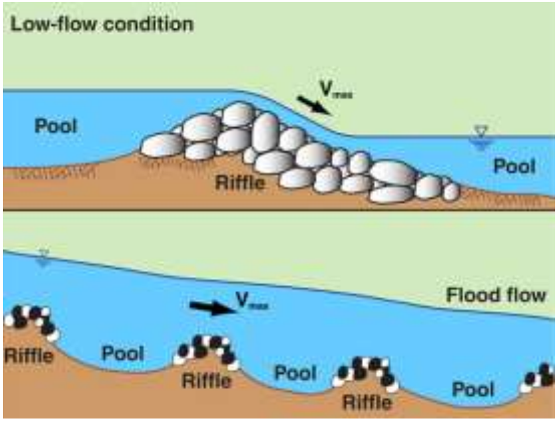
Pool-riffle system, Queanbeyan River, NSW

Length and volume of pools in wide channels

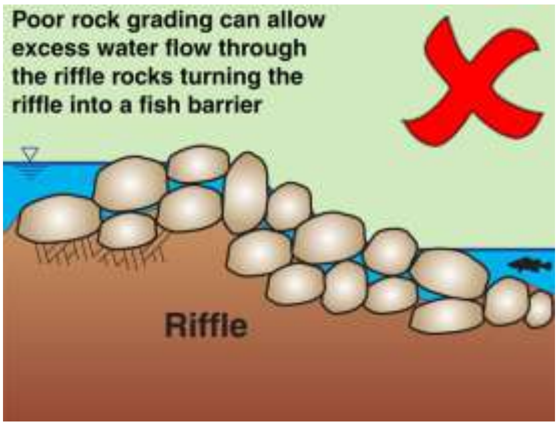
- The length of the pool is likely to relate solely to the spacing of the riffles.
- A pool of some type must exist at the base of the riffle in order to dissipate energy.
- The depth of the pool immediately downstream of the riffle will likely relate to the riffle fall.
- The suggested minimum length of a pool is twice the pool width, but it would be better to survey existing pools in the river.

Constructed riffles – Rock sizing for riffles

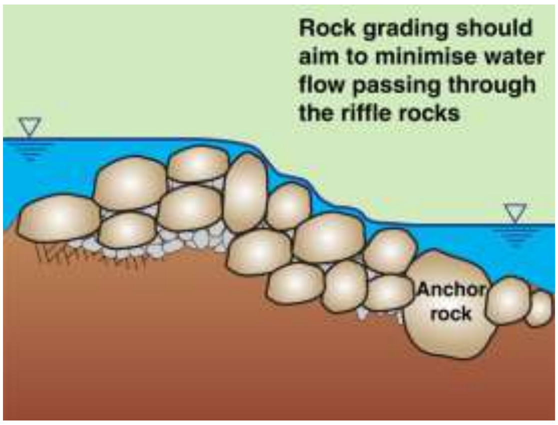
Rock sitting high with exposed edges



Design flow conditions



Consequence of poor rock grading



Optional use of anchor rocks

Critical design issues

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

Design flow conditions

- Rock size usually needs to be checked for both low-flow (shallow flow) and high-flow (deep water) conditions.
- During low-flow conditions the water velocity is usually governed by the riffle slope.
- During high-flow conditions the water velocity is likely to be governed by the overall channel slope (i.e. the pools and riffles simply become part of the overall bed roughness).

Distribution of rock sizes

- There are many circumstances where a near-uniform rock size is desirable, but in constructed riffles this can result in fish passage problems.
- The rocks used in constructed riffles are usually larger than those found in natural riffles because it is usually necessary for these rocks to be stable (i.e. not migrate downstream during flood events).
- The use of large rock can result in excess water passing through the rock during dry weather (low flow) conditions, which can block fish passage.
- To avoid such problems, there needs to be a certain percentage of smaller rocks in order to minimise the void spacing.
- The recommended distribution of rock sizes for constructed riffles is provided in Table 12.2 over the page.
- An option also exists for the placement of large anchor rock at the base of the riffle (i.e. below the normal pool water level) in order to increase the stability of the riffle rock during flood events.

Constructed riffles – Sizing rock for low-flow conditions

Low-flow condition (Qld)

Flow approaching drowned conditions

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

$$d_{50} = \frac{SF.K_1.K_2.V^2}{(A - B.\ln(S_o)).(s_r - 1)} \qquad (12.6)$$

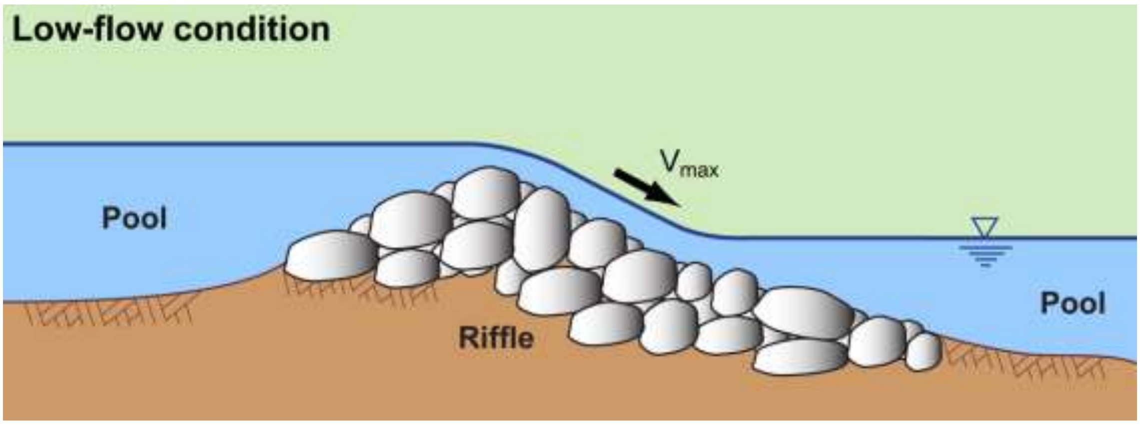
For SF = 1.2: A = 3.95, B = 4.97 (default)

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

Tabulated rock sizes can be obtained from tables 12.4 to 12.7.

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

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

Constructed riffles – Sizing rock for high-flow conditions

The high-flow hydraulic check requires the nomination of the maximum flood event during which the riffle rock is required to be stable, e.g. the 1 in 10 year (10% AEP) or 1 in 50 year (2% AEP) discharge. This flow condition is then modelled to determine the maximum depth-average flow velocity passing over the riffle.

It is important that the calculated depth-average velocity is representative of the **actual** flow velocities above the riffle, **not** the flow velocity averaged across the full cross-section.

Minimum mean rock size for these high flow conditions may be determined from Equation 12.7.

$$d_{50} = \frac{K_1 . V^2}{2 . g . K^2 (s_r - 1)} \qquad (12.7)$$

where:

- K = equation constant based on flow conditions
  - = 1.1 for low-turbulence, deep water flow, or 0.86 for highly turbulent flow; otherwise, refer to Table 12.1 for suggested vales of 'K' based on the flood gradient
- V = nominated design flow velocity over the rocks [m/s]
- g = acceleration due to gravity [m/s^2]

Table 12.1 – Suggested values of 'K' for various flood gradients

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

Specification of rock for constructed riffles

In circumstances where the constructed riffle is required to simulate 'natural' bed conditions, and the riffle is located in a waterway that contains natural pool–riffle systems, then the rocks used in construction of the riffle should match the size distribution of the natural riffle systems. However, for constructed riffles that are required to be stable during major flood flows, then the following rock specifications should be considered.

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more 'natural' appearance and is considered more fish friendly. A 36% increase in rock size is recommended for rounded rock (i.e. $K_1 = 1.36$).

Broken concrete and building rubble should not be used.

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

The maximum rock size generally should not exceed twice the mean (d_{50}) rock size.

Table 12.2 provides recommended distribution of rock sizes for constructed riffles.

Table 12.2 – Recommended distribution of rock size for constructed riffles

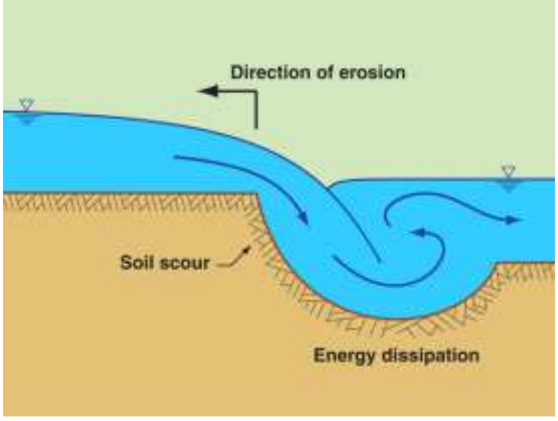
Rock size ratio	**Assumed distribution value**
d_{100}/d_{50}	2.0
d_{90}/d_{50}	1.8
d_{75}/d_{50}	1.5
d_{65}/d_{50}	1.3
d_{40}/d_{50}	0.65
d_{33}/d_{50}	0.50
d_{25}/d_{50}	0.45
d_{10}/d_{50}	0.20

Constructed riffles – Stabilisation of a head-cut using a plunge-pool

Head-cut erosion (Qld)

Head-cut erosion

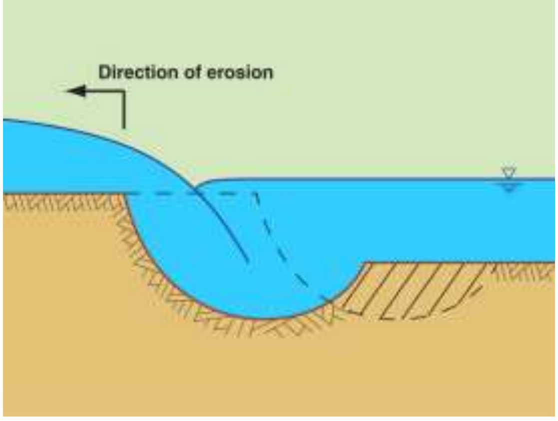
- A 'head-cut' is a sudden drop in the bed level, which migrates up the channel, usually during flood events, but the erosion can also grow slowly during regular dry weather flows.
- Immediately downstream of the head-cut there is usually a scour hole that also migrates up the channel.
- The existence of the scour hole is critically important for the dissipation of flow energy.



Head-cut erosion

Hydraulics of head-cut erosion

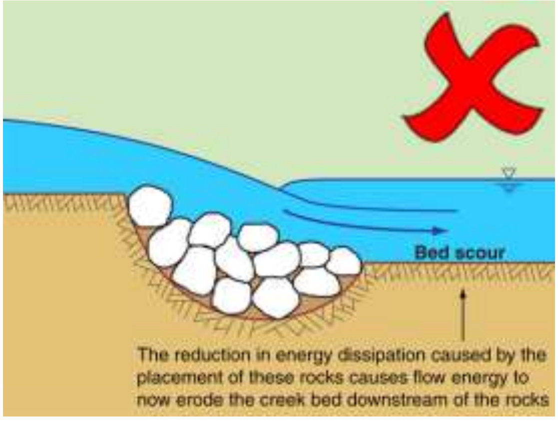
- The creek flow gains velocity and kinetic energy as it falls to a lower elevation.
- The increase in energy is then dissipated as it enters the downstream pool.
- The flow continues to erode the plunge pool until the pool achieves the 'volume' necessary to dissipate the excess kinetic energy.
- In effect, the erosion process forms a type of mobile pool-riffle system.



Migration of head-cut erosion

Migration of head-cut erosion

- Turbulence within the plunge pool causes ongoing soil scour to occur on the face of the head-cut.
- Over time the erosion migrates up the channel, and a new plunge pool is formed.
- The old plunge pool usually becomes backfilled with the sediment scoured from the new pool.
- The size of the plunge pool is related to the flow rate and the fall of the bed.

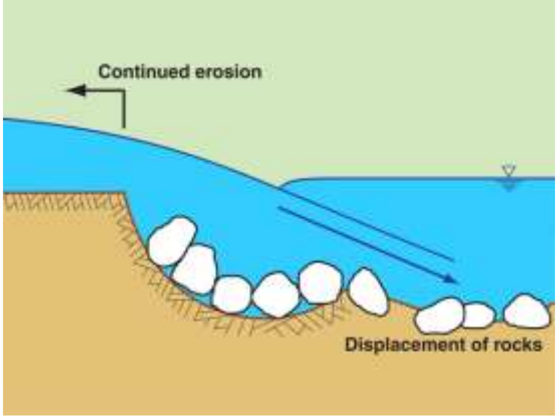


Problems caused by filling pool with rock

Inappropriate stabilisation with rock

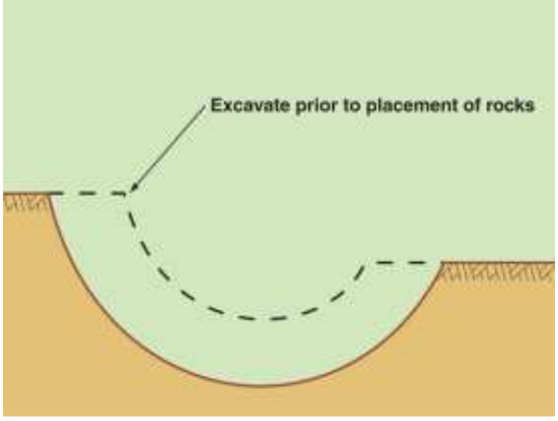
- Waterway managers can be tempted to simply fill the scour hole (plunge pool) with rock in an attempt to stabilise the erosion.
- Unfortunately, this bed level condition needs the continued existence of a plunge pool in order to dissipate energy.
- Filling the plunge pool with rock will cause the flow energy to be directed downstream of the rock, where it will form a new energy dissipation pool.

Constructed riffles – Stabilisation of a head-cut with a plunge-pool



Problems caused by filling pool with rock

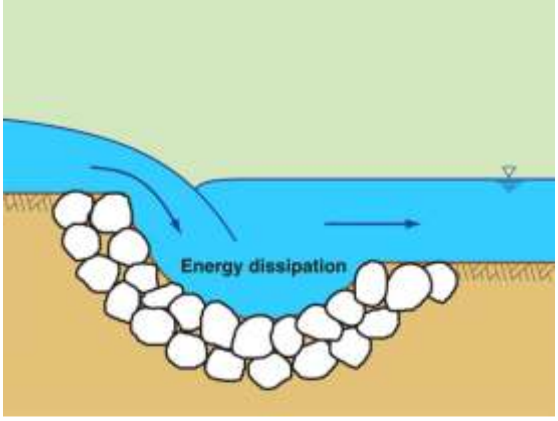
Failed placement of rock



Over-excavation of dissipation pool

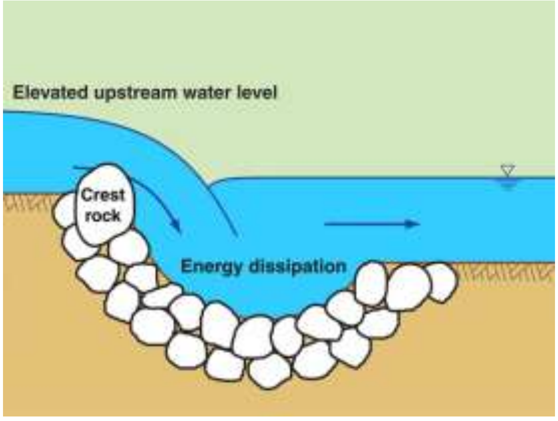
Appropriate placement of rock

- The correct approach to stabilising this type of erosion is to:
  - measure the dimensions of the existing plunge pool
  - enlarge the pool to allow placement of rock without loss of pool volume
  - line the enlarged pool with rock.
- Currently there are no equations specifically developed for sizing rock placed in plunge pools, so a best guess is required, usually 450 to 600 mm.



Placement of rock in downstream pool

Example of constructed plunge pool



Use of enlarged crest rock

Optional use of elevated crest rock

- Large rock can be placed along the crest of the plunge pool structure in order to:
  - further raise upstream water levels
  - slow upstream flow velocities
  - improve energy dissipation.
- This crest rock usually has a diameter in excess of 500 mm.
- Plunge pool designs may or may not be fish friendly depending on the fall height and design of the 'riffle'.

12.3 Rock Chutes and Rock Ramps

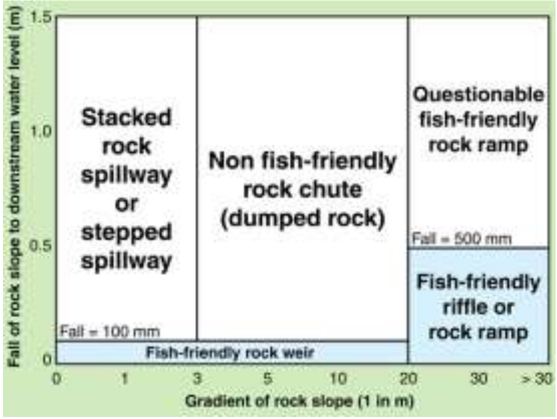
Rock chute stabilising gully erosion (Qld)

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.

Constructed rock ramp (fishway) in Tamworth, NSW

Rock chutes and rock ramps



General classification of structures

Rock ramp (NSW)

Stormwater inflow 'batter chute' (Qld)

Upstream and downstream pools (NSW)

Fish-friendly structures

- Rock chutes/ramps placed in creeks are normally required to be fish friendly, while rock chutes placed in gullies are usually not fish friendly.
- The conditions that make a structure fish friendly vary depending on the swimming ability of the target species.
- Typical fish passage requirements are:
  - a fall not exceeding 500 mm
  - a gradient not steeper than 1 in 20

Use of fish-friendly rock chutes/ramps

- Fish-friendly rock chutes and ramps are used to:
  - stabilise bed scour, including head-cut erosion, in waterways
  - form a constructed riffle
  - stabilise a drop inlet upstream of a culvert
  - stabilise the outlet of a culvert
  - construct a bypass fishway around a fish barrier.

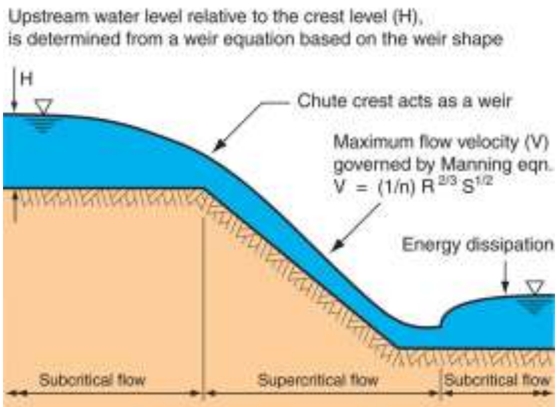
Use of non fish-friendly rock chutes

- Non fish-friendly rock chutes are used to:
  - stabilise head-cut erosion in gullies
  - stabilise a drop inlet upstream of a culvert that crosses a gully
  - stabilise a drop outlet downstream of a culvert that crosses a gully
  - stabilise stormwater inflows entering gullies and waterways (these structures are commonly referred to as batter chutes).

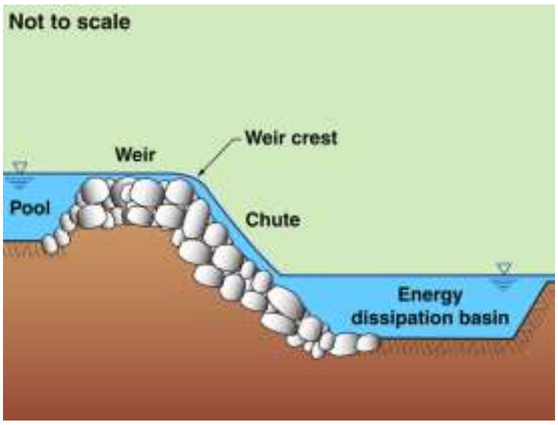
Existence of upstream and downstream pools

- In order for a rock chute to be fish friendly, not only does the 'chute' need to be fish friendly, but the channel upstream and downstream of the chute must also be fish friendly.
- This usually means that resting pools need to be positioned immediately upstream and downstream of the chute.
- Of course the downstream pool also acts as an energy dissipation basin.

Rock chutes and rock ramps – Weir crest

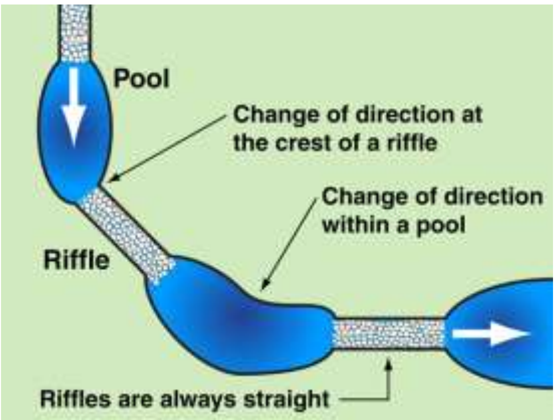


Chute hydraulics



Raised weir crest

Typical straight (trapezoidal) crest (Qld)



Straight chutes and changes of direction

Critical design issues for the weir crest

- Critical design issues include:
  - the choice of a 'bed-level' or 'raised' weir crest (with or without a low-flow channel)
  - the choice of a straight, flat or slightly curved weir crest
  - the alignment of the weir crest and chute
  - the chute slope, fall and rock size
  - the depth, width and volume of the energy dissipation pool (basin).

Benefits of a raised weir crest

- The benefits of a raised weir crest include:
  - formation of a pool upstream of the chute to allow migrating fish to recover their energy
  - lower flow velocities upstream of the chute, thus reducing the risk of erosion and vegetation damage.
- The disadvantages of a raised weir are:
  - more rock is required
  - potential stagnant water issues during periods of zero flow.

Choice of straight or curved weir crest

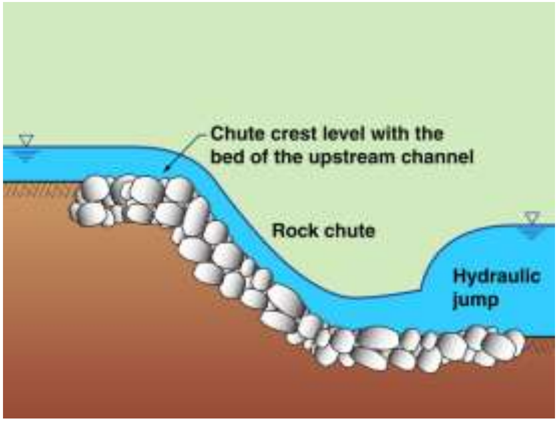
- The crest can be straight or slightly curved along the vertical and/or horizontal planes.
- The benefit of a straight crest is uniform hydraulic stress down the chute.
- The benefit of slightly curving the crest is the production of variable flow condition, which can benefit fish passage, and a concentration of flow energy towards the centre of the downstream pool.
- A curved crest may be used on a narrow chute, but most rock chutes have a straight crest with a uniform chute profile.

The importance of a straight chute

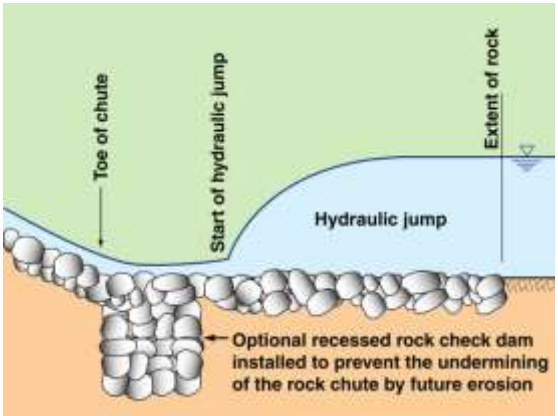
- It is essential that the alignment of the rock chute (in plan view) is 'straight'.
- This is because the flow down the chute is likely to be supercritical, and such flow does not like to change its direction.
- The upstream portion of the pool should also align with the direction of the chute so that energy dissipation can be fully contained within the pool (thus avoiding bank erosion along the edges of the pool).

Rock chutes and rock ramps – Energy dissipation at base of the chute

Energy dissipation basin at base of chute



Rock chute without a downstream pool



Extent of rock within the basin

Pool downstream of a rock chute (NSW)

Design of the chute outlet and energy dissipation

- Appropriate energy dissipation must occur within the 'basin' at the base of the chute.
- The design of this basin must be assessed on a case-by-case basis.
- The type and extent of scour control within the energy dissipater basin depends on:
  - the fall height of the chute
  - the expected tailwater conditions, and
  - whether or not the energy dissipation basin can be recessed into the bed.

Rock chutes without downstream 'pools'

- Unlike a pool-riffle system, a rock chute can be designed with or without a downstream pool.
- However, fish-friendly structures are likely to incorporate upstream and downstream pools.
- In those ephemeral waterways where fish migration is only likely to occur during periods of stream flow, the upstream and downstream channels effectively act as extended pools.

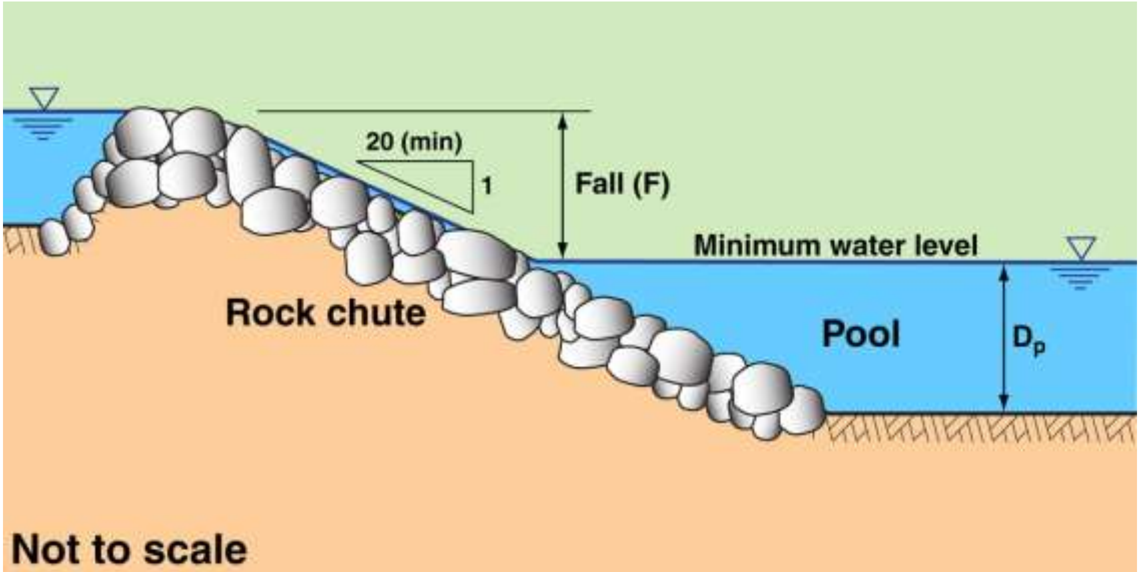
Design of rock chutes <u>without</u> a downstream pool

- If the rock chute does not have a recessed pool downstream of the chute, then energy dissipation must occur in the form of a hydraulic jump.
- The design of a hydraulic jump basin requires detailed hydraulic analysis in order to determine the size and location of the hydraulic jump.
- Rock scour protection normally needs to extend well downstream of the hydraulic jump.

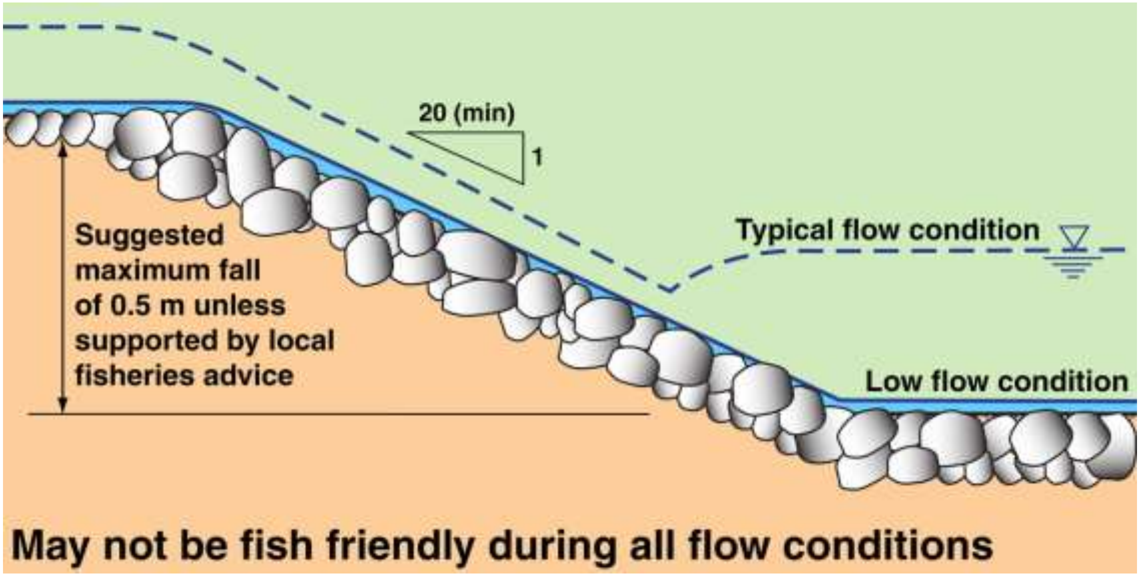
Design of chutes <u>with</u> a downstream pool

- The depth, width and length of the pool should be based on the same design recommendations as for pool-riffle systems (Section 12.2).
- The required length of the pool is likely to be longer than the specified minimum length (hydraulic analysis is required).
- The extent of rock protection depends on whether or not a hydraulic jump is generated within the downstream pool, which depends on the flow energy and tailwater conditions.

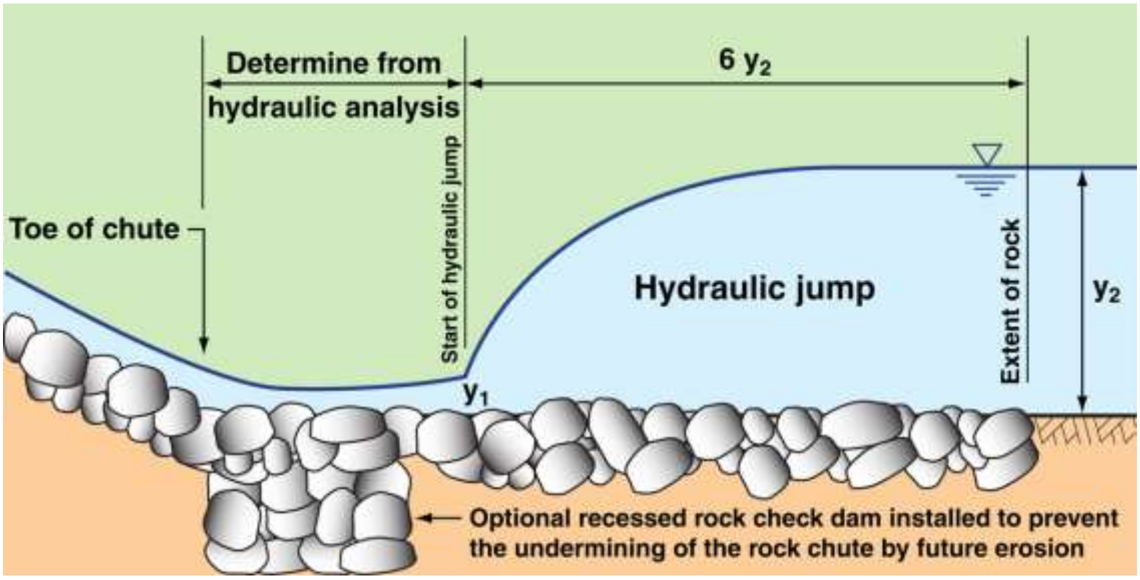
Rock chutes and rock ramps



Rock chute with raised weir crest and upstream/downstream pools

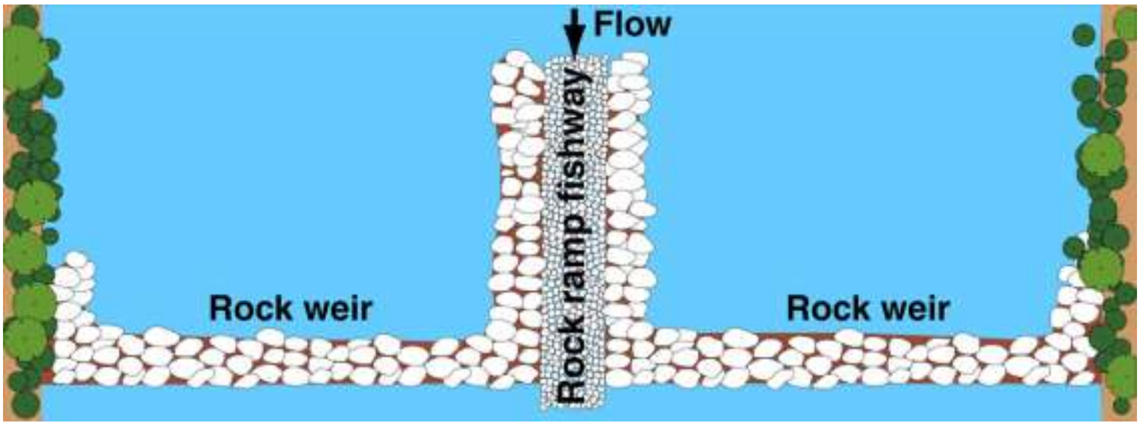


Rock chute with bed-level crest and no pools



Energy dissipater basin of a rock chute without a permanent downstream pool

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



Layout of the rock ramp fishway

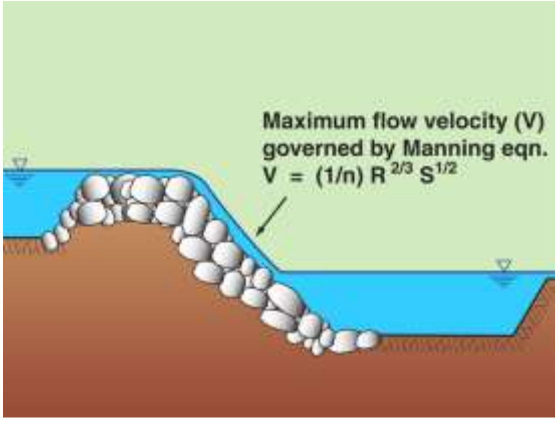
Rock ramp fishway viewed from the right bank (Tamworth)

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

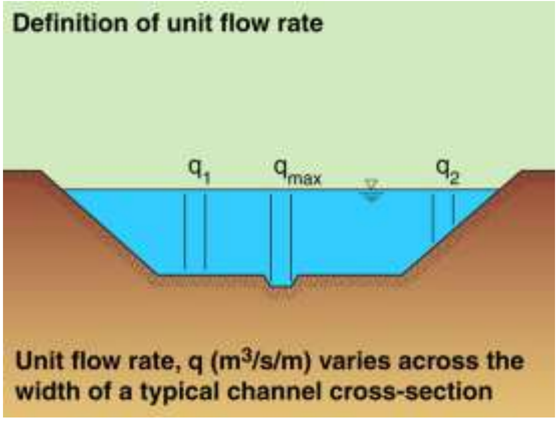
Rock ramp fishway looking downstream from the top of the fishway (Tamworth)

Rock chutes and rock ramps – Sizing of rock

Supply of rock to a work site (Qld)



Maximum flow velocity



Unit flow rate within an irregular channel

Low-flow channel set in grouted rock

Introduction

- Unlike natural riffles, the rock used in the construction of a rock chute must be stable during the nominated design storm.
- Hydraulic failures of rock chutes are relatively common compared to the failure of other waterway structures.
- It is suspected (by the author) that these failures are likely due to:
  - the supply of undersized rock
  - the occurrence of flows in excess of the nominated design storm.

Problems associated with using flow velocity to determine rock size

- Using flow velocity (V) to determine rock size introduces unnecessary 'errors' into the design procedure due to the problems of determining the Manning's roughness.
- There are conflicting methods for the determination of the Manning's roughness coefficient (n) for rock structures.
- Any variation in the Manning's roughness will result in a similar variation in the maximum flow velocity down the face of the rock chute.

Use of unit flow rate (q) as the primary design variable

- Potential problems caused by variations in the choice of Manning's roughness can be reduced (but not eliminated) by using unit flow rate (q) as the primary design variable instead of flow velocity.

The units of 'q' are [m^3/s/m] = [m^2/s]

$$q = (1/n) \cdot y^{5/3} \cdot S^{1/2} \qquad (12.8)$$

where:

y = water depth at a given location [m]

S = hydraulic gradient of flow [m/m]

Formation of a low-flow channel through the weir crest

- If a low-flow channel must pass through the rock chute (which is generally undesirable), then the depth of this channel should be minimised, especially at the crest of the chute.
- It can be very difficult to form a low-flow channel through a structure formed from large rock.
- Better results are normally achieved by forming the weir crest with a slight curved or v-shaped profile.

Rock chutes and rock ramps – Sizing of rock

Rock placement (Qld)

Introduction

- No single factor is more critical in determining the overall stability of a rock chute than the size of the rock.
- Rock size is normally presented in terms of the equivalent diameter of the mean rock size (d_{50}).
- However, the diameter of the rock is not the only factor that determines the stability of an individual rock.

Constructed rock chute (Qld)

Safety factor (SF)

- For low risk sites, a safety factor of 1.2 is recommended.
- Examples of low-risk structures include:
  - most bank stabilisation measures
  - riffles and chutes in low-gradient creeks
- For high risk sites, a safety factor of 1.5 is recommended, for example:
  - bed stabilisation in steep creeks
  - areas of very high turbulence.

Rounded river rock (USA)

Effects of rock shape (K_1)

- Fractured rock is generally more stable than natural rounded rock.
- Most rock sizing equations, including those presented within this document, are based on the use of fractured (angular) rock.
- A correction factor (K_1 = 1.36) must be applied if rounded rock is used.
- This means rounded rock needs to be 36% larger than angular rock.

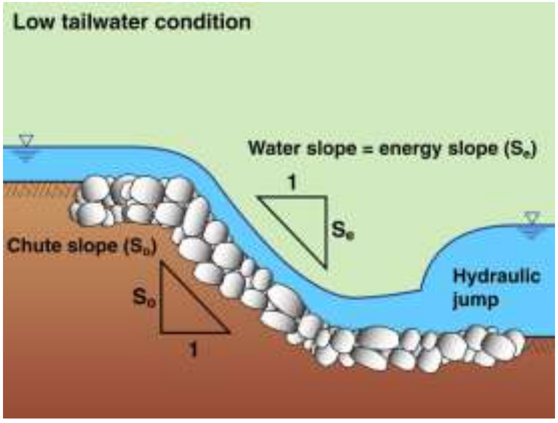
Gravel-based creek (Qld)

Exposure of individual rocks to high velocity flow

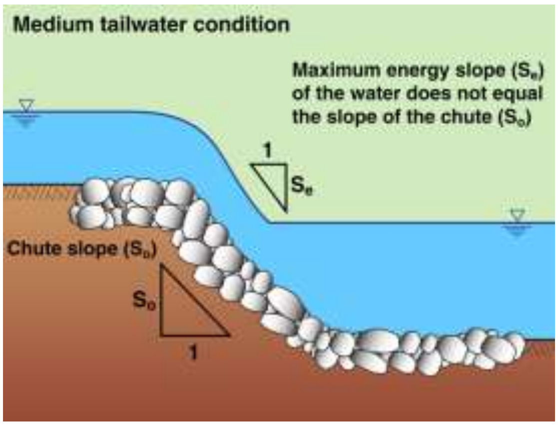
- The occasional exposed boulder can provide:
  - a more natural (random) appearance
  - resting areas for migrating fish.
- However, such exposure increases the potential hydraulic forces on the rock.
- Suggested sizing considerations include:
  - diameter > 2 d_{50} typical equal to d_{100}
  - diameter > 60 V^2

Rock chutes and rock ramps – Design flow conditions

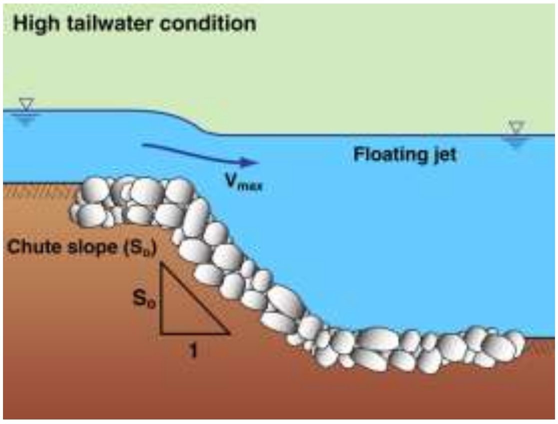
Partially drowned chute (Qld)



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 state, 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 (see over page).

$$d_{50} = \frac{127.SF.K_1.K_2.S_o^{\,0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$$

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 (see over page).

$$d_{50} = \frac{127.SF.K_1.K_2.S_o^{\,0.5}.V^{2.5}.y^{0.75}}{V_o^{\,2.0}\,(s_r - 1)}$$

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 12.9.

$$d_{50} = 0.04\ V^2 \qquad (12.9)$$

Sizing rock for the face of waterway and batter chutes

Application	Equation
Application of Equation 12.10 • The preferred design equation. • Applicable for uniform flow conditions only, $S_e = S_o$ • Batter slopes (S_o) flatter than 50% (1 in 2)	**Equation 12.10** $d_{50} = \frac{127.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$
Application of Equation 12.11 • A simplified equation independent of flow depth. • Applicable for uniform flow conditions only, $S_e = S_o$ • Batter slopes (S_o) flatter than 50% (1 in 2)	**Equation 12.11** $d_{50} = \frac{SF.K_1.K_2.S_o^{0.47}.q^{0.64}}{(s_r - 1)}$
Application of Equation 12.12 • A simplified, velocity-based equation. • Applicable for uniform flow conditions only, $S_e = S_o$ • Batter slopes (S_o) flatter than 33% (1 in 3)	**Equation 12.12** $d_{50} = \frac{SF.K_1.K_2.V^2}{(A - B.\ln(S_o)).(s_r - 1)}$ For SF = 1.2: A = 3.95, B = 4.97 For SF = 1.5: A = 2.44, B = 4.60
Application of Equation 12.13 • Suitable for use in the design of partially drowned waterway chutes. • Applicable for steep gradient, non-uniform flow conditions, $S_e \neq S_o$ • Batter slopes (S_o) flatter than 50% (1 in 2)	**Equation 12.13** $d_{50} = \frac{127.SF.K_1.K_2.S_o^{0.5}.V^{2.5}.y^{0.75}}{V_o^{2.0}(s_r - 1)}$

where:

d_X	=	nominal rock size (diameter) of which X% of the rocks are smaller [m]
A & B	=	equation constants
K	=	equation constant based on flow conditions
	=	1.1 for low-turbulence, deep water flow; 1.0 for low-turbulence shallow water flow; and 0.86 for highly turbulent and/or supercritical flow
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 $K_2 = 1.0$ ($1.5 < C_u < 2.5$)
ln	=	means natural logarithm to base-e
q	=	flow per unit width down the embankment [m^3/s/m]
s_r	=	specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)
S_e	=	slope of energy line [m/m]
S_o	=	bed slope = tan(θ) [m/m]
SF	=	factor of safety
V	=	actual depth-average flow velocity at location of rock [m/s]
V_o	=	depth-average flow velocity based on **uniform** flow down a slope, S_o [m/s]
y	=	depth of flow at a given location [m]
θ	=	slope of channel bed [degrees]

Table 12.3 provides suggested safety factor values. Tables 12.4 and 12.5 provide mean rock size (rounded up to the next 0.1 m unit) for angular rock, for a factor of safety of both 1.2 and 1.5. These tables are based on Equation 12.10, and are best used in the design of long chutes. Use of the 'unit flow rate' (q) as the primary design variable is preferred to the use of flow velocity (V) because it avoids errors associated with the selection of Manning's roughness.

Alternatively, tables 12.6 and 12.7 provide mean rock size for angular rock and a safety factor of 1.2 and 1.5, based on a modification of Equation 12.10, but with flow velocity presented as the primary variable. These tables are best used in the design of waterway chutes where uniform flow conditions are unlikely to be achieved down the face of the chute.

Table 12.3 – Recommended safety factor for use in determining rock size

Safety factor (SF)	Recommended usage	Example site conditions
1.2	• Low risk structures. • Permanent rock chutes with all voids filled with soil and pocket planted.	• Waterway chutes where failure of the structure is likely to result in easily repairable soil erosion.
1.5	• High risk structures. • Failure of structure may cause loss of life or irreversible property damage.	• Waterway chutes where failure of the structure may cause severe gully erosion or damage to important infrastructure.

Thickness and height of rock layer

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size. In order to allow at least two layers of rock, the minimum thickness of rock protection (T) can be approximated by the values presented in Table 10.6.

Generally, the minimum height of the rock protection placed on the banks should be equal to the critical flow depth (at the crest) plus 0.3 m.

Rock type and grading

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more 'natural' appearance. A 36% increase in rock size is recommended for rounded rock (i.e. K_1 = 1.36). Typical rock densities (s_r) are presented in Table 10.4.

The rock should be durable and resistant to weathering, and should be proportioned so that neither the breadth nor the thickness of a single rock is less than one-third of its length. Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size. On very steep grades, the maximum rock size should not exceed 1.25(d_{50}).

Tables 10.5 and 12.2 provide a suggested distribution of rock sizes for waterway chutes.

Backing material or filter layer

A geotextile filter is unlikely to be required (or desired) under the bed of a waterway chute.

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

If the rock is placed on a dispersive (e.g. sodic) soil (a condition **not** recommended), then prior to placement of filter cloth, the exposed bank **must** first be covered with a layer of non-dispersive soil, typically minimum 200 mm thickness, but preferably 300 mm.

Placement of vegetation over the rock

Vegetating rock chutes can significantly increase the stability of these structures, but can also reduce their hydraulic capacity. Obtaining experienced, expert advice is always recommended before establishing vegetation on waterway structures.

Table 12.4 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

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

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

Table 12.5 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate (m^3/s/m)	**Bed slope = 1:10**		**Bed slope = 1:15**		**Bed slope = 1:20**		**Bed slope = 1:30**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.11	**0.10**	0.11	**0.10**	0.11	**0.10**	0.11	**0.05**
0.2	0.17	**0.20**	0.17	**0.20**	0.18	**0.10**	0.18	**0.10**
0.3	0.22	**0.20**	0.23	**0.20**	0.23	**0.20**	0.24	**0.10**
0.4	0.26	**0.20**	0.27	**0.20**	0.28	**0.20**	0.29	**0.20**
0.5	0.31	**0.30**	0.32	**0.20**	0.32	**0.20**	0.34	**0.20**
0.6	0.35	**0.30**	0.36	**0.30**	0.37	**0.20**	0.38	**0.20**
0.8	0.42	**0.40**	0.43	**0.30**	0.44	**0.30**	0.46	**0.20**
1.0	0.49	**0.40**	0.50	**0.30**	0.51	**0.30**	0.53	**0.30**
1.2	0.55	**0.50**	0.57	**0.40**	0.58	**0.30**	0.60	**0.30**
1.4	0.61	**0.50**	0.63	**0.40**	0.64	**0.40**	0.67	**0.30**
1.6	0.67	**0.50**	0.69	**0.50**	0.70	**0.40**	0.73	**0.30**
1.8	0.72	**0.60**	0.74	**0.50**	0.76	**0.40**	0.79	**0.40**
2.0	0.77	**0.60**	0.80	**0.50**	0.82	**0.50**	0.85	**0.40**
3.0	1.01	**0.80**	1.04	**0.70**	1.07	**0.60**	1.11	**0.50**
4.0	1.23	**1.00**	1.27	**0.80**	1.30	**0.70**	1.34	**0.60**
5.0	1.43	**1.10**	1.47	**0.90**	1.50	**0.80**	1.56	**0.70**

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

Table 12.6 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.2

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

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

Table 12.7 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05
1.0	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.3	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.5	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
1.8	0.50	0.50	0.40	0.40	0.30	0.30	0.30	0.20
2.0	0.70	0.60	0.50	0.50	0.40	0.40	0.30	0.30
2.3	0.80	0.70	0.60	0.60	0.50	0.40	0.40	0.40
2.5	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
2.8	1.20	1.00	0.90	0.80	0.70	0.60	0.60	0.50
3.0	1.40	1.20	1.10	1.00	0.80	0.70	0.70	0.60
3.5	1.90	1.70	1.50	1.30	1.10	1.00	0.90	0.80
4.0			1.90	1.70	1.40	1.30	1.10	1.00
4.5					1.80	1.60	1.40	1.30
5.0						1.90	1.80	1.60
6.0								2.20

[1] Based on uniform flow conditions, safety factor = 1.5, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

12.4 Ridge Rock Ramps

Ridge rock ramp (Qld)

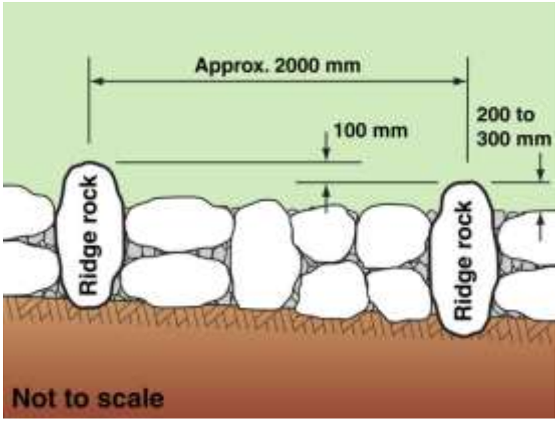
Description

- 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.

Rock fishway (NSW)

Ridge rock ramps

Ridge rock ramp (Qld)



Typical dimensions

Potential site for a ridge rock ramp (Qld)

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.

Baffled fishways

Precast concrete fishway (Qld)

Introduction

- Precast concrete units can be used as an alternative to ridge rock ramps.
- Such units can be used to form bypass fishways that are built to the side of, or separate to, the main waterway channel.
- These fishways have been used to provide fish passage through roadway culverts that have become 'elevated' as a result of downstream bed erosion.
- These structures do not repair the channel erosion, but they can help to return fish passage to the waterway.


Downstream end of fishway (Qld)

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) is a sign that fish are actually using the fishway.


Debris blockage of fishway (Qld)

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 precast 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.

Upstream end of fishway (Qld)

Directing low flows into the fishway

- It is important that the design of the fishway allows 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.
- The site presented here is a Walaman system installed on Enoggera Creek, Brisbane.

12.5 Recessed Rock Check Dams

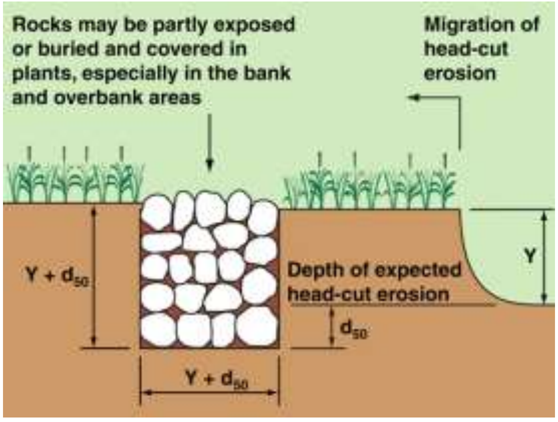

Recessed rock check dams (Qld)

Description

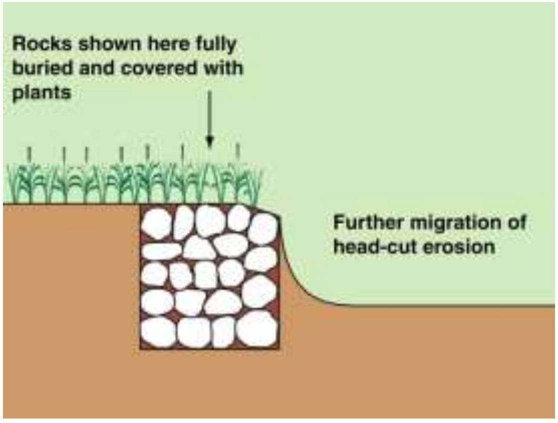
- Unlike other structures, the purpose of recessed rock check dams is to address bed erosion that is expected to occur some time in the future.
- The term ‘check’ is used in relation to its meaning: ‘to stop or arrest the motion’.
- Each check dam consists of a deep trench filled with rock and soil (i.e. no voids).
- The check dams can be totally buried, or partially exposed, the latter allows the upper part of the dams to act as rock weirs.

A series of partially exposed recessed rock check dams forming a pool-riffle system

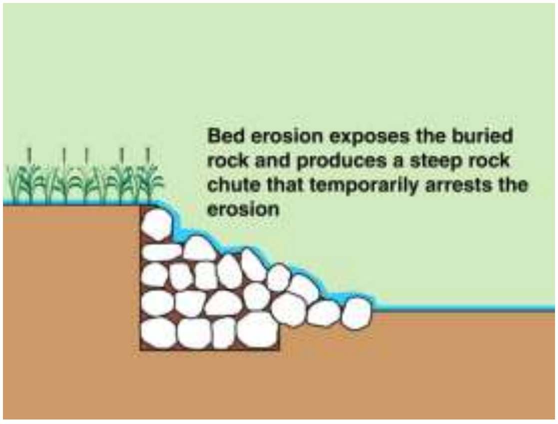
Recessed rock check dams



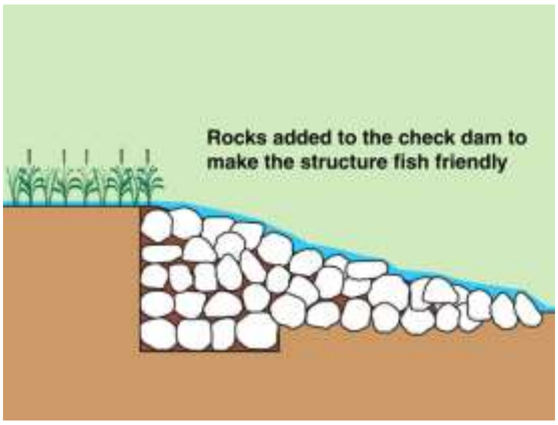
Suggested minimum dimensions



Progression of bed erosion



Exposure of rock check dam



Post-flood repair of rock check dam

Use of recessed rock check dams

- Recessed rock check dams can be used for the following purposes:
  - as an insurance policy against future bed erosion possibly resulting from the urbanisation of a catchment
  - treatment of bed erosion that is currently in an inaccessible location, or located within a downstream property
  - as an insurance policy within a constructed channel in case a major storm occurs during the revegetation phase.

Hydraulic function of recessed rock check dams

- The primary purpose of a recessed rock check dam is to achieve short-term channel stability in the event that severe bed erosion migrates up a channel.
- It is unlikely that these structures will provide a desirable long-term outcome if the erosion does occur.
- Waterway managers should expect to have to apply some maintenance work after the check dam is first exposed.

Design features

- The most critical aspect of the design of recessed rock check dams is 'common sense'—designs must be appropriate for the site conditions, and must be realistic.
- Typical design attributes are:
  - depth and width should exceed the depth of the approaching bed erosion
  - rock size based on a chute design
  - rock should extend well into the banks to prevent the channel erosion passing around the check dams.

Likely fish passage outcomes

- It is unlikely that these structures will remain fish friendly once first exposed to stream flows.
- It is likely that additional rock will need to be placed over the check dam in order to achieve a maximum 1 in 20 gradient.
- It may be necessary for several recessed check dams to be installed upstream of a major erosion problem in order to achieve long-term stability and suitable fish passage outcomes.

12.6 Rock Weirs

Constructed rock weir (Qld)

Rock weirs

- Hydraulically, fish-friendly rock weirs are similar to each 'ridge' in a ridge rock ramp.
- However, rock weirs can be used in deeper water than ridge rock ramps.
- Similar to ridge rock ramps, the maximum water level fall across each weir should be around 100 mm.
- Rock weirs can also be used to form stepping stones across a shallow waterway.

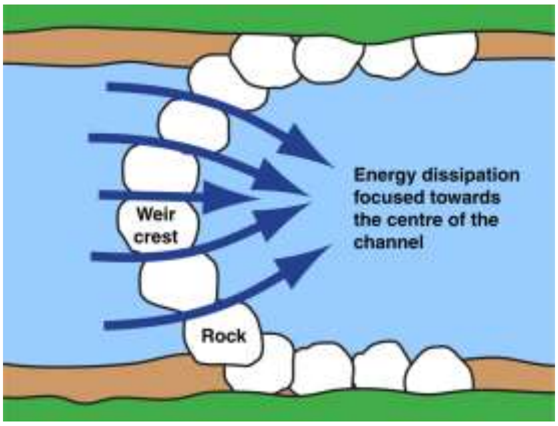
Stepping stones (Torrens River, SA)

Rock weirs

Rock weir / stepping stones (Qld)

Rock weir (Qld)

Water passing through rocks



Concave rock weir

Use of rock weirs

- Rock weirs can be used to:
  - increase the low-flow water depth, and thus reduce the low-flow water velocity
  - enhance the aquatic habitat potential of a waterway that is experiencing a gradual reduction in low-flow conditions
  - increase in-channel sedimentation
  - gradually raise low-flow water levels in order to drown out an upstream fish barrier.

Use in specific waterways

- In clay-based creeks, rocks can be anchored in a concrete base, or in a manner similar to ridge rock ramps.
- In sand-based creeks, stepping stones are possibly best formed by standing suitably capped concrete pipes vertically in the sand bed (see examples over page).
- In gravel-based creeks, stepping stones should be considered temporary structures that will need to be reconstructed after each flood event.

Hydraulic design

- The weirs should contain sufficient fines to prevent (minimise) inter-void flow, and should have a maximum water fall of 100 mm in order to allow fish passage.
- Rock weirs typically sit above the normal bed level, thus increasing their exposure to direct hydraulic forces and potential displacement by flood debris.
- Rock size depends on the anchoring system, but should exceed Equation 12.9.

Try: $$d_{50} = 0.06\ V^2 \qquad (12.14)$$

Design of weir crest in wide and narrow channels

- If a rock weir is formed in a narrow channel, then the crest of the weir should be curved in the horizontal plane in order to direct spilling flows away from the banks and towards the centre of the downstream channel.
- In wide channels, V-weirs and W-weirs can be used.
- In plan view, a V-weir has the shape of a 'V', but a W-weir can zigzag several times as it crosses a channel (e.g. WWW).

Stepping stones

Stepping stones (Qld)

Use as stepping stones

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

Stepping stones (Qld)

Stepping stones (Qld)

Stepping stones (SA)

Stepping stones (Qld)

Wetland stepping stones (ACT)

Concrete stepping stones (Qld)

12.7 Log Weirs

Log weir (USA)

Description

- Log weirs are not popular in Australia because of the limited supply of durable timber.
- Suitable species include, Fraser Island Turpentine, Brush Turpentine, Giant Ironwood.
- Log weirs are used for the same purpose as small rock weirs.
- These structures may or may not be fish friendly depending on the log diameter and the flow conditions.

Log weir (South Carolina, USA)

12.8 Pile Fields

Pile field (Qld)

Description

- A pile field is a collection of piles, usually timber, that are driven vertically into the creek bed to form artificial channel roughness.
- Typically placed in a regularly spaced grid of one, two or three rows.
- The piles effectively act like closely spaced trees, or exposed tree roots, which slow the approaching flow and thus reduce the risk of channel erosion upstream of the pile field.

A pile field formed in the bed of a sand-based creek (Qld)

Pile fields

Initial placement of logs (Qld)

Driving piles into the sand bed (Qld)

Logs trimmed to a suitable height (Qld)

Pile field (Vic)

Use of pile fields

- Pile fields can be used for the following purposes:
  - reduce upstream flow velocities
  - increase upstream sedimentation
  - reduce the risk of overbank flood flows cutting a new bypass channel
  - assist in the rehabilitation of a temporary bypass channel (as per images shown here)
  - as a flow diversion system when installed on channel banks.

Hydraulic function of pile fields

- When the piles are free of flood debris, the piles provide flow resistance similar to closely spaced trees.
- When the piles become partially blocked with flood debris, the pile field begins to act like a leaky weir.
- It is important to choose the correct top elevation of the piles similar to choosing the top elevation of a rock weir.
- When placed on a creek bank, it is important to consider the effects of large-scale eddies formed around the edges.

Design attributes

- When placed across the bed of a channel, the top of the piles is usually well below the height of the banks (as for a rock weir).
- When placed within a floodplain or bypass channel, the top of the piles are normally level with the elevation of the adjacent floodplain.
- When placed on creek banks, the piles normally vary in elevation, decreasing in height as they approach the main channel.

Fish passage attributes

- Pile fields work well in clay and sand-based creeks.
- Bed sand can flow past the piles, which means a gradual bed gradient usually forms, which should be fish friendly.
- Piles can be very difficult to drive into the bed of gravel-based creeks.
- If excessive flood debris collects on the piles, then this can temporarily interfere with fish passage.

13. Non Fish-Friendly Bed Stabilisation Methods

Introduction

Several gabion drop structures (NT)

Stepped gabion spillway (Qld)

Gabion drop structure (Qld)

Drop structure fishway (USA)

Introduction

- Non fish-friendly bed stabilisation structures include:
  - culverts
  - drop structures (various types)
  - steep rock chutes
  - weirs
- One of the advantages of culverts over bridges is their ability to contribute to the stability of the channel bed, often helping to prevent the ongoing migration of head-cut erosion.

Drop structures

- Techniques grouped under the heading of ‘open channel drop structures’ include:
  - gabion drop structures
  - grouted boulder drop structures
  - inclined and baffled drop structures
  - rock chutes
  - stepped drop structures
  - tyre chutes
  - vertical drop structures
  - weirs

Public safety

- The increasing attention to public safety has seen a declining use of open channel drop structures.
- Most of these grade control structures are not only problematic for fish movement, they also represent a major safety risk to any person swept over the structure during a flood event.

Use of fishways

- These non fish-friendly grade control structures can be made ‘somewhat’ fish friendly through the incorporation of a fishway or bypass fishway channel.
- Bypass fishway channels allow fish to migrate around a fish barrier within a constructed fish-friendly channel.
- These fishways are rarely ideal, and should not be presented as a legitimate alternative to the construction of a fish-friendly grade control structure wherever such a structure is considered feasible.

13.1 Baffled Drop Structures

Baffled drop structure (Qld)

Description

- In a baffled drop structure, rows of concrete baffle blocks are placed down the face of the chute.
- The intent is for there to be no increase in energy levels as the water descends the drop structure.
- For design information refer to US Bureau of Reclamation 'Basin Type IX'.
- These structures present a very high safety risk to people and fish swept through the structure.

Baffled drop structure (Qld)

13.2 Gabion Drop Structures

Gabion channel and drop structure

Description

- Gabion drop structures are formed from rectangular wire baskets or mattresses filled with well-graded rock.
- Heavily galvanised, PVC coated baskets should be used within waterways.
- The wire can be damaged by flood debris.
- When used within the splash zone of weirs and drop structures, at least two layers of minimum 300 mm thick mattresses should be used.

Gabion drop structures (Qld)

Gabion drop structures

Maccaferri, 1981

Reference documents

- Design information can be found in various Maccaferri publications, including:
  – *'Flexible gabion structures in river and stream training works'*, Maccaferri S.p.A. 1981
- Also see Section 13.7 – *'Stepped Drop Structures'* of this field guide.

Gabion drop structure (Qld)

Design issues

- Gabion grade control (drop) structures can be very adaptable in their design features.
- In arid areas, gabion structures can be very durable without the aid of vegetation cover.
- In all other waterway environments, these structures need to have full vegetation cover in order to achieve long-term use.
- In tropical areas, vegetation growth can become excessive and difficult to maintain at the required level of hydraulic roughness.

Gabion-lined channel in construction (Qld)

Same structure with excessive growth

Gabion-lined drainage channel (Qld)

Same structure with excessive growth

13.3 Grouted Rock Drop Structures

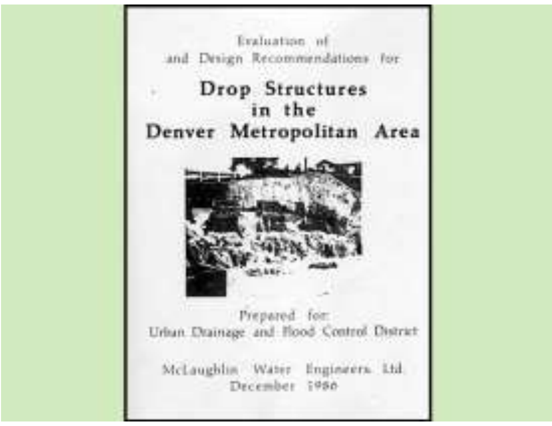
Grouted rock chute (Qld)

Description

- Grouted rock drop structures are very similar in appearance to normal rock chutes; however, grout is placed between the rocks to improve the structure's stability.
- The durability of these structures depends on:
  - the stability of the foundations
  - clean bonding between grout and rocks.

Grouted rock drop structure (Denver, Colorado, USA)

Grouted boulder drop structures


Evaluation of
and Design Recommendations for
Drop Structures
in the
Denver Metropolitan Area

Prepared for
Urban Drainage and Flood Control District

McLaughlin Water Engineers Ltd.
December 1986

McLaughlin Water Engineering, 1986

Reference manual

- Design information can be obtained from:
  - *'Evaluation of and Design Recommendations for Drop Structures in the Denver Metropolitan Area'*, McLaughlin Water Engineering Ltd., December 1986, Urban Drainage and Flood Control District, Denver, Colorado, USA

Grouted rock drop structure (USA)

Use

- Grouted rock drop structures are most commonly used in locations where fish passage is not critical, and the required rock size for an equivalent loose rock structure exceeds 600 mm.
- For drop heights less than 1 m, rock size is 450 mm and grout thickness is 300 mm.
- For drop heights exceeding 1 m, rock size is 600 mm and grout thickness is 450 mm.
- All rocks must be washed clean of dirt before installation.

Failed grouted rock (Qld)

Design issues

- The long-term durability of grouted boulder drop structures is questionable.
- It is generally accepted that the grout will eventually fracture (separate) from the rock, which can result in the loss of rocks during flood events.
- Such structural failures have already occurred in Brisbane.
- The grouted rocks/boulders can also be attached to reinforced concrete, such as weirs or stepped spillways.

Rocks grouted to concrete channel (Qld)

Grouted rock stepped spillway (ACT)

13.4 Inclined Drop Structures

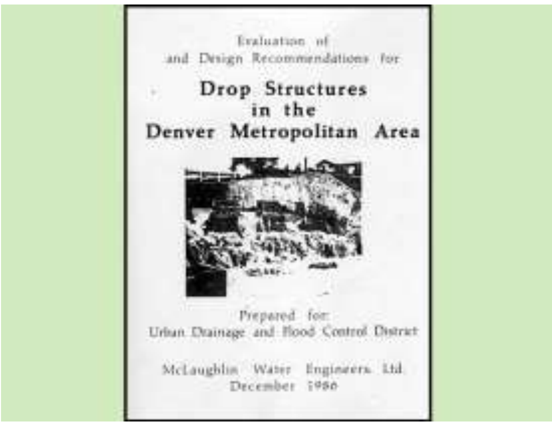
Concrete chute (NSW)

Description

- A drop structure with a steeply-inclined chute.
- An energy dissipation pool/basin normally exists at the base of the chute.
- The weir crest usually has either a rectangular (preferred), or trapezoidal cross-section.

Inclined drop structures (Denver, Colorado, USA)

Inclined drop structures



McLaughlin Water Engineering, 1986

Reference manual

- Design information can be obtained from:
  - *'Evaluation of and Design Recommendations for Drop Structures in the Denver Metropolitan Area'*, McLaughlin Water Engineering Ltd., December 1986, Urban Drainage and Flood Control District, Denver, Colorado, USA
  - also various Australian design manuals and hydraulics text books on hydraulic jump structures.

Trapezoidal, inclined drop structure (Qld)

Use

- Typically used in grassed floodways and stormwater channels.
- The trapezoidal cross-section can concentrate flow energy towards the centre of the channel:
  - which can prevent the formation of an 'ideal' hydraulic jump
  - which can cause 'jetting' to move well downstream of the drop
  - which can result in significant bed scour.

Scour downstream of drop (Qld)

Design issues

- It is **important** <u>not</u> to confuse the design of inclined drop structures with the design of road floodways (as presented in many Main Roads design manuals).
- Unlike floodway embankments, when sloping drop structures are installed in stormwater or waterway channels, it is important to ensure that a suitable energy dissipation basin and/or scour control zone exists downstream of the drop.

Whitewater rafting chute (USA)

Safety risks

- Excessive turbulence at the base of the chute can cause head injuries to people swept over the structure.
- The excessive turbulence at the base of the chute can also interfere with fish passage.

13.5 Rock Chutes

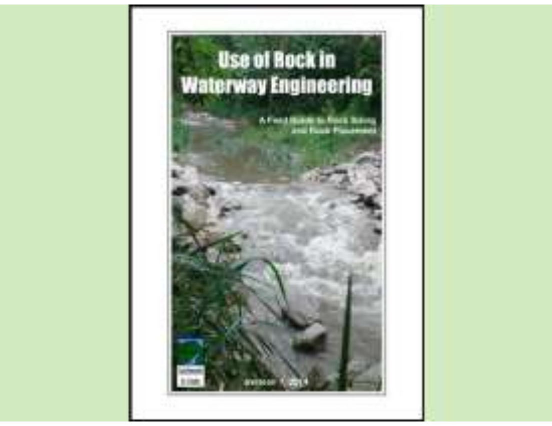
Rock chute (Qld)

Description

- Rock chutes and rock weirs can be formed with a chute gradient as steep as:
  - 1 in 1 for small stacked rock weirs
  - 1 in 2 for dumped rock chutes
  - 1 in 20 for fish-friendly structures
  - 1 in 30 for small constructed riffles.
- Rock chutes with a gradient steeper than 1 in 20 are not considered fish friendly.

Rock chute (Qld)

Rock chutes (non fish-friendly)



Catchments and Creeks (2020)

Design manuals

- Design information can be found in Part 12.3 of this field guide, and in the separate field guide:
  - *'Use of Rock in Waterway Engineering'*, Catchments and Creeks Pty Ltd
- Also refer to *'Evaluation of and Design Recommendations for Drop Structures in the Denver Metropolitan Area'*, Denver.
- Also various Australian creek and river erosion guidelines.

Rock-lined drop structure (Qld)

Use

- Non fish-friendly rock chutes are used for such purposes as:
  - grade control structures in the upper reaches of waterways where fish passage has not been judged to be a design issue
  - batter chutes directing stormwater (overland flow) into a waterway
  - grade control structures in gullies.

Rock-lined batter chute (Qld)

Design issues

- Refer to Section 12.3 of this field guide for design information.
- Rock size should be checked for:
  - low tailwater (Equation 12.10)
  - medium tailwater (Equation 12.13)
  - high tailwater (Equation 12.9).
- It is again noted that fractured rock is more stable than rounded rock.
- In ephemeral waterways it can be beneficial to promote vegetation cover.

Rock-lined spillway (Qld)

Safety risks

- Rock chutes are one of the safest grade control structures in regards to a person being swept through the structure.
- However, similar to 'inclined drop structures', high turbulence at the base of the chute can pose a risk to both humans and fish.

Rock chutes and rock ramps – Common problems

Rocks too small

Suitable rock unavailable

- If the required rock size cannot be obtained from local sources, then placing a larger volume of smaller rock is not a suitable alternative.
- Undersized rock will simply wash away causing failure of the structure.

Single layer of rock on filter cloth

A single layer of large rock on filter cloth

- It is generally recommended that there should be at least two layers of rock.
- However, when the specified rock size is close to 600 mm, then the adoption of two layers of rock can significantly increase the volume of required rock.
- Such large rock can be placed on a layer of smaller (300–450 mm) rocks.
- A single layer of rock should not be placed directly on filter cloth.

Erosion of adjacent creek bank

The chute directs flows towards an adjacent creek bank

- Both the weir crest and the rock chute should direct flows towards the centre of the downstream channel (or energy dissipation pool).
- In meandering channels it may be necessary to stabilise the outer banks of these dissipation pools to prevent water jetting causing bank erosion.

Rocks placed on a dispersive soil

Rocks placed on a dispersive or slaking soil

- If a rock chute needs to be placed on a dispersive or slaking soil, then a deep foundation of non dispersive soil needs to be placed over the in-situ soil prior to:
  - the placement of filter cloth, or
  - the placement of a gravel filter layer.
- Filter cloth must not be placed directly over a dispersive soil.

13.6 Soil-Cement Drop Structures

Soil-cement drop structure (USA)

Description

- Soil-Cement is a mixture of soil, Portland cement and water, which is then roller compacted to a high density.
- For design information refer to:
  - *'Soil-Cement Guide for Water Resources Applications'*, Portland Cement Association, 2006, Illinois, USA
- Designers should investigate the latest information on durability issues, and should consider the suitability of the construction technique to their local region.

Soil-cement drop structure (Denver, Colorado, USA)

13.7 Stepped Drop Structures

Neil Turner Weir, Mitchell, Qld

Description

- Stepped drop structures are used in the design of both grade control structures and detention basin spillways.
- The hydraulics of these structures becomes more complicated as the 'width' of each step increases (i.e. the gradient of the structure becomes more gradual), but in general terms these structures can simply be viewed as 'inclined drop structures' with increased chute roughness.

Stepped, gabion spillway (Qld)

Stepped drop structures


The University Of Queensland

DEPARTMENT OF CIVIL ENGINEERING

REPORT CH45/94
February 1994

HYDRAULIC DESIGN OF STEPPED CHANNELS AND SPILLWAYS

H. CHANSON

Hubert Chanson (1994)

Reference manual

- Design information can be obtained from:
  - *'Hydraulic Design of Stepped Channels and Spillways'*, H. Chanson, 1994, The University of Queensland.
  - *'The Hydraulics of Open Channel Flow'*, Hubert Chanson, 1999, Arnold, London, ISBN 0-340-74067-1.

Grouted rock stepped drop structure (ACT)

Use

- Typical uses include:
  - grade control structures within the upper reaches of waterways where fish passage has not been judged to be a design issue
  - grade control structures within stormwater channels
  - dam, weir and detention basin spillways.

Stepped gabion drop structure (Qld)

Control of vegetation cover

- In waterway environments, all gabion structures need to have full vegetation cover in order to achieve long-term use.
- In tropical areas, vegetation growth can become excessive and difficult to maintain at the required hydraulic roughness.
- The key is to establish the preferred plants during initial construction, thus avoiding the invasion of unsuitable species.
- Caution the establishment of woody species on stepped gabion spillways.

Stepped gabion spillway (1992)

Same stepped gabion spillway (2010)

13.8 Tyre Chutes

Car tyre chute (USA)

Description

- Old car and truck tyres can be chained together and/or filled with rock (similar to rock-filled gabions) to produce an inclined or stepped drop structure.
- The tyres cannot simply be placed freely within a gully or chute, but must be suitably anchored.
- Best results are achieved when appropriately integrated with vegetation.
- Warning; some design concepts are controlled by copyright conditions.

Rock and tyre chute (NT)

13.9 Vertical Drop Structures

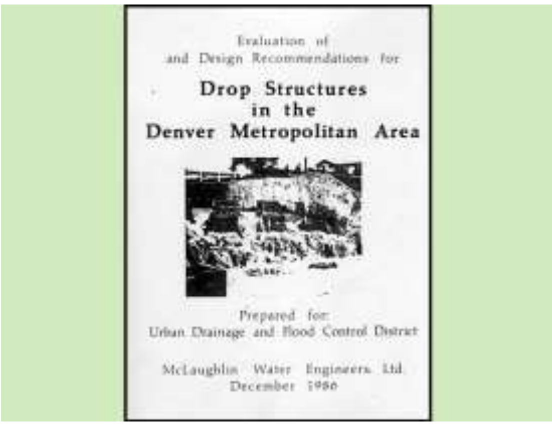
Steel sheet piling drop structure (USA)

Description

- Vertical drop structures incorporate a single vertical step.
- An energy dissipation pool/basin normally exists at the base of the drop.
- The weir crest usually has either a rectangular (preferred), or trapezoidal cross-section.

Decorative drop structure with energy dissipation blocks (Denver, Colorado, USA)

Vertical drop structures



McLaughlin Water Engineering, 1986

Reference manual

- Design information can be obtained from:
  - *'Evaluation of and Design Recommendations for Drop Structures in the Denver Metropolitan Area'*, McLaughlin Water Engineering Ltd., December 1986, Urban Drainage and Flood Control District, Denver, Colorado, USA
  - also various Australian design manuals and hydraulics text books on hydraulic jump structures.

Vertical drop structure (SA)

Use

- Typically used in stormwater channels and gullies.
- The trapezoidal cross-section can concentrate flow energy towards the centre of the channel:
  - which can prevent the formation of an 'ideal' hydraulic jump
  - which can cause 'jetting' to move well downstream of the drop
  - which can result in significant bed scour.

Vertical, baffled drop structure (NT)

Design issues

- Various standard designs exist.
- Some designs incorporate energy dissipation blocks (baffles) and end sills.

Vertical drop structure (Qld)

Safety risks

- Excessive turbulence at the base of the drop can cause head injuries to people swept through the structure.

13.10 Weirs

Richmond River, Casino, NSW

Description

- Weirs can be used as grade control structures, as well as minor instream water storages.
- Modern weirs usually incorporate a fishway, either directly attached to the weir, or in the form of a bypass fishway that allows fish to migrate around the structure.
- The design of fish-friendly weirs is a specialist profession.

Concrete weir with fishway (Torrens River, SA)

13.11 Weir and Drop Structure Fishways

Torrens River Fishway (SA)

Description

- Fishways can allow some degree of fish passage past weirs and drop structures.
- However, fishways are rarely ideal, and should not be presented as a legitimate alternative to the construction of a proper fish-friendly structure wherever such a structure is considered feasible.

Bypass fishway, Lock No. 10, Murray River, Victoria

13.12 Bypass Fishway Channels

Bypass fishway channel, Bundaberg

Description

- A fish-friendly bypass channel can be constructed as an alternative to a traditional fishway.
- These channels are designed using the principles of *Natural Channel Design*, and usually incorporate a series of pools and riffles.

Riffle zone with a bypass fishway channel, Bundaberg, Queensland